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To cite this article: Yunlong Hu *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **692** 022092

Research on Evaluation Index System of Autonomous and Controllable Capability of Aerospace Test and Launch System

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Abstract. In order to solve the potential risks of code opening, backdoors, logic bombs, etc. in the key components, operating systems, and software of various hardware and software equipment in the aerospace test and launch system, an evaluation and research on its autonomous controllability is conducted. This paper analyzes the current status of the evaluation of the autonomous controllability of the space test launch system, put forwards the construction method of the evaluation index system of autonomous and controllable capability and the principle of index extraction, and constructs the evaluation index system. Finally, a case study is carried out based on the improved AHP method. The analysis results show that the research is of great significance to the development of autonomous controllability of aerospace launches and enhancement of the autonomy and advancement of aerospace test launch technology.

Keywords: Test launch system, localization, autonomous controllability, index extraction, index system.

1. Introduction

For a long time, the technical development level of domestic software and hardware in our country is limited. As a result, a large part of the various software and hardware equipment used in the aerospace test and launch field are from abroad. These equipments have low-cost performance, long order cycle, and purchase. Various problems such as poor channels, unopened underlying codes, and uncontrollable technical services have seriously threatened the safety and reliability of my country's space test launches. Recently, with the escalation of frictions between my country and foreign powers, especially the United States, the U.S. policy toward China has become increasingly tough. Recently, it has announced that it will comprehensively curb all aspects of my country’s production development, various software and hardware resources, technology, and intellectual property rights. All will be monopolized in all directions, which will directly restrict the development process of my country's space launch.

Then, an important means to solve this problem is to take the road of autonomous and controllable space launch. As the country puts forward clear requirements for the independent and controllable construction of test equipment and systems for aerospace test missions, my country’s aerospace test and launch system has been localized, but there is currently no feasible index system for the autonomous controllability of the test and launch system. Measure.

By constructing an index system to conduct horizontal research and comparison of aerospace test launch systems, it is possible to find out the gaps in independent production and controllability between different sub-systems, different components, and different manufacturers; by longitudinal research and comparison, you can find As well as the weak links in the production process, we will focus on rectifying and improving the weak links in the later stage and increase the investment of resources and personnel. In turn, we can more intuitively understand the structural characteristics of the space test launch system and the details of its various aspects of autonomous controllability, which can more quickly provide the evaluator with the decision direction and basis for decision-making, thereby promoting the autonomous controllability of the space test launch system controllability protects the development of my country's aerospace industry.

2. Related Technology Status

2.1. Current Status of Autonomous Controllable Evaluation of Space Test Launch System

My country has little research on the evaluation of autonomous controllability, especially the autonomous controllability of space test launch systems. In similar fields, Zhao Feng [1] used the grey clustering method to conduct research and pointed out the index conditions that should be met to improve the ability of independent innovation. Fu Weizhong [2] et al. studied the independent innovation ability of the experimental area based on principal component analysis. Luo Yafei and Cai Qianlong [3,4] explained the concept of effective external technology dependence in the article, which has a revelatory effect on the evaluation of the autonomous controllability of the space test launch system. Zhu Shuai [5] based on the product external dependence the domestic CPU has carried out evaluation research, which is conducive to promoting the independent development of domestic CPU. Song Jundian [6] et al. conducted research on the evaluation method of localization capability, and calculated the localization capability by establishing a comprehensive evaluation function, which has reference significance for the study of autonomous controllability.

There are also few reports on the research work of the space test launch system evaluation by foreign aerospace powers. Literature [7] points out all the 25 indicators frequently used by the National Aeronautics and Space Administration (NASA) for the assessment of ground station resource capabilities, but the duplication of each indicator is more serious. European Space Agency (ESA) in the mission planning and scheduling plan of the measurement and control network ESTRACK [8], although the total service time is selected as the evaluation criterion to measure the quality of the scheduling strategy, it is not clear in various tasks. Pointing out the concept of the service capability of the aerospace measurement and control system also fails to show exactly the dilemma currently faced by the aerospace measurement and control system.

