RESEARCH ON TECHNOLOGICAL INNOVATION CAPABILITY EVALUATION INDEX FOR AVIATION INDUSTRIES

Wenyuan CHENG[1], Rongtao Fan[2], Jia XU[1], Hui ZHANG[1], Zexi WANG[1]

[1] System Engineering Research Division, Aviation Industry Development Research Center of China (ADR) Beijing China 100029

[2] Aviation Industry Corporation of China, Ltd (AVIC) Beijing China 100028

Abstract

Science, technology and innovation play a significant role in economic and social development, especially technological innovation in aviation industry has become more and more important in defense development. The technological innovation activities in aviation industry were analyzed using the Zachman Framework Model, and the structural model for aviation technological innovation with identical core elements was established. According to this, a set of evaluation index and assessment model for aviation technological innovation value oriented were established based on current innovation evaluate model. Then some aviation institutes were chosen as example, and had been evaluated through data collect and compute using the above evaluation index. Finally, some suggestions were given for technological innovation capability evaluation for aviation industries.

Keywords: technological innovation, Zachman Framework Model, evaluation index

1. General Introduction

Technological innovations play an increasingly prominent role in the growth of leading industrial economies and has become becoming an important engine in new development era. With the new round of technological revolution and industrial transformation, global scientific technological innovation presents a new development trend and characteristics. Science, technology, and engineering penetrate each other, and knowledge innovation, technological innovation, and industrial innovation are deeply integrated, which make the scientific and technological innovation system more perfect and complex. Technological innovation is an important driving force for aviation industry’s sustainable development, which helps to promote technological progress and industrial upgrading in this field. Through technological innovation, the aviation industry can continuously improve the performance and quality of products, meet the needs of domestic and foreign markets, and enhance international competitiveness. Meanwhile, technological innovation also helps to solve many technical problems and challenges faced by the aviation industry, and promotes the industry's development to a higher level.

However, technological innovation faced with many troubles such as insufficient resource, environment and management, etc., which affects the efficiency of technological innovation output. With the help of evaluation tools, the current situation, advantages, and shortcomings of the aviation industry in technology innovation can be identified, providing strong support for formulating more precise technology innovation policies. Secondly, evaluation work helps to promote the aviation industry to increase investment in scientific and technological innovation, optimize the allocation of innovation resources, and enhance overall innovation capabilities. In addition, evaluation can promote healthy competition and cooperation within the aviation industry, compare and learn from the innovation capabilities of other enterprises, discover gaps and draw on experience, stimulate innovation vitality, and promote to develop towards higher quality [1,2].

At present, the theoretical basis for evaluating technological innovation capability mostly refers to the innovation theories proposed by scholars such as Schumpeter and Lance Davis [3,4] revealing the main connotations and important elements of innovation from different levels such as economic benefits, enterprise management, and national innovation. At the enterprise level, technological innovation can be understood as the recombination of production factors, production conditions, and production organization in economic activities, and the introduction of new concepts, technologies, etc. Through institutional arrangements, support, and interaction, a new production system with better efficiency and higher efficiency is formed. New products are developed and produced, new services are provided, new markets are occupied, and greater profits are obtained. The innovation evaluation practices conducted domestically and internationally mainly focus on the evaluation of scientific and technological innovation at the national, industrial, and regional levels, and have not yet formed a normalized monitoring and management mechanism for the aviation industry. In this paper, the laws of aviation technology innovation activities were explored, based on the Zachman model and the five-element model, the roles and focus of different dimensions and responsibilities in aviation technology innovation activities were analyzed, and the influence of each element in aviation technology activities was grasped. On this basis, a qualitative and quantitative evaluation index system for aviation technology innovation capability was established to identify the advantages and disadvantages of innovation capability, and clarify the optimization direction [5,6].

2. Logic Model for Aviation Technological Innovation Activities

2.1 Laws of Aviation Technological Innovation Activities

Technological innovation generally refers to the ability to continuously make breakthroughs in technology development under certain technological investment conditions, and create new ideas, methods, and technologies with economic value, social value, and ecological value. The better the conditions for technological investment and the stronger the accumulation of technology, The value of innovation may be greater. The development of an organization is sustainable with both a certain amount of investment and expected value. In order to achieve the expected results and value of technological innovation, and provide strong technical support for the improvement of enterprise core competitiveness, it is necessary to form a scientific and reasonable operating law of technological innovation itself and establish a complete technological innovation system.

