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A Comprehensive Model for Evaluation of Sport Coaches' Performance

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Abstract*—Based on the analytic hierarchy process (AHP) and grey relational analysis (GRA), a comprehensive mathematical model is proposed to evaluate sport coaches' performance during their whole careers. First, the AHP is used to determine the evaluation criteria and weights. By adopting a questionnaire survey, the fuzzy mathematic theory is taken into account to construct quantitative criteria. Then, the GRA is adopted to evaluate the coaches by incorporating all the available information/data. Last, the sensitivity test is performed with respect to the resolution ratio. The effectiveness of the proposed model is demonstrated by a case study. Based on the AHP, the weights of personal qualification, training qualification and team achievements are determined, respectively. Our results show that the team achievements have the most significant weight. Five representative coaches are evaluated and ranked by the GRA. The final ranking of the coaches is in well agreement with the fact and confirms the effectiveness of the proposed model.

***Index Terms*—analytic hierarchy process; fuzzy mathematic theory; grey relational analysis; sensitivity test.**

I. INTRODUCTION

There has been an increasing interest in sports coaches' ranking in recent years. To compare the performance of coaches, a convincing and fair evaluation method is demanded. In fact, it is very difficult to rank excellent coaches because of the non-uniqueness of the evaluation criteria about coaches. However, it is essential to choose several evaluation criteria. In some literatures, coaching expertise or effectiveness was defined by athletes' level of achievement (win-loss percentage), or athletes' personal attributes (satisfaction, enjoyment) [1]. If we identify and rank the performance of coaches as excellent solely based on athletes' performance, we may be misled based on the indirect behavioral measures. Côté *et al* proposed that an excellent coach should be knowledgeable and can assemble a mental model that enables him/her to effectively manage the central duties of coaching-organization, training, and competition [2]. MacLean and Chelladurai proposed a framework for performance evaluation of coaches. The performance of coaches should be evaluated from two respects, that is, the process and the results of work behavior [3]. Meanwhile, the coaching expertise was also defined by a coach's years of experiences (e.g, 5 years, 10 years) [1]. Coté *et al* also pointed out that the evaluation components should consist of competition, training, organization, coaches' personal characteristics, gymnasts' personal characteristics and level of development, and contextual factors [4]. Additionally, some researchers believed that an outstanding evaluation model for coaches' performance should include multiple factors, such as coaches' educational roles in training and competition, strategies used in coaching, coaching demands or gender differences in coaching [5]-[8].

Over the last 30 years, many methods have been published to evaluate coaches, and several conceptual models have been developed for different type coaches in different career stages [9]-[11]. Based on the balanced scorecard, Li designed 12 coaches' performance evaluation indicators, such as training results, training programs, *etc*. Li also calculated the indicators weights by the analytic hierarchy process (AHP) [12]. MacLean and Chelladurai proposed an evaluation theory in multidimensional performance [3]. Zhang studied a system that evaluates the comprehensive capacities of an excellent college track and field by doing a questionnaire survey and using fuzzy mathematics [13]. Till now, most of the existing methods evaluate sports coaches qualitatively from the professional perspectives and they lack of quantitative calculation [1]-[3], which are not convincing. Although there are some quantitative analysis methods available, they are not popular because their methods are simple and many factors have not been considered. The AHP and data envelopment analysis are usually employed to evaluate coaches. However, these methods have several shortcomings when they are applied separately [12]-[14]

Despite the evaluation methods of coaches have been studied to different extent with different approaches, the researchers' work usually focus on a special sport and their methods may not be applied to evaluate coaches in all the sport fields. In this paper, we will develop a comprehensive mathematical model to evaluate sport coaches in different fields. To systematically evaluate the performance of coaches, we choose eight evaluation criteria, which are coaching time, gender, organizational capability, management capability, race command capability, wins, win-loss percentage and performance in league matches. In order to evaluate different coaches' qualification and achievements effectively, the grey relational evaluation method based on the well known AHP will be used to evaluate the coaches' performance from three aspects (personal qualification, training qualification and team achievements). The AHP is used to determine the final evaluation criteria and weights, the fuzzy theory is used to quantify some qualitative criteria, and the grey relational analysis GRA is used to synthetically evaluate coaches. Finally, by taking basketball coaches as an example, we will verify the correctness of this algorithm and test its sensitivity.