2.2. Concept of Autonomous Controllability of Space Test Launch System

The term “independent and controllable” was first applied to computer information systems. It has two meanings: one is to realize localization in the computer field, and the other is to emphasize the localization of independent intellectual property rights and hardware in the computer and its key software and hardware. And the overall system requirements are "controllable" [9]. In the space test launch system, the autonomous and controllable capabilities can be divided into two aspects, namely "autonomous capabilities" and "controllable capabilities." "Independent capability" refers to the ability to independently complete the process of creation, R&D, design, production, upgrade and maintenance of aerospace test launch system relying on the existing domestic production materials and technologies independently mastered. Its core technology, key components, and various software, etc. are all localized, can be independently developed and manufactured, not dependent on or controlled by others. "Controllable" refers to being able to control, and "controllable capability" refers to a process or behavior imposed on the control object, that is, the space test launch system, so that it can reach the

IOP Conf. Series: Earth and Environmental Science **692** (2021) 022092 doi:10.1088/1755-1315/692/2/022092

control subject's assignment under specified conditions and within a specified time. The ability to set functions and goals must be able to prevent various accidents in the system. There is both a difference and a connection between "autonomy" and "controllable". "Autonomy" is a prerequisite for "controllable" and an important technical guarantee for "controllable". At the same time, when autonomous capabilities are poor, there are certain disadvantages or When there is potential danger, the situation can be controlled through some controllable means, and the two can influence and interact together to realize the safety and reliability of system functions.

3. Construction Method of Autonomous Controllable Capability Index System of Space Test Launch System

3.1. Analysis of Influencing Factors of Autonomous and Controllable Ability

The factors affecting autonomy are as follows.

(1) Ability qualification. An important factor that affects autonomous capabilities is competence qualification. The competence qualification for system production and R&D is an important prerequisite for ensuring that the system is autonomous and controllable. Capabilities and qualifications mainly include: the nature of the manufacturer, the composition of the manufacturers and personnel responsible for product development and development fundamentally affect the independence of the product; R&D investment, sufficient time and capital investment can ensure the development and progress of the independent level; personnel capabilities, R&D personnel Innovative ability, professional technical ability, management ability, etc.

(2) Technical level. To enhance the independent development capabilities of key components and various types of software and hardware, to master the control of product technology and independent intellectual property rights, in essence, it is necessary to improve the technical level of R&D and production. Especially for the aerospace test launch system, which is related to the strength of my country's national defense industry, we need to master advanced core technology. At the same time, due to the continuous interest disputes of various countries and the increasingly fierce competition in defense technology, the access to core technology products is limited. The advanced level of similar software and hardware technology often means a leading position in national defense. Therefore, the level of technology is the main factor to measure the autonomy.

The factors affecting controllability are as follows.

(1) Device management. How to screen (quality requirements, quality testing, etc.) and collocation of the various components that make up the system is an important means to fundamentally ensure product safety and improve system controllability, which often requires a full understanding of the entire system.

(2) Technical means. The detection, investigation, and processing of system failures and confidential information through various technical means can effectively improve the controllability of the system. At the same time, advanced controllable technical means can also make up for the weakness of certain product autonomy, thereby ensuring the system’s performance. normal work.

(3) Work ability. The working ability of the system is an important basis for measuring its controllability, and the controllable ability essentially serves the stable and effective work of the system. Therefore, it is necessary to study the actual working ability of the system to study its controllability.

3.2. Index Selection Principle

The principle of index extraction is as follows.

(1) Systematic principle. The entire relatively complex R&D and production process of the aerospace test launch system is investigated. The selected indicators should have the characteristics of large aggregation, small overlap, and strong systemicity. At the same time, the indicator system should be avoided from being too complicated.

(2) Key principles. The evaluation index system should theoretically cover all the production processes of all equipment. However, considering the actual domestic production status, needs and

evaluation feasibility, the selected index should cover the main influencing factors and key steps, which can be from autonomy, reliability, risk identification, Risk assessment and safety control are considered to select evaluation indicators.

(3) Objective principle. According to the typical application support capability of aerospace test launch system, its index system and weight should be established and valued to more accurately judge the autonomous controllability of the aerospace test launch system.

(4) The principle of operability. The purpose of establishing the index system is to evaluate the autonomous controllability of the space test launch system. The index system should have the characteristics of strong operability and quantify the index as much as possible. The selected index should be clearly defined and have clear boundaries.