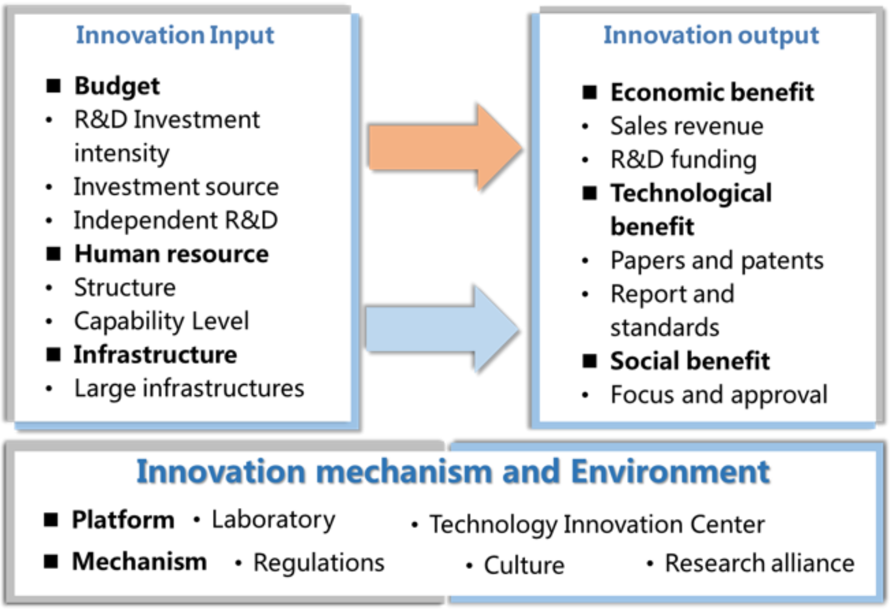

Figure 1 – Logic model for aviation technological innovation activities

A complete technological innovation system includes innovation organizations (carriers), innovation policies, innovation funds, innovation talents, innovation platforms, and innovation outputs. Each element provides support for innovation activities at different stages.

Following the general laws of innovation activities and focusing on the characteristics of aviation technology innovation programs and projects, the logical model for aviation technology innovation activities includes three aspects: demand and investment, research activities, and output and effects. As shown in Figure 1. Generally, innovation input refers to the budget, human, and material resources invested in innovation activities, which is a necessary condition for carrying out innovation activities and reflects the basic ability and investment intensity of the innovative entities to carry out innovation activities. The innovation mechanism and environment include the platforms, regulations, culture, etc., which are the guarantee elements for carrying out innovation activities, promoting the transformation of innovation input into innovation output, and reflecting the support of innovative entities for carrying out innovation activities. Innovation output is the ultimate product and benefit of innovation activities, which directly reflects the actual effectiveness of the innovative in the combination of various elements of innovation and is also a key item in the assessment of innovation capability.

2.2 Analysis for Aviation Technological Innovation using the Zachman Model

Aviation technology innovation activities usually relate to researchers and managers from industries and research institutes. Due to differences in responsibilities, these stakeholders often have different perspectives and considerations in aviation technology innovation activities. After comparison and analysis, we have chosen the Zachman model with more robust features as the reference model. Analyze the relationships from different dimensions and establish an architectural framework to evaluate and manage aviation technology innovation activities [7].

Table 1 – Analysis for aviation technological innovation activities based on Zachman model

	Data (What)	Function (How)	Network (Where)	People (Who)	Time (When)	Motivation (Why)
Scope (Planner)	Needs and requirements	Analysis of materiel requirements	Nation	Service technological innovation organization	Milestones	Advanced technology capability
Business concepts (Owner)	Critical technology lists	Allocation of human, budget and infrastructure resource	Aviation industry	Technological innovation management department (AVIC)	Main schedule	Technology roadmap
System logic (Designer)	Technological research program list	Design, calculation, analysis, fabrication, test	Innovative entities (Institute, laboratory)	Program manager (Innovative entities)	Schedule	Program/project plan implemented
Technology physics (Engineer)	Research and management activities	Design, calculation, analysis, fabrication, test	Innovative entities (Institute, factories, laboratory)	Integrate Product Team (IPT)	Sub-Schedule	Technology achievements
Component assembly (Technician)	Research and management activities	Design, calculation, analysis, fabrication, test	Innovative entities (factories, laboratory)	Integrate Product Team (IPT)	Sub-Schedule	Technology achievements
Operations classes (User)	Technology application	Operational test	End users	End users	Sub-Schedule	Defense systems

