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Analysis and Evaluation of Youth Robotic Science and Technology Innovation Competition

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***Abstract*：** *The primary objective of this paper is to systematically analyze and evaluate the Youth Robotics Science and Technology Innovation Competition using the Analytic Hierarchy Process (AHP). This approach aims to provide decision-making support for both organizers and participants. The paper identifies key dimensions for evaluating the competition, including competition quality and reputation, time planning and investment, team resources and funding, as well as awards. The AHP methodology is employed to assign weights to each evaluation criterion, ensuring the rationality of the evaluation model through a consistency test. The findings indicate that competition quality and reputation are the most critical factors in assessing the youth robotics competition. Additionally, the current needs of youth align most closely with STEM education-based competitions. The paper also examines the differences in evaluation preferences among various stakeholders and offers corresponding recommendations for improvement.*

Keywords: *Robot Science and Technology Innovation Competition; Weight Vector; Judgment Matrix; Analytic Hierarchy Process*

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I. INTRODUCTION

With the growing number of youth robotics competitions worldwide, these events have become essential platforms for students to showcase their innovation and practical skills while advancing STEM (Science, Technology, Engineering, and Mathematics) education. Robotics competitions promote the integration of theoretical knowledge with practical application, helping students better understand STEM subjects through hands-on experience [1]. In the United States, competitions such as VEX, Botball, and RoboRAVE have evolved into arenas where young technology enthusiasts can demonstrate their talents [2]. Research shows that participation in robotics competitions significantly boosts students' motivation and achievement in STEM fields [3].

These competitions not only require students to apply theoretical knowledge to real-world challenges, but also deepen their understanding through practical problem-solving [4]. Additionally, participants must prepare technical reports and present project defenses, further enhancing their comprehensive skills [5]. Each year, these events attract a diverse group of students from around the globe, who come together to exchange ideas and compete for recognition in this grand celebration of science and technology.

Despite the global success of youth robotics competitions, systematically evaluating how these events stimulate students' innovative potential and develop practical abilities remains a challenge that requires further exploration [6]. Most existing evaluations focus on educational outcomes and technical performance, but lack a multidimensional analysis [7]. This paper aims to examine multiple factors influencing youth robotics competitions from the perspective of participants, including competition quality and reputation, time planning and investment, team resources and funding, and awards [8]. By employing the Analytic Hierarchy Process (AHP), this study seeks to provide an objective and fair evaluation model for various types of robotics competitions, guiding educators, students, and parents toward more meaningful and productive participation [9].

The significance of this research lies not only in offering a systematic evaluation method for competitions but also in providing practical recommendations for improving the organization and implementation of youth robotics competitions, thereby promoting the further development of STEM education [10].

II. METHODOLOGY

2.1 Fundamental Principles of AHP

This paper employs the Analytic Hierarchy Process (AHP) to systematically analyze and evaluate the Youth Robotics Science and Technology Innovation Competition. AHP is a widely used decision-making method proposed by Thomas L. Saaty in the 1970s [9]. It combines mathematics and psychology to solve complex decision-making problems. By breaking down a decision problem into sub-problems that are easier to analyze, and considering various factors comprehensively, a final decision result can be obtained [10]. The fundamental concept of AHP involves decomposing a complex decision-making problem into three levels:

Goal Level: The ultimate decision-making objective, which defines the problem to be solved.

Criterion Level: Various factors or criteria that affect the decision-making process, which serve as the basis for making decisions.

Program Level: The different alternatives adopted to achieve the objective [11]. In this study, we categorize the evaluation criteria for youth robotics competitions into four fundamental dimensions: competition quality and reputation, time planning and investment, team resources and funding, and the significance of awards. These dimensions are further divided into sub-factors, including educational merit, student participation levels, required technical infrastructure, and financial resources [12].