3.3. Index System Construction Method

The space test launch system is a complex system, and its multi-index evaluation can adopt the method of "from main body determination to structural decomposition" [10]:

(1) Determine the main external entities that affect the status of the assessment system;

(2) Analyze the impact of external entities on the current system;

(3) Simplify the system and decompose the evaluation system. The methods that can be used include top-down layer decomposition, process traversal analysis, etc.;

(4) Construct an analysis framework describing the characteristics of the evaluation system.

This process can make it easier for the assessor to grasp the characteristics of the assessed object, and have a more specific and intuitive understanding of its autonomous controllability and various aspects of the impact it is subjected to, making it easier to analyze, judge and evaluate the assessed object.

4. Index System of Autonomous Controllable Capability of Aerospace Test and Launch System

4.1. Index System of Autonomous and Controllable Ability

Based on the above research and analysis, through the understanding of the production and development process of the aerospace test launch system and the realization of its functions, according to the principles of system city, criticality, targetability, and operability, design questionnaires to solicit suggestions from experts in related fields. Established an evaluation index system for the autonomous controllability of the space test launch system. The indicator system can be divided into 4 levels, namely the first, second, third and fourth level indicators. The specific structure of the index system is shown in Fig. 1.

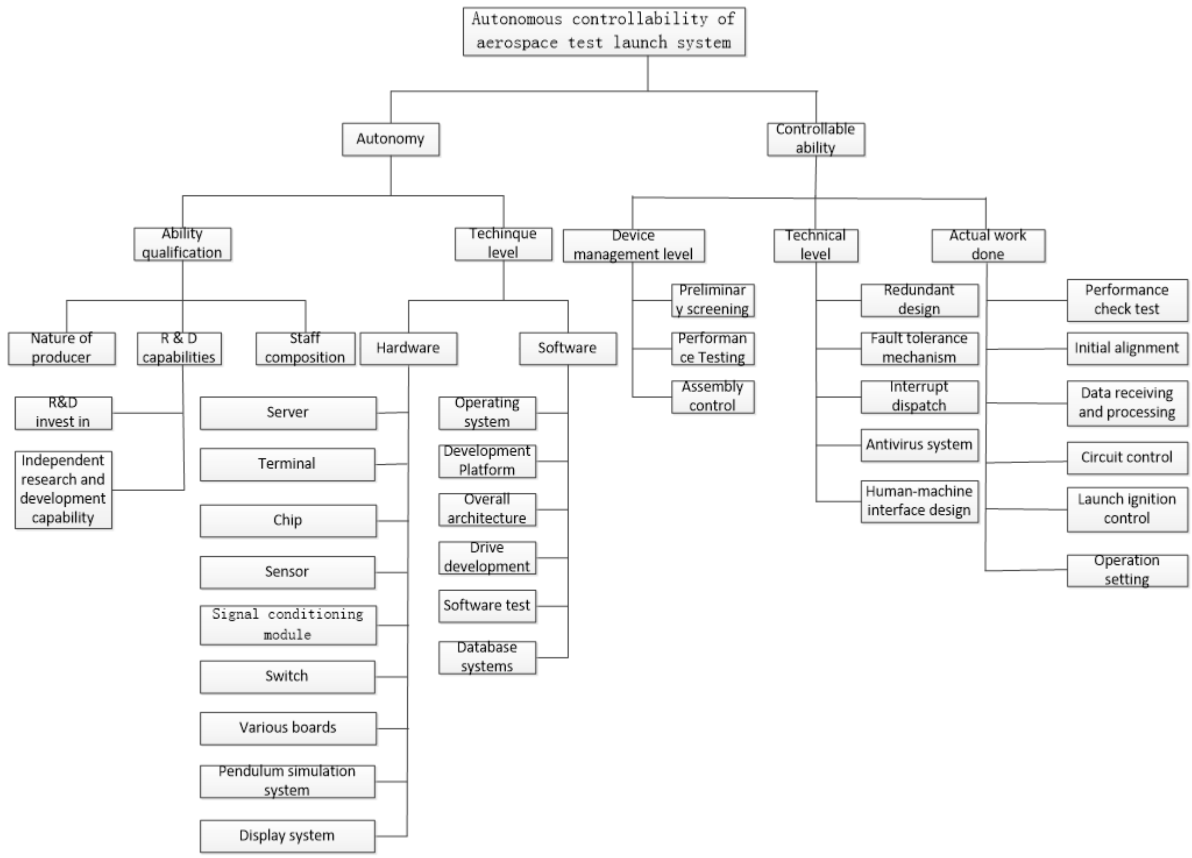

Figure 1. Evaluation index system of autonomous controllability capability of aerospace test launch system