Scope (Planner), Business concepts (Owner), System logic (Designer), Technology physics (Engineer), Component assembly (Technical), and Operations classes (User) cover the entire aviation material cycle and are the six stages of innovation activities in the aviation industry. Each stage carries out different types of technological innovation, such as management, basic research, design, manufacturing, and testing, according to the division of responsibilities. Among them, the Scope (Planner) program and Business Concepts (Owner) are the responsible entities for aviation industry technology innovation, and are also important inputs for guiding aviation industry technology innovation, deploying and implementing aviation industry technology innovation activities. They pay more attention to the formulation of needs, the construction of capabilities, as well as the allocation of resources, the formulation of plans, and the effectiveness of products. System logic (Designer), Technology physics (Engineer), Component assembly (Technician), and Operations classes (User) are the collective organizations that carry out specific scientific and technological innovation research activities in the aviation industry. They represent the comprehensive capabilities of aviation industry scientific and technological innovation, and pay more attention to resource acquisition, engineering implementation, technology realization, product development, test results, and maintenance efficiency.

3. The Evaluation Model for Aviation Technological Innovation

3.1 The Evaluation Model based on the Five-element Model

Generally, basic elements in a science and technology evaluation standardly include five aspects: who will implement the evaluation, what will be evaluated, how to conduct the evaluation, and the effectiveness [8]. In this paper, basic elements for aviation technological innovation evaluation were analyzed, and evaluation framework was built based the five-element model, as shown in figure 2.

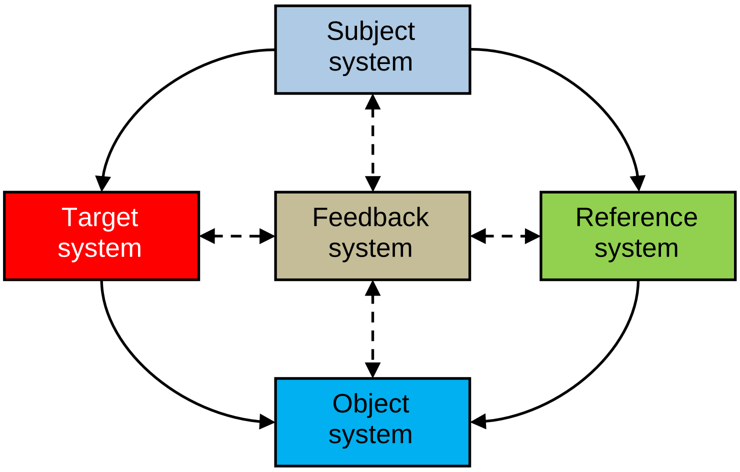

Figure 2 – The technological innovation evaluation system based on the five-element model

In the model, five systems were established and integrated with each other, which form a loop and evaluation system.

- The subject system is comprised of value subject that represents the whole aviation industry and evaluate subject including independent review team.
- The object system comprises value object that represents effects for aviation technological innovation activities in each institute and evaluate object that include all institutes in aviation industry.
- The target system is the expectation or goal from values subject to values object, in other words, technological innovation supporting high quality development of aviation systems sustainably and effectively.

- The reference system represents evaluation index system that provides criteria for evaluation.
- The feedback mechanism was established for form a loop in the evaluation systems, which make the evaluation system can be optimized.

3.2 Evaluation Indicator System

Based on the theory and logical model mentioned above, a three-layer evaluation index for aviation technological innovation capability has been established, as shown in table 2, including target layer, evaluation indicator and assessment criteria. The target layer of this evaluation index consists of four first level indicators:

- Technological innovation investment.
- Environment and mechanism.
- Innovation outputs.
- Additional indicators.

It reflects the intensity of resource investment in scientific and technological innovation activities, the basic ability of scientific and technological innovation objects, and the benefits of scientific and technological innovation output. The added benefits mainly highlight innovative achievements with scientific and technological value and influence, and include 12 indicators such as funds, personnel, facilities, management, results, income, and international patents.