2.2 Establishing the AHP Model and Calculation Process

To ensure an objective evaluation, we employ a pairwise comparison matrix and a 9-point scale to assign scores to each criterion and sub-factor [13]. By following the structured computational procedures of AHP, we derive the comprehensive weightings for different types of youth robotics competitions. This systematic analysis allows us to establish a priority ranking and evaluate these competitions based on evidence [14].

2.2.1 Establishing the Hierarchical Structure Model

Based on application requirements, we build a hierarchical structure model, identifying the goal level, criterion level, and program level. The goal level is to conduct a comprehensive evaluation of different youth robotics competitions. The criterion level includes the four key factors affecting competition evaluation: competition quality and reputation, time planning and investment, team resources and funding, and awards. The program level categorizes competitions into STEM education-based competitions, competitive confrontation competitions, and academic research competitions [15].

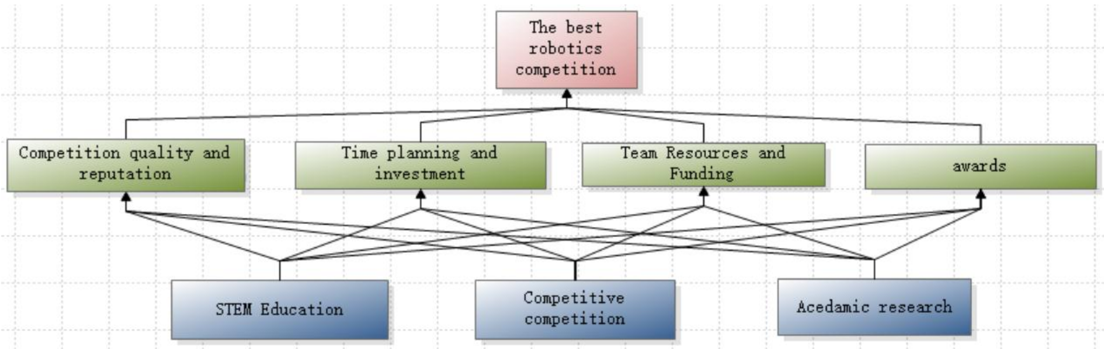

Figure 1： Ladder Structure Model of Robot Competition

2.2.2 Constructing a Pairwise comparison matrix

Let the number of factors in the criterion layer be n, and compare their influence on the factors in the previous layer. And thus determine their weight in each norm. The scale of 1 ~ 9 can be used for comparison. Let denote the result of the comparison of the i th factor with respect to the j th factor, then

$$a_{ij} = \frac{1}{a_{ji}} \quad (1)$$

where aij represents the result of comparing factor i to factor j.

$$A = (a_{ij})_{n\times n} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \quad (2)$$

Call A pairwise comparison matrix.

Table 1：Definition of Judgement Proof Scale

Scale	Meaning
1	The *i* th factor has the same effect as the *j* th factor
3	The *i* th factor has a slightly stronger effect than *j* th factor
5	The influence of the *i* th factor is stronger than *j* th factor
7	The influence of the *i* th factor is stronger than that of the *j* th factor.
9	The influence of the *i* th factor is stronger than that of the *j* th factor

2, 4, 6, 8 means that the influence of the i th factor relative to the j th factor is between the two adjacent levels mentioned above. According to, it is not difficult to define the meaning of the reciprocal of the above scales. Because the two comparison objects are the same, it is not difficult to conclude that = 1.

2.2.3 Hierarchical single sorting and one-time inspection

We randomly construct pairwise comparison matrices and compute consistency indices (CI) and random indices (RI) to ensure the rationality of the judgment matrices. When the consistency ratio (CR) is less than 0.1, the judgment matrix is deemed acceptable [16]. A one-time indicator, can be obtained.

$$RI = \frac{CI_1,CI_2,\dots,CI_{500}}{500} = \frac{\frac{\lambda_1,\lambda_2,\dots,\lambda_{500}}{500} - n}{n-1} \quad (3)$$

Calculate the one-time index (consistency index)CI as follows;

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

Where, is the maximum eigenvalue of the judgment matrix,Finding one-time indicators.