The rest of this paper is organized as follows. In next section, we will introduce the AHP. In section III, we will

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present the details of our mathematical model. In section IV, we will report our case study results to demonstrate the application of the proposed mathematical model. In the last section, we will discuss some related issues and conclude the paper.

II. ANALYTIC HIERARCHY PROCESS

There are plenty of evaluation criteria about coaches' performance, and more than 54 evaluation criteria have been reported till now. Because the AHP is a useful tool to analyze the relationship among several factors and create a progressive hierarchical structure, we will use it to select the most influential factors. By comparing the importance of each pair of factors, the AHP can help us to determine the major factors and their weights, respectively. We evaluate coaches' performance from three aspects including personal qualification, training qualification and team achievements. The proposed hierarchy system of coach evaluation is shown in Fig.1. Basically, there are 4 levels. The top level is Goal Level, the second one is Criterion Level, the third one is Sub-criterion Level, and the bottom one is Coach Level.

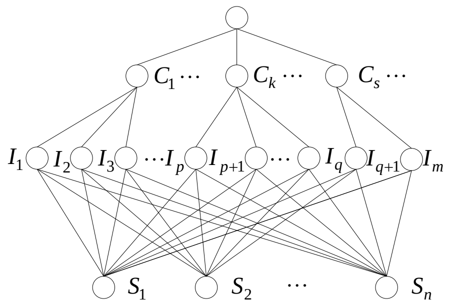

Fig. 1. Illustration of the hierarchy system for coach evaluation.

Each pair of factors should be evaluated in the process of determining levels. There is a dominant relationship between the upper and lower levels. Every node in the upper level is dominated by at least one node in the lower level. The correlation between upper and lower level nodes is greater than that in the same level. A significant rule is to avoid major correlation between nodes in the same level. In our analysis, there is only one node in the top level and every node is dominated by less than 9 nodes in its lower level. The major task is to compare the importance of each pair of factors in the same level using all the criteria in upper level and construct the corresponding comparative matrix. The AHP is used to perform qualitative analysis with quantitative calculation. To quantify the evaluation criteria, we construct a judgment matrix based on the hierarchy structure. We construct the comparison matrix by comparing u_i with u_j that dominated by the corresponding criterion level and assigned weights on their importance based on Table I [15].

For the criterion level C, the judgment matrix $A = (a_{ij})_{n\times n}$ of every coach of every criterion is determined by comparing the importance of each pair of factors in the same level, where a_{ij} represents quantitative value of importance degree of two coaches with respect to the evaluation criterion C and it satisfies $a_{ij} > 0, a_{ji} = 1/a_{ij}$ for $i, j = 1,2,\cdots,n$.

In the next step, we calculate the relative weights of comparative matrix with respect to the criterion level based on the judgment matrix and test its consistency.

(1). Calculating weights: For an n-rank matrix, the weighting vector is approximately calculated as the normalized arithmetic mean of the n column vector, that is

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}}, i = 1,2,\cdots,n, \quad (1)$$

where i represents the evaluation criterion. The weighting vector of the judgment matrix $w = (w_1, w_2, \cdots, w_n)^T$ is determined.