Table 2 – Evaluation indicators for aviation technological innovation management

Target layer(T)	Evaluation indicator (E)	Assessment criteria (C)
1 Technological innovation investment	1 R&D funding	1 Annual R&D investment intensity 2 Ratio of R&D investment to new assets 3 Ratio of R&D investment to sales revenue
	2 R&D talent	4 Ratio of R&D personnel 5 The proportion of phD 6 The proportion of technical experts
	3 Infrastructure	7 proportion of infrastructure update funds
2 Environment and mechanism	4 Innovative platform	8 Cooperation between university, institute and factories 9 Technology innovation centers 10 Laboratories 11 International cooperation centers
	5 Innovation mechanism	12 Intelligence property 13 Personnel promotion system 14 Incentive and exemption system 15 Strategy Management 16 Corporate Culture
	6 External cooperation	17 Usage of external talents and technology
3 Innovation outputs	7 Technological outcomes	18 Inventions, proprietary technology, and patent ownership 19 Number of awards for scientific and technological achievements 20 Academic journals
	8 Talent training	21 Outstanding talent training
	9 Economic benefits	22. Sales revenue from new products as a percentage of total revenue 23. The proportion of new product profits in total profits 24 The number of technological achievements converted into productivity
	10 Social benefits	25 Brand strength 26 Customer satisfaction

		27 PCT applications as a percentage of invention patent applications
4 Additional indicators	N/A	28 Major throughout in technology development
	N/A	29 Technology award
	N/A	30 International patent
	N/A	……

In third layer, the evaluation criteria for the innovation investment layer focus on seven indicators:

- The technological innovation investment indicator focuses on the proportion of funds invested in innovation activities, the proportion of R&D personnel, employee with doctoral degree, experts in the assessment of R&D personnel, and the proportion of technical renovation funds invested in carrying out innovation activities as the facility dimension assessment.
- The environment and mechanism indicator focuses on 10 indicators, including the construction of open innovation platforms, the construction of management mechanisms to support and guarantee innovation activities, and the introduction of external advantageous resources.
- The assessment criteria for the innovation output layer focus on 10 indicators, including soft science achievements such as inventions, patents, academic journals, the proportion and profit of new product sales, and social and customer satisfaction.
- The additional indicators focus on technological award, international patent, etc.

After that, a three-layer evaluation index for aviation technology innovation capability has been established around the "goal-indicator-standard" evaluation framework.

3.3 Calculation method of indicator system

3.3.1 Variables normalization

The evaluation indicators refer to multiple aspects such as investment, personnel, facilities, achievement, economic benefits, social benefits and management, which were measurement with different method. Usually, there are differences in the data types and volumes of each indicator. The evaluation value varies with the proportion of the actual data, and there are curve patterns in which the influence of the change of the curve type and the indicator value on the overall level of changes gradually. In order to eliminate the influence of measurement units on the original data, the inverse index is converted into positive index, and the indicator values of different measurement units are transformed into the same dimension values that can be added directly, i.e., the data is normalized through mathematical transformation. Taking the model of indicator “Development budget”, after calculating the Annual R&D investment intensity, Ratio of R&D investment to new assets, Ratio of R&D investment to sales revenue, perform normalization processing. The calculation formula of the indicator is:

$$E1 = w1\ (An/An_{max}) + w2\ (Ra_1/Ra_{1max}) + w3\ (Ra_2/ Ra_{2max}) \tag{1}$$

Here, $E1$ refer to development budget, An refer to annual R&D investment intensity, Ra_1 refer to ratio of R&D investment to new assets, Ra_2 refer to ratio of R&D investment to sales revenue. And $w1$, $w2$, and $w3$ refer to the weights.

3.3.2 Residual sum of squares

Residual Sum of Squares is a measure of the degree of model fit in a linear model, which is the sum of the squared differences between the actual value and the estimated (or target) value. Residual Sum of Squares can effectively represent the difference between the average (or target) value and the actual evaluation value. Based on the requirements of goal oriented and directional evaluation work, we obtain the average value through known data and use the residual sum of squares calculation method to evaluate the difference between the evaluation object and the average value, determine whether the evaluation object is above, equal to, or below the average level, and screen out the evaluation level. Taking "R&D personnel" as an example, the calculation formula for this indicator is:

$$E2=\Sigma(Pe-\widehat{Pe})^2+\Sigma(Ph-\widehat{Ph})^2+\Sigma(Te-\widehat{Te})^2 \quad (2)$$

Here, *E2* refer to development talent, *Pe* represents the proportion of R&D personnel, *Ph* represents the proportion of phD, and *Te* represents the proportion of technical experts.