4.2. Explanation of Autonomous Controllability Index

In the above-mentioned aerospace test launch system's autonomous controllability evaluation index system, the first-level indicators include autonomy and controllability. The safety and reliability of the aerospace test launch system is not only reflected in its independent innovation, but also its safety and controllability. It needs to be considered from various aspects of the system's production and development methods, main components, and actual functions. During the inspection process, the bottom-level indicators were mainly inspected for invention patents, technical materials, manufacturers, and production process environment.

The detailed and detailed scoring indicators are more complicated, including 2 first-level indicators, 5 second-level indicators, 20 third-level indicators, and 33 bottom-level indicators. The article mainly explains some of the bottom-level indicators in the indicator system.

The degree of independence of R&D capabilities is mainly considered from two aspects: R&D investment and personnel capabilities. The main purpose is to consider the degree of external subordination in the R&D process. The R&D process can be checked and has the characteristics of continuity, so it can use continuous quantitative indicators. The evaluation of the indicators, as shown in Table 1.

Table 1. Low-level indicators of the degree of independent control of R&D capabilities

Serial number	Index name	Aims	Strategy	Quality index type
1	R&D invest in	Investigate capital and production investment	Total investment in R&D and production	Continuous quantitative index
2	Independent research and development capability	Investigate the design and processing capabilities of R&D personnel	Consider from the scale of R&D personnel and the average number of years engaged in such work	

The degree of autonomy and controllability of hardware technology is mainly considered from the main components that affect the degree of autonomy of the space test launch system. The main sub-systems that affect the autonomous and controllable performance of the system are the control system (operating and controlling certain key nodes in the working process) and the communication system (mainly responsible for the transmission and processing of various signals and information. The safety and accuracy of information will directly Affect the safety and reliability of the system), here consider the key components of the two sub-systems. After investigation, the degree of independence of these indicators such as servers, terminals, and display systems is integral, so 0-1 indicators are used; such as chips, sensors, signal conditioning modules, switches, various boards, swing rod simulation systems, etc. The indicators are often scattered and inconsistent, but the use list of each component can be checked. Therefore, continuous quantitative indicators are used. The explanation of the indicators is shown in Table 2.

Table 2. Low-level indicators of the degree of independent control of R&D capabilities

Serial number	Index name	Aims	Strategy	Quality index type
1	Server	Examine the source and degree of autonomy of the server	Consider the server type	0-1 type indicator
2	Terminal	Examine the source and degree of autonomy of the terminal	Consider using terminal type	
3	Display system	Investigate the source and degree of autonomy of system displays	Consider the display type	
4	Chip	Investigate the source and degree of autonomy of the chip	Consider various chip specifications and quantity ratios	Continuous quantitative index
5	Sensor	Investigate the source and degree of autonomy of various sensors	Consider sensor specification ratio and quantity ratio	
6	Signal conditioning module	Investigate the source and degree of autonomy of various accessories	Consider the proportion of independent research and development accessories	
7	Switch	Examine the source and degree of autonomy of the switch	Consider the switch specification ratio and quantity ratio	
8	Various Board	Investigate the source and degree of autonomy of various boards	Consider the type and quantity ratio of various boards	
9	Pendulum simulation system	Investigate the source and degree of autonomy of various accessories	Consider the proportion of independent research and development accessories	

The degree of independent controllability of software technology is mainly considered from the influence of the development process of the aerospace test launch system software. The operating system, development platform and database system are integrated, using 0-1 indicators; the overall architecture and drive development can be divided for different levels, such as completely independent design, retrofitting foreign design, referring to foreign design, using foreign design, etc., discrete indicators can be used; and software testing does not have quantitative characteristics, so qualitative indicators are used. The indicator explanations are shown in Table 3.