(2). Testing consistency: As we mentioned before, this method doesn't check the consistency of judgment matrix when it is constructed. Due to complexity of objects and diversity of human's acknowledge, it is difficult for a judgment matrix, calculated by the importance of evaluation criterion, to keep consistency. Therefore, some results may be contrary to common sense. For example, a_1 is more important than a_2, a_2 is more important than a_3, and a_3 is more important than a_1. Obviously, those results are contrary to common sense. Therefore, it's necessary to perform consistency test. The steps are as follows: First, a consistent index (CI) is calculated $C.I. = \frac{\lambda_{max}-n}{n-1}$, where λ_{max} represents the largest eigenvalue defined as

$$\lambda_{max} \approx \sum_{i=1}^{n}\frac{(Aw)_i}{nw_i} = \frac{1}{n}\sum_{j=1}^{n}\frac{\sum_{i=1}^{n}a_{ij}w_j}{w_i}. \quad (2)$$

In Eq.(2), $(Aw)_i$ represents the i^{th} component in the matrix Aw. For $n = 1,2,\cdots,9$, constructing positive reciprocal matrix by getting values from $1,\ldots,9$ and their reciprocal, we obtain the mean value of the largest eigenvalue λ'_{max} and define random index (RI) as $R.I. = \frac{\lambda'_{max}-n}{n-1}$[15]. After that, the consistency is calculated by looking up the corresponding average RI as shown in Table II and the final consistent ratio (CR) is defined as $CR = CI/RI$.

When CR<0.10, we accept the consistency of the judgment matrix. Otherwise, we need to modify it. Finally, we calculate the comprehensive weight of each node with respect to the systematic object and rank the coaches. The final rank weights can be calculated by synthesizing a single criterion weight from top to bottom.

Table I. The definitions of every comparative importance

Comparative importance	Definition	Note
1	Equally important	Two decision factors equally affect the parent decision factor.
3	Moderately important	One decision factor is moderately important than the other.
5	More important	One decision factor is more important than the other.
7	Significant important	One decision factor is significantly important than the other.

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9	Extremely important	One decision factor is extremely important than the other.
2,4,6,8	Intermediate judgment values	Judgment values between equally, moderately, more, significant, and extremely.

Table II. The average RI for various *n*

n	1	2	3	4	5	6
RI	0.00	0.00	0.52	0.89	1.12	1.26
n	7	8	9	10	11	12
RI	1.36	1.41	1.46	1.49	1.52	1.54

III. AHP-BASED GREY RELATIONAL ANALYSIS

A. AHP Data and Fuzzy Analysis

The GRA method is a branch of grey system theory, which is widely applied to solve problems of evaluating, modeling, system analysis, decision-making, *etc*. This method needs to first refer to uncertain relationships among various elements, and then calculate the correlation between the corresponding criteria of the object and reference data. This means the relational analysis is an alternative quantitative analysis method for the evaluation. Therefore, the concrete data is of great importance to perform GRA. Because the results from the AHP include both quantitative and qualitative (or uncertain) criteria for coach evaluation, it is necessary to qualify each criterion to produce the preliminary data required by the GRA method.

For the quantitative criterion, such as coaching time, the number of wins and win-loss percentage, we can obtain accurate and detail data from public resources, such as government authority reports. The National Collegiate Athletic Association and National Association of Intercollegiate Athletes have made statistics for all coaches in all kinds of sports and established public databases that can be directly accessed.

For the qualitative (or uncertain) criteria, there are no relevant databases to provide detail information. Therefore, the evaluation data should be established by analyzing the non-database information, such as student assessment, social reputation, *etc*. In order to improve the scientificalness and objectivity of the evaluation, here we adopt a questionnaire survey to determine coaches' capability of qualitative criteria. Based on the above analysis, the qualitative information can be modeled as a subjective function based the fuzzy theory. Among the 8 evaluation criteria provided by the AHP, 5 of them are qualitative criteria which are gender, organization capability, management capability, race command capability and performance in league matches. For these criteria except the gender, decision makers can classify them into five grades with descriptive language such as excellent, good, moderate, poor and very poor. Accordingly, the corresponding subjective grade can be set as 0.9, 0.7, 0.5, 0.3 and 0.1, respectively [16]. Take organization capability for example, "*excellent*" indicates that the coach could accurately judge the athletes' physique and sports characteristics, and adopt scientific methods to make reasonable perfect training plan. "*Very poor*" means the coach lacks of management skills for the whole training and the athletes' comprehensive quality potential could not be maximized. According to the middle degrees of this capability, there are good, moderate and poor grades. As for gender criterion, there are only two grades (male and female). The subjective grades are assigned as 0.3 and 1 considering the fact that male coaches have great advantages over females in the sport coaching field [10].