3.3.3 Piecewise function method

After statistical analysis of some data samples, it is found that most data are in the state of normal distribution. According to the characteristics of target orientation, an interval assignment method based on Gaussian distribution is proposed to design the calculation model. Firstly, the data distribution range of the data samples is divided into several internals. Combined with practical experience, the Delphi method is used for different intervals Line subjective assignment. Taking the calculation model of indicator funding as an example, the equation is:

$$E8=\begin{cases} 1,\ a>125\% \\ 0.8*a,\ 100\%<a<125\% \\ (a-1)*\frac{0.8}{0.6},40\%<a<100\% \\ 0,\ a<40\% \end{cases} \qquad a=GF/GF_{avg} \quad (3)$$

Here, *E8* refer to indicator funding, *GF* refer to funding growth, *a* refer to the proportion of funding growth rate to average growth rate. In data samples, the funding growth rate is different in each stage. When funding growth rate is less than average growth rate, the indicator value changes greatly, otherwise, the indicator value changes linearly. And when the proportion (*a*) is greater than 25%, the evaluation value changes less.

3.3.4 Weighted average evaluation based on ranking method and normal distribution method

Ranking method refers to replace the data by their rank and convert to evaluation value. And normal distribution method refers to examine the relative distance between the actual value and the optimal value. Here, Firstly, ranking actual value in each indicator separately, and converting the ranks to evaluation values, finally, calculating the indicator by weighted average method. This indicator is application to economic benefits, social benefits. Taking "economic benefits" as an example, the calculation formula for this indicator is:

$$E9= w1|1-Sa/Sa_{avg}| + w2\ (Pr/Pr_{max})\ +w3\ (Nu/Nu_{avg}) \quad (4)$$

Here, *E9* refer to economic benefits, Sa refer to Sales revenue from new products as a percentage of total revenue, *Pr* refer to the proportion of new product profits in total profits, *Nu* refer to the number of technological achievements converted into productivity.

4. Case studies

4.1 Overall results

In this paper, 50 institutions were selected as evaluation samples in the Aviation Industry Corporation of China (AVIC) and were divided into three categories, including: basic research, research and development, and production. The evaluation was conducted using a "one size fits all" approach. Firstly, the working group collected and revised 50 sample data through survey questionnaires, visits and research, meetings and discussions, and expert scoring in order to ensure the authenticity, rationality of the data and the scientific, effective evaluation results. Secondly, carry out sample data calculation. Based on the three categories of the sample, determine the actual score of a single indicator through normalization, weighted sum based on normal distribution method, and other calculation methods; The evaluation result is determined by the sum of the scores of all three level indicators. Thirdly, based on data and indicator orientation, conduct multidimensional and multi-level analysis on the evaluation results, including classification ranking analysis, analysis of the strengths and weaknesses of individual samples, analysis of the overall capabilities of the aviation industry, etc., comprehensively sort out the current situation and problems of innovation, and clarify the development direction.

Table 3 – The numeric results for evaluation indicators

No.	Index name	Average score	Max score	Min score
1	R&D funding	54%	92%	29%
2	R&D talent	52%	97%	18%
3	Infrastructures	97%	100%	42%
4	Innovation Platform	68%	100%	28%
5	Innovation mechanism	73%	97%	43%
6	External cooperation	37%	100%	9%
7	Technological outcomes	50%	76%	30%
8	Talent training	33%	100%	16%
9	Economic benefit	30%	70%	10%
10	Social benefit	35%	100%	18%
11	Additional indicators	32%	100%	23%

According to the score results in table 3, innovation infrastructure, innovation platforms, and innovation mechanisms got an average score of over 60%. The utilization rate of external resources, talent cultivation, economic benefits, social benefits, and additional benefits are far lower than the passing score. In summary, AVIC is lack of awareness in innovation activities, and imbalance in capacity building and development. However, some units have already set a good example for technological innovation. According to the ranking results in figure 3, among the three types of samples, there is a significant difference in the scores of basic research units, while the scores of research and development units are relatively concentrated. Production units have prominent advantages among individuals. All three types of samples have a relatively high proportion of scores in terms of technological innovation investment, and the innovation output is significantly insufficient.