Table 3. Low-level indicators of the degree of autonomy of system software

Serial number	Index name	Aims	Strategy	Quality index type
1	Operating system	Examine the source and degree of autonomy of the operating system	Consider operating system type	0-1 type indicator
2	Development platform	Examine the source and degree of autonomy of the development platform	Consider the type of development platform	
3	Database systems	Examine the source and degree of autonomy of the database	Consider the database type	
4	Overall architecture	Whether the software architecture design is complete and independent	Investigate assignments, requirements, design documents	Discrete index
5	Drive Development	Whether the design of the drive is complete and autonomous	Review design documents	
6	Software test	Check whether the software test verification phase is independent and complete	Review the test verification process, test documentation, and evaluation report	Qualitative indicators

The safety and controllability of the system's actual ability to complete the work can be considered from the main functions that the space test launch system can complete and its efficiency. The safety and controllability of these indicators can be divided into different levels. Discrete indicators are used. The inspection of operation settings is subjective. Therefore, qualitative indicators are used. The indicators are explained in Table 4.

Table 4. Low-level indicators of the safety and controllability of actual work capabilities

Serial number	Index name	Aims	Strategy	Quality index type
1	System performance check test	Check the reliability of the system to complete rocket performance testing	Consider the number of completed inspections	Discrete index
2	Initial alignment	Check the system leveling and aiming situation	Consider alignment and completion times	
3	Data receiving and processing	Examine the system's ability to process collected data	Consider response speed and data accuracy	
4	Circuit control	Investigate system power distribution and power supply	Consider the number of completed power supply	
5	Launch ignition control	Investigate the system's control of rocket ignition	Consider the speed of reflection	
6	operating Set up	Check system operation	Consider whether the operation is convenient and fast	Qualitative indicators

The controllability of the system technology can be considered from some controllable means. The inspection of these indicators is generally subjective, so qualitative indicators are used. The indicator explanations are shown in Table 5.

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Table 5. Low-level indicators of the degree of safety and control at the technical level

Serial number	Index name	Aims	Strategy	Quality index type
1	Redundancy design	Examine the working capacity of redundant equipment in the system	Consider the working condition of its redundant equipment when it fails	Qualitative indicators
2	Fault tolerance mechanism	Check system fault tolerance	Consider the number of times the system covers and shields failures	
3	Interrupt scheduling	Examine the system's ability to interrupt in time	Consider the number of timely interruptions when the system fails	
4	Antivirus system	Examine the system's ability to detect and eliminate viruses	Consider the antivirus cycle, the number of successful antivirus, etc.	
5	Human-machine interface design	Examine the working ability of false trigger protection mechanism	Consider the activation of safety-critical functions	

The qualitative evaluation of the indicators in the constructed system mainly starts with invention patents, design description documents, design codes, work description documents, etc., and evaluates the assessed from various links such as production environment, production process, production equipment, working timeliness, and work ability. The independent controllability of indicators should be investigated, and the experience of experts in related fields should be combined as much as possible.

5. Research Strategy and Case Analysis

5.1. Research Strategy

Through the research on the evaluation index system of the autonomous controllability of the space test launch system, we have an intuitive understanding of the system. The next step is to establish an evaluation model for the index system for actual evaluation. Here we use the Analytic Hierarchy Process (AHP), mainly made the following improvements:

(1) Design the questionnaire and construct the judgment matrix

When using the AHP pairwise comparison method to construct the judgment matrix, there is an unavoidable problem, that is, the arbitrariness of the experts when filling out the form or other factors, so that the recovered questionnaire often fails to pass the consistency test, and the survey is fed back again. There is no guarantee that the watch can be used, which makes the work time-consuming and laborious. Therefore, it is planned to use the Delphi method to construct the judgment matrix, and then use the AHP method to calculate the weight value. The specific process of the Delphi method is shown in Fig. 2.