B. Normalization for the Original Data

The original data for each coach is collected from the current database and the subjective function of fuzzy theory. Data sequence of *n* coaches for *m* criteria can be written as a matrix,

$$(A_1', A_2', \cdots, A_n') = \begin{pmatrix} a_1'(1) & \cdots & a_n'(1) \\ \vdots & \ddots & \vdots \\ a_1'(m) & \cdots & a_n'(m) \end{pmatrix}, \qquad (3)$$

$$A_i' = \left(a_i'(1), a_i'(2), \dots, a_i'(m)\right)^T, i = 1,2,\cdots,n,$$

where *m* presents the number of metrics. The original data is noted as A_i', and the data after dimensionless process is noted as A_i.

Because the dimensions of criteria are different, the normalization process of every criterion is to convert an absolute value to a relative value. In fact, there are two types of criteria, positive and negative. For the positive criteria, the lager the value is, the better performance the coach does. However, for the negative criteria, the smaller the value is, the better performance the coach does. During the linear normalization process, the base points of the positive criteria are different from those of the negative criteria, which will lead to opposite results and failure for comparison. Therefore, two different linear normalization expressions are applied to the criteria data [17]. For a positive criterion,

$$A_i(j) = [(A_i'(j) - A_i'(j)_{\min}) / (A_i'(j)_{\max} - A_i'(j)_{\min})] \times 100\% \qquad (4)$$

and for a negative criterion,

$$A_i(j) = [(A'(j)_{\max} - A_i'(j)) / (A_i'(j)_{\max} - A_i'(j)_{\min})] \times 100\% \qquad (5)$$

where *i* represents the index of coaches, *j* represents the index of metrics, $A_i'(j)_{min}$ is the minimal value of the j^{th} metrics, $A_i'(j)_{max}$ is maximum value of the j^{th} metrics, and $A_i(j)$ is the normalized value of the j^{th} metrics of the i^{th} coach. Thus, the normalization matrix can be expressed as $(A_1, A_2, \cdots, A_n)$.

C. Grey Relational Evaluation

Because the relationship between every criterion and the final result is sophisticated and interacting, the GRA is adopted to analyze and evaluate general performance of coaches based on the normalization datasets. The detail steps are as follows [18].

Step 1: Choosing reference data series as ideal comparison criteria. Generally speaking, the reference data series consist of the optimal values of every metric, and we can choose reference data for different goals of evaluation. The relationship is shown as the following equation,

$$A_0 = (a_0(1), a_0(2), \cdots, a_0(m)),$$

where every optimal value is chosen as reference data series, that is $A_0 = (1, 1, \cdots, 1)$.

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***Step* 2:** Calculating the absolute difference between the comparison series and reference series for every coach to be evaluated. That is

$$\Delta_i(j) = |a_i(j) - a_0(j)|,$$

$a_0(j)$ represents the reference data of the j^{th} evaluation criterion

***Step* 3:** Determining the values of p and q.

$$p = \min_{1\le i\le 1} \min_{1\le j\le m}\{\Delta_i(j)\},$$
$$q = \max_{1\le i\le 1} \max_{1\le j\le m}\{\Delta_i(j)\}.$$

***Step* 4**: Calculating the relational coefficient with respect to every comparison series and reference data series. The procedure can be formulated as

$$y_i = \frac{p+q\rho}{\Delta_i(j)+q\rho}, j = 1,2\cdots,m, \qquad (6)$$

where the resolution ratio $\rho \in (0,1)$. The difference of relational coefficient increases when ρ decreases. Here, we set $\rho = 0.5$.