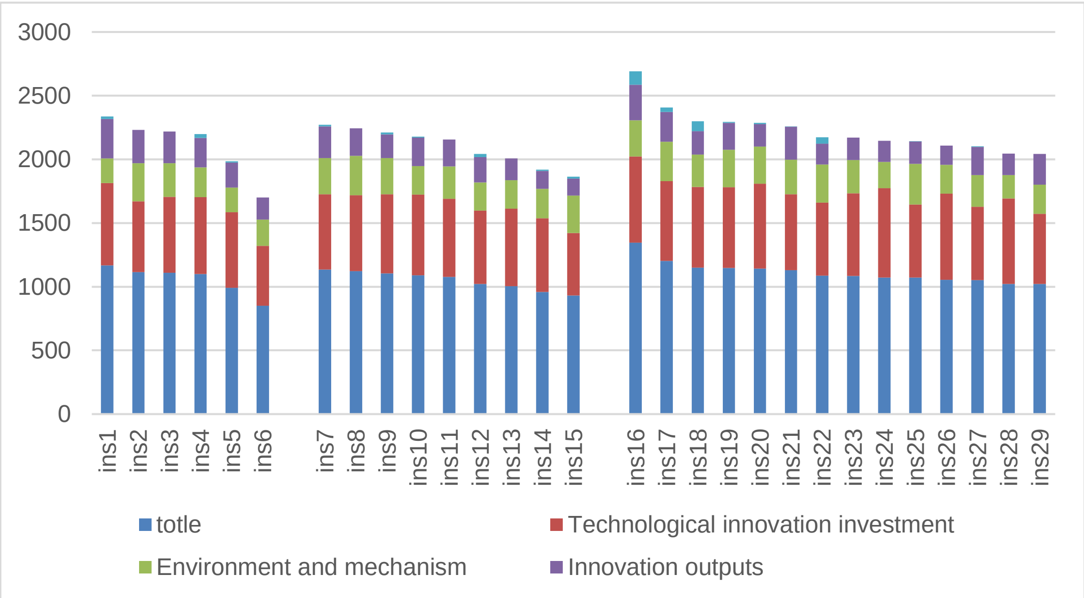

Figure 3 – Partial institutes' classification ranking

4.2 Analysis of typical indicator results

Taking R&D funding as an example, the R&D funding indicator mainly assesses the annual R&D investment intensity, the ratio of annual R&D investment to newly added assets, and the ratio of annual R&D investment to sales revenue. From the score perspective, the 50 units generally scored higher, showing a trend of concentration towards moderate to high scores. But only 1 unit is close to full score, 35 units reach the average level or above. As shown in figure 4.