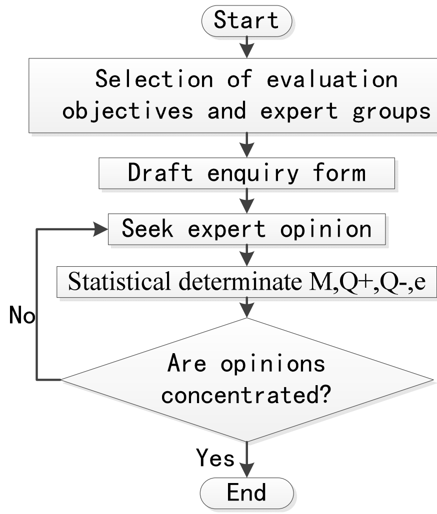

Figure 2. Implementation steps of Delphi method

In the figure, M is the median of expert opinions, Q^+ is the upper quartile, Q^- is the lower quartile, and e is the concentration coefficient. Among them, $e=\left(Q^+-Q^-\right)/\left(\max-\min\right)$, the smaller the e, the more concentrated the opinion.

(2) Introduce the optimal transfer matrix

Based on the construction of the pairwise comparison judgment matrix, the concept of the optimal transfer matrix is introduced, and the improved judgment matrix is obtained after the matrix undergoes a series of transformations. The operation steps [11] are as follows:

a) Collect expert opinions;

b) Construct a judgment matrix A, $a_{ij}=1/a_{ji}$;

c) According to the matrix A, solve its antisymmetric matrix B, $b_{ij}=\lg a_{ji}$, $B=\lg A$;

d) Solve the optimal transfer matrix C of the antisymmetric matrix B, $c_{ij}=\frac{1}{n}\sum_{k=1}^{n}\left(b_{ik}-b_{jk}\right)$;

e) Improved judgment matrix A^*, $a_{ij}^*=10^{c_{ij}}$.

This method is simple to calculate, can make full use of all the information of the judgment matrix, has high calculation accuracy, and has relatively little dependence on the consistency of the judgment matrix constructed by expert opinions. Generally speaking, the final weight value can be obtained at one time through this method, and no consistency check is required, which greatly reduces the workload.

(3) Introduce multi-data source fusion algorithm

In the evaluation process, the reasonableness of the bottom-level indicator score determines whether the evaluation is true and effective, and a single bottom-level indicator score is often given by multiple experts. Different experts have different understandings and perceptions. The AHP method is simple to evaluate. The processing method is generally to average, which is likely to cause uneven collocation of information, so we introduce a multi-data source fusion algorithm based on extended Bayes: according to Bayesian decision theory, the expert's scores of indicators are fused to get better the form of expression makes it more reasonable and effective. The algorithm is as follows:

$$M=CK+\left(1-C\right)\left(1-K\right) \tag{1}$$

$$N=C\left(1-K\right)+\left(1-C\right)K \tag{2}$$

$$\alpha = \frac{1}{\prod_{p=p_1}^{p_n} M + \prod_{p=p_1}^{p_n} N} \tag{3}$$

$$p(\theta = yes) = \alpha \prod_{p=p_1}^{p_n} M \tag{4}$$

In the formula: $p(\theta = yes)$ represents the score after the expert group believes that an indicator meets the evaluation criteria, K represents the degree of knowledge the indicator has, and C represents the satisfaction level of the indicator, α is called the standardization factor.

After using the extended Bayes algorithm to obtain the comprehensive index score, since there is no weight distribution problem between the autonomy and controllability of the two first-level indicators, for multiplicative integration, only the weight distribution of the lower-level indicators needs to be calculated independently. Then the autonomous controllability of the aerospace test launch system Z is

$$Z = z_1 * z_2 \tag{5}$$

$$z = \sum_1^m W(u_i) * p(u_i \mid \theta = yes) \tag{6}$$

In the formula: z_1 is the degree of autonomy, z_2 is the degree of controllability, $W(u_i)$ is the weight of the underlying indicators, and m is the total number of underlying indicators.

5.2. Case Analysis.

By collecting data and consulting relevant experts in the form of questionnaires, the importance of the comparison between the indicators and the scores of the underlying indicators are determined. The weights of the underlying indicators are calculated below.