***Step* 5**: Calculating the mean value of relational coefficient of every evaluation criterion and reference data series to find the relationship between every coach data and reference data series. It is defined as correlation as follows,

$$r_j = \frac{1}{n}\sum_{i=1}^{n} y_i(j). \qquad (7)$$

***Step* 6**: Calculating the weight of every evaluation criterion. That is,

$$r_j' = \frac{r_j}{\sum_{k=1}^{m} r_k}, j = 1,2,\cdots,m. \qquad (8)$$

***Step* 7**: Constructing a final quantitative evaluation model

$$Z_i = r_1' a_i(1) + r_2' a_i(2) + \cdots + r_m' a_i(m) \quad i = 1,2,\cdots,n. \qquad (9)$$

where $i = 1,2,\cdots,n$ represents the index of coaches, $j = 1,2,\cdots,m$ represents the index of evaluation criteria, and

IV. CASE STUDY

A. Data Collection

MacLean and Chelladurai suggested that the evaluation criteria of coaches should include the process and the results of work behavior [12]. Zhang pointed out those different principles should be considered to establish a fair and convincing unified criteria to evaluate coaches [13]. In this paper, we develop the AHP by considering three main factors including coaches' personal qualification, training qualification and team achievements. **Personal Qualification:** Coaches' personal qualification consists of coaching time and gender [12]. Because gender of coaches can be divided into male and female, we should consider the difference of gender. Coaching time could reflect coaches' time consumption on their career developments. **Training Qualification:** From the previous study of evaluation coaches [3,12,13], we conclude that the training qualification should consist of organizational capability, management capability and race command capability. **Team Achievements:** Team achievements are the results of coaches' performance and they directly reflect coaches' capability. People usually pay more attention to the team achievements compared with other factors. Wins, win-loss percentage and performance in league matches can well reflect team achievements [6-8]. Through the above analysis of three major factors that significantly affect the evaluation results, a hierarchy structure for all the factors is shown in Fig.2.

Starting from the second level in the hierarchy structure, we determine the comparison matrix by the comparison methods of 1-9. The weights of personal qualification, training qualification and team achievements are obtained as listed in Table III. Eq.(2) is applied to find the largest eigenvalue λ_{max} that is used to calculate the weight for each criterion, leading to $\lambda_{max} = 3.0044$ and w_c=(0.1947,0.0881, 0.7172). Table III shows that the weight of team achievements criterion is 0.7172 as compared to 0.1947 for the personal qualification criterion, indicating that the importance of the team achievements criterion is twice more than that of the personal qualification criterion. It is obvious that the team achievements factor is often considered when the coaches are evaluated for ranking. To perform the consistency test, the value of CI is calculated as 0.0022 and the RI is 0.52 when the number of criteria is 3 as shown in Table II. Therefore, the CR is 0.0043 (less than 0.1) and the results pass the consistency test.

In the same way, the weights of sub-criteria to criteria can be obtained. The weights of sub-criteria are listed in Table IV. Through the calculation of comparison matrix, we know that all consistency tests are right. The combined weighting vector of criteria with respect to evaluation method of coaches is shown in Table IV. They can be used to evaluate and rank coaches.