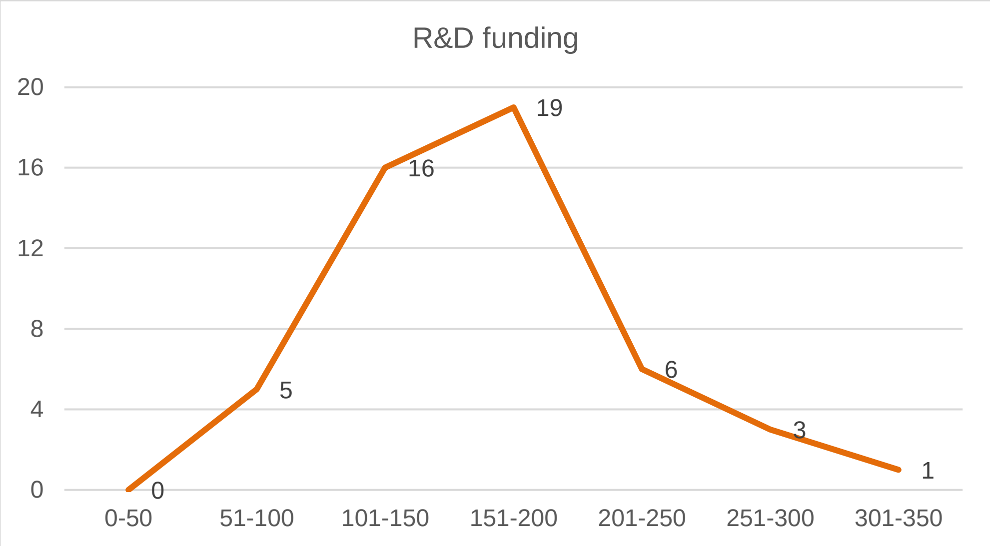

Figure 4 – R&D funding score range

4.3 Typical Institute Result Analysis

A certain evaluation sample 12 is chosen and analyzed in figure 5, which shows 11 indicators with scores.

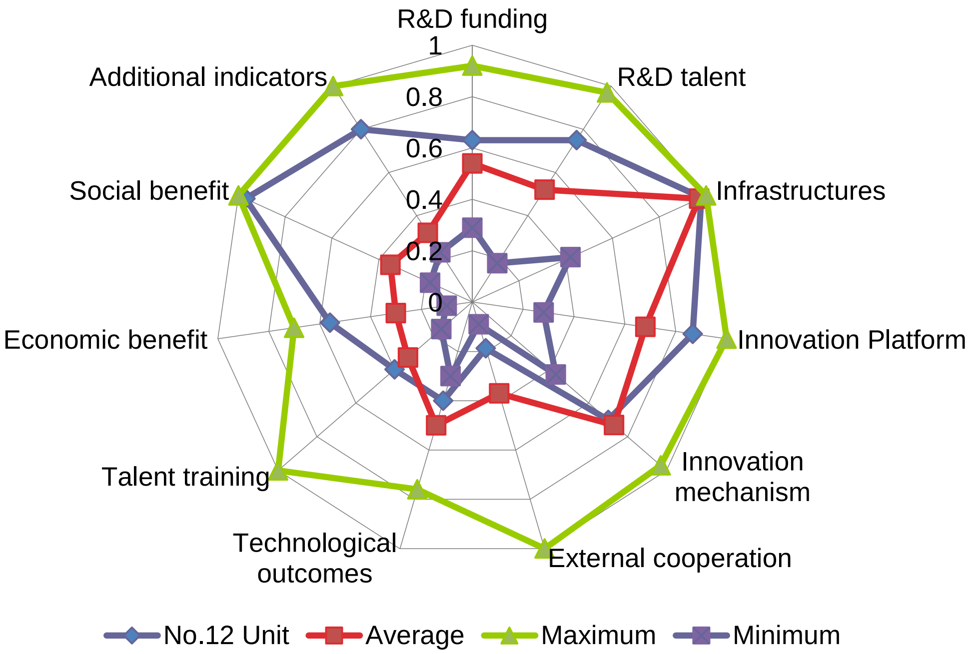

Figure 5 – Indicators score of No.12 unit

The social benefits score is close to the full score, while infrastructure, innovation platforms, R&D talent, and economic benefits exceed the average score. However, the scores for innovation mechanisms, external resource utilization, and technological outcomes are relatively low, and the additional items are not scored. Through evaluation, it can be seen that the sample has achieved good results in brand influence, talent cultivation, research facility construction, etc., but the investment in innovation environment construction and innovation achievement output is insufficient. It can basically clarify the goals and directions of future work on technological innovation.

5. Conclusions

The aviation technological innovation model has been established and the evaluation model has been designed in this paper, and some case was studied. Through the theory and practice, we found that:

1)The Zachman model is feasible in analyzing and constructing an aviation technological innovation framework. And the evaluation system consists of object system, subject system, target system, reference system, and feedback system has been proven a feasible model for innovation evaluation.

2)The established evaluation indicators cover the whole important elements of aviation technology innovation activities, with good consistency and completeness, and can play a correct guiding and leading role in aviation industry technology innovation activities.

3)The evaluation indicators have been validated through practice, demonstrating good scientific, operability, and effectiveness. They can fully demonstrate the current state of technological innovation capabilities in the aviation industry, while also identifying shortcomings in a timely manner, clarifying the direction of future improvement and breakthrough, and have further implementation value.

6. Contact Author Email Address

Contact author: Wenyuan CHENG

E-mail address: xiaoyangadr@163.com(W.CHENG)

7. Copyright Statement

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