According to the index fusion model, a total of 10 judgment matrices needs to be constructed. Now take the comparison matrix of the lower-level index importance of ability and qualification as an example,

$$R_{11} = \begin{bmatrix} 0.5 & 0.6 & 0.4 \\ 0.4 & 0.5 & 0.5 \\ 0.6 & 0.5 & 0.5 \end{bmatrix}.$$

Improved judgment matrix by introducing transfer matrix,

$$R_{11}^* = \begin{bmatrix} 1 & 1.0627 & 0.9283 \\ 0.9410 & 1 & 0.8736 \\ 1.0772 & 0.1447 & 1 \end{bmatrix}.$$

And get the feature vector, W_{11}=[0.9940 0.9353 1.0757]^T, the weight of the lower-level indicators of competency is r_{11}=[0.331 0.312 0.357].

According to this method, 10 matrices are calculated sequentially, and the final relative weights can be obtained as follows:

r_1=[0.551 0.449];

r_2=[0.304 0.293 0.403];

r_{11}=[0.331 0.312 0.357];
r_{12}=[0.5 0.5];
r_{21}=[0.411 0.375 0.214];
r_{22}=[0.198 0.216 0.225 0.247 0.114];
r_{23}=[0.178 0.153 0.177 0.228 0.151 0.113];
r_{112}=[0.423 0.577];
r_{121}=[0.124 0.103 0.0845 0.1487 0.136 0.111 0.1284];
r_{122}=[0.176 0.198 0.195 0.157 0.096 0.188].

Finally, calculate the combined weights of the underlying indicators. After fusion, the relative weight of the 19 underlying indicators of autonomy is

W_1= [0.182 0.073 0.099 0.197 0.0278 0.0231 0.0190 0.0334 0.0109 0.0305 0.0249 0.0260 0.0288 0.0395 0.0445 0.0438 0.0352 0.0216 0.0422].

The relative weight of 14 underlying indicators of controllable ability is

W_2= [0.1249 0.1140 0.0651 0.0580 0.0633 0.0659 0.0724 0.0334 0.0717 0.0617 0.0713 0.0919 0.0609 0.0455].

Combining the multi-data source fusion algorithm to obtain the underlying indicators of system autonomy and controllability, the final score is

B_1= [1 0.8 0.6 1 1 0.8 0.7 0.87 0.9 0.8 0.7 0.7 1 0.9 0.8 0.75 0.9 0.8 0.9];

B_2= [0.9 0.9 0.8 0.8 0.6 0.7 0.9 0.3 0.6 0.8 0.7 0.8 0.6 0.8].

B_1 means autonomy and B_2 means controllability, their values indicate to a certain extent the degree of autonomous controllability of the corresponding underlying indicators. Then the degree of autonomy and controllability of the system is obtained

$$Z = B_1 W_1^{\mathrm{T}} . B_2 W_2^{\mathrm{T}} = 0.8750 \times 0.7615 = 0.6663 .$$

The evaluation results preliminarily show that the space test launch system has a relatively high degree of autonomous controllability and basically meets the needs and goals of research and development. Judging from the scoring of indicator weights and the scoring results of the underlying indicators, the chips, sensors, and various boards used in the system have a relatively low degree of autonomy and a large proportion, which will affect the autonomy of the system to a certain extent. We must increase R&D investment in these areas, increase R&D efforts to reduce its external dependence, and at the same time vigorously develop controllable technical means to enhance the fault tolerance of the system, so as to improve the independent controllability of my country’s space test launch system. Promote the progress and development of the aerospace industry.

6. Conclusion

On the basis of studying the status quo of related technologies of aerospace test launch system, the relevant factors affecting autonomous controllability are analyzed, and the corresponding system construction methods and index selection principles are determined, and then the construction is easy to understand, strong in hierarchy, and significant in objectives. The independent controllable ability evaluation index system of the company, and improvement and innovation on the basis of traditional AHP evaluation, have improved the rationality and operability of the evaluation. Case studies show that the evaluation index system can provide effective evaluation methods and technical support for the evaluation of my country's space test launch system. At the same time, the evaluation index system has the advantages of strong compatibility and easy expansion, and it can also be applied to other sub-systems to provide the necessary theoretical and practical basis for the comprehensive autonomous control of my country's space missions.

Acknowledgments

This work was financially supported by Autonomous Controllable Technology and Application of Key Equipment for Aerospace Test Launch fund.

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