Table 2:Average random one-time indicators

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0	0	0.52	0.89	1.12	1.24	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58

Calculate the consistency ratio (CR):

$$CR = \frac{CI}{RI} \quad (5)$$

When< 0.10, the consistency of the judgment matrix is acceptable, otherwise, the judgment matrix should be modified appropriately.

2.3 Hierarchical General Sorting and Consistency Inspection

Finally, we need to calculate the ranking weight of each element relative to the overall goal to select the best option. It is also necessary to check the consistency of the overall hierarchy ranking to ensure that the total ranking is rational. The synthetic weight of each layer' s element is calculated with respect to the overall system goal, and the alternatives are ranked accordingly. Compute the weight vector W.

2.3.1 Calculating the Weight Vector

We use both the geometric mean method (square root method) and the arithmetic average method (summation method) to calculate the weight vector:

Geometric Mean Method (Square Root Method):

$$W_i = \frac{(\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}}{\sum_{i=1}^{n}(\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}}, \quad i = 1,2,\ldots,n$$

(6)

The calculation steps are as follows:

Multiplying the elements of by rows to obtain a new vector.

Squaring each component of the new vector to the power .

And normalize that obtained vector to obtain a weight vector.

Arithmetic average method (summation method)

Because each column of the judgment matrix approximately reflects the distribution of weights, The arithmetic mean of all the column vectors can be used to estimate the weight vector. That is

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad i = 1,2,\ldots,n \tag{7}$$

The calculation steps are as follows:

To normalize the elements of , that is, to find; $a_{ij} / \sum_{k=1}^{n} a_{kj}$

Sum the normalized columns.

Divide the summed vector by n to obtain the weight vector.

2.3.2 Consistency Inspection

We calculate the Consistency Index (CI) and Random Index (RI) and then compute the Consistency Ratio (CR):

CR=CI/RI

When CR<0.10, the consistency of the judgment matrix is considered acceptable. Otherwise, the judgment matrix should be modified appropriately.

III. APPLICATION OF ANALYTIC HIERARCHY PROCESS IN THE EVALUATION OF TEENAGER ROBOTIC COMPETITION

In this study, the Analytic Hierarchy Process (AHP) is applied to comprehensively evaluate various aspects of the Youth Robotics Science and Technology Innovation Competition. Through analyzing factors such as competition quality and reputation, time planning and investment, team resources and funding, and awards, we conducted a detailed comparison of different types of robotics competitions. Below are the specific steps and results of the analysis.

3.1 Classification of Robotics Competitions

Based on the characteristics and objectives of different competitions, youth robotics competitions can be roughly divided into three categories:

3.1.1.STEM Education Competitions:

These competitions focus on education and inspiration, encouraging students to explore science, technology, engineering, and mathematics. They are highly respected in both educational and academic fields [1]. Examples include RoboRAVE, VEX, and the FIRST series of competitions. These events often align with the academic calendar, allowing students to participate in their free time, thus requiring less time and investment [2].

3.1.2.Competitive Confrontation Competitions:

Known for their high competitiveness and intense confrontations, these competitions are highly entertaining and enjoy a strong reputation among the public and media. Such competitions require more extensive time planning and investment, with teams undergoing intensive training throughout the season [3].

3.1.3.Academic Research Competitions:

Academic research competitions often address issues related to current research hotspots, promoting technological innovation and enjoying high prestige in academic and research circles. These competitions offer more flexible time planning but usually require longer research and development periods and substantial financial support [4].