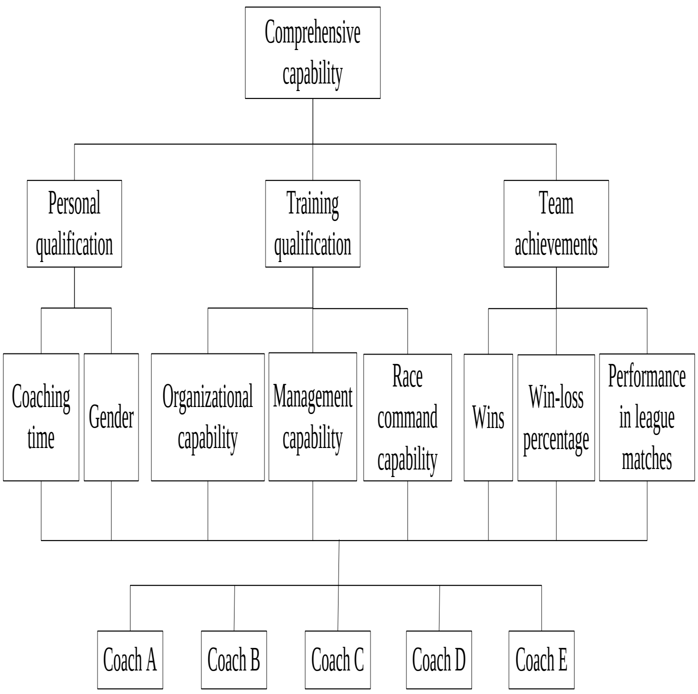

Fig. 2. Hierarchy structure for all the factors.

Table III. Pair wise comparison matrix of hierarchy I-II

Comprehensive Capability	Personal Qualification	Training Qualification	Team Achievements	Weight
Personal Qualification	1	3	0.2	0.1947
Training Qualification	0.3333	1	0.1667	0.0881
Team Achievements	5	6	1	0.7172

Table IV. Weights for the overall evaluation model

Criteria	Weight	Rank	Sub-criteria	Weight	Final Weight	Rank
Personal Qualification	0.1947	2	Coaching time	0.6667	0.1298	1
			Gender	0.3333	0.0649	2
Training Qualification	0.0881	3	Organizational capability	0.1998	0.0176	2
			Management capability	0.1168	0.0103	3
			Race command capability	0.6833	0.0602	1
Team Achievements	0.7172	1	Wins	0.3331	0.2389	2
			Win-lose percentage	0.5695	0.4084	1
			Performance in league matches	0.0974	0.0699	3

Table V. The original and qualitative data of 5 representative coaches

Criterion	Sub-Criterion	Coaches				
		A	B	C	D	E
C_1 Personal quality	S_1 Coaching time	45	47	41	37	48
	S_2 Gender	1	0.3	0.3	1	0.3
C_2 Training quality	S_3 Organizational capability	0.9	0.7	0.5	0.7	0.9
	S_4 Management capability	0.5	0.7	0.7	0.9	0.3
	S_5 Race command capability	0.7	0.9	0.5	0.7	0.7
C_3 Team achievements	S_6 Wins	976	1076	786	634	719
	S_7 Win-loss percentage	0.714	0.708	0.666	0.596	0.735
	S_8 Performance in league matches	0.7	0.7	0.9	0.3	0.5

Table VI. Normalized data and grey relational coefficients

Criteria	Sub-Criteria	Normalized data						Grey relational coefficients				
		REF	A	B	C	D	E	A	B	C	D	E
C_1	S_1	1	0.727	0.909	0.364	0.000	1.000	0.647	0.846	0.440	0.333	1.000
	S_2	1	1.000	0.000	0.000	1.000	0.000	1.000	0.333	0.333	1.000	0.333
C_2	S_3	1	1.000	0.500	0.000	0.500	1.000	1.000	0.500	0.333	0.500	1.000
	S_4	1	0.333	0.667	0.667	0.333	0.333	0.429	0.600	0.600	1.000	0.333
	S_5	1	0.500	1.000	0.000	0.500	0.500	0.500	1.000	0.333	0.500	0.500
C_3	S_6	1	0.774	1.000	0.344	0.000	0.192	0.688	1.000	0.432	0.333	0.382
	S_7	1	0.849	0.806	0.504	0.000	1.000	0.768	0.720	0.502	0.333	1.000
	S_8	1	0.667	0.667	1.000	0.000	0.333	0.600	0.600	1.000	0.333	0.429

For 5 representative coaches, we collected the original and qualitative data as listed in Table V. Because the team achievement is the most important criterion and its weight is up to 0.7172, a coach usually can have a better rank if his/her team has great achievements. In the coach evaluation criteria, coaching time, gender, wins, win