3.2 Construction of the Pairwise Comparison Matrix and Weight Calculation

Based on survey results and expert opinions, this study constructed a pairwise comparison matrix for youth robotics competitions. Using the 9-point scale, scores were assigned to each dimension, and the weights were calculated through the AHP method. The final weights are as follows:

$$A = \begin{pmatrix} 1 & 2 & 2 & 1/4 \\ 1/2 & 1 & 4 & 1/3 \\ 1/2 & 1/4 & 1 & 1/5 \\ 4 & 3 & 5 & 1 \end{pmatrix} \quad (8)$$

According to the table, competition quality and reputation, time planning and investment, team resources and funds and awards,The judgment matrices are: B_1; B_2; B_3; B_4

$$B_1 = \begin{pmatrix} 1 & 1/4 & 1/6 \\ 4 & 1 & 1/3 \\ 6 & 3 & 1 \end{pmatrix} \quad B_2 = \begin{pmatrix} 1 & 5 & 4 \\ 1/5 & 1 & 2 \\ 1/4 & 1/2 & 1 \end{pmatrix} \quad (9)$$

$$B_3 = \begin{pmatrix} 1 & 6 & 7 \\ 1/6 & 1 & 3 \\ 1/7 & 1/3 & 1 \end{pmatrix} \quad B_4 = \begin{pmatrix} 1 & 9 & 7 \\ 1/9 & 1 & 2 \\ 1/7 & 1/2 & 1 \end{pmatrix}$$

Table 3: Weight coefficient of competition quality and reputation judgment matrix

	W_1	W_2	W_3	λ_{max}	CR
Competition quality and reputation	0.0852	0.2706	0.6442	3.0536	0.0516
Time planning and investment	0.6870	0.1865	0.1265	3.0940	0.0904
Team Resources and Funding	0.7504	0.1713	0.0782	3.0999	0.0961
Awards	0.7959	0.1211	0.0830	3.0999	0.0961

Calculate the composition weight of each layer to the target layer:

The hierarchy weight values of the factors included in the previous hierarchy are respectively. If the one-time indicator of some factors in the hierarchy for single sorting is, the corresponding average random one-time index is, then the total ranking random one-time ratio of the hierarchy is:

$$CR = \frac{\sum_{i=1}^{n} b_i CI_i}{\sum_{i=1}^{n} b_i RI_i} \quad (10)$$

When CR< 0.10, the total ranking result of the hierarchy meets the one-time requirement, and the total weight of each region can be obtained.

$$CR = 0.0717 \quad (11)$$

Table 4: Weight distribution of each region

Factor	Team Resources and Funding	Awards	Time planning and investment	Competition quality and reputation
Weight	0.2019	0.1825	0.0782	0.5374

3.3 Final Scores for Each Type of Competition

Based on the calculated weights, the final scores for the three types of robotics competitions are as follows:

- STEM Education Competitions: 0.3962
- Competitive Confrontation Competitions: 0.2166
- Academic Research Competitions: 0.3870

The results indicate that STEM education competitions are the most favored among youth, followed closely by academic research competitions. This aligns with the current demand for STEM education and the support provided by schools for these types of events [5].

Table 5:Final Rating

STEM education	Competitive confrontation	Academic research
0.3962	0.2166	0.3870

IV. MODEL EVALUATION

In this section, we evaluate the AHP model used in this study, discussing its strengths and weaknesses, and proposing directions for future improvement.

4.1 Advantages of the Model

The Analytic Hierarchy Process (AHP) is an effective multi-criteria decision-making tool, especially for complex decision problems. The main advantages of AHP include:

4.1.1Structured Decision Process:

AHP allows decision-makers to break down complex problems into hierarchical levels, enabling them to systematically evaluate and compare the relative importance of different factors [1]. This is particularly useful for evaluating youth robotics competitions, which involve multiple intertwined evaluation dimensions.

4.1.2Flexibility:

AHP allows decision-makers to adjust the model based on real-world conditions, especially by incorporating various criteria and sub-criteria, which enhances the model's flexibility and adaptability [2]. In this study, AHP successfully integrated multiple dimensions such as competition quality, time planning, funding, and awards.

4.1.3Combining Quantitative and Qualitative Analysis:

AHP combines both quantitative data and qualitative judgments through the use of pairwise comparison matrices and weight allocation, making the evaluation process both scientific and rational [3]. This is particularly important when dealing with multidimensional issues like educational competitions.

4.2 Limitations of the Model

Despite its strengths, the AHP model also has certain limitations:

4.2.1Subjectivity:

The weight distribution in AHP relies on expert judgment, which introduces an element of subjectivity [4]. While consistency checks help reduce bias, they cannot eliminate it entirely.

4.2.2Interdependence of Criteria:

AHP assumes that the criteria are independent, but in real evaluations, criteria may influence each other [5]. For example, competition quality and reputation may be related to time planning and funding.

4.2.3Inability to Handle Dynamic Changes:
AHP is inherently a static model, meaning it does not account for dynamic changes in evaluation factors over time [6]. This may limit its applicability in contexts where continuous monitoring and assessment are required.

4.3 Directions for Future Improvement
To enhance the applicability and scientific robustness of the AHP model, future research can consider the following improvements:

4.3.1Integrating Other Evaluation Methods:
AHP can be combined with other methods, such as the Fuzzy Comprehensive Evaluation or Delphi Method, to improve the objectivity and accuracy of the model [7].

4.3.2Introducing Dynamic Weight Adjustment Mechanisms:
Developing a dynamic model that allows weights to be adjusted over time or in response to external conditions would make the model more adaptable to real-world scenarios [8].

4.3.3Collaborative Expert Evaluation:
Introducing more experts into the evaluation process and taking the weighted average of their opinions can further reduce the subjectivity of individual judgments [9].

V. CONCLUSION AND RECOMMENDATIONS

Youth robotics competitions have gained increasing attention worldwide, not only advancing STEM education but also providing a platform for students to showcase their innovation and practical skills. Through the application of the Analytic Hierarchy Process (AHP), this study systematically evaluated the Youth Robotics Science and Technology Innovation Competition. The results indicate that competition quality and reputation are the most critical factors, followed by team resources and funding.

The key conclusions of this study are as follows:

Competition Quality and Reputation Are Key Factors: For youth robotics competitions, the quality and reputation of the event are crucial to its success. A high-quality, well-reputed competition can inspire more students to participate, attract more resources, and enhance the overall impact of the event [1].

STEM Education Competitions Are Most Appealing: According to the evaluation results, STEM education competitions are the most favored among youth. These competitions typically align with school schedules, allowing participants to engage during their free time, with lower time and financial investments, and more rewarding prize structures [2].

Different Competition Types Have Distinct Characteristics: Competitive confrontation and academic research competitions each have their strengths and weaknesses. While the former offers greater entertainment and public appeal, it requires more time and resources; the latter emphasizes academic research and innovation, demanding higher levels of expertise and financial support [3].

5.1 Recommendations for Event Organizers
Based on the findings of this study, event organizers can take the following steps to further improve the quality and impact of youth robotics competitions:

5.1.1Enhance the Academic Depth of Competitions:
By incorporating more research elements into the competitions, organizers can attract students with a keen interest in science and technology, thereby increasing the educational value of the events [4].

5.1.2.Lower Barriers to Entry:
Reducing the time and financial commitments required for participation can attract a more diverse group of students, thereby increasing the inclusivity and diversity of the competitions [5].

5.1.3.Optimize the Reward System:
Introducing more awards related to innovation and teamwork can encourage students to unleash their full potential in collaborative efforts [6].

5.2 Directions for Future Research
Future research could further explore the integration of other evaluation models, such as the Fuzzy Comprehensive Evaluation, to address the subjectivity issues inherent in AHP. Additionally, incorporating

dynamic evaluation models that allow weights to be adjusted based on real-world conditions could further enhance the scientific rigor and applicability of the assessment process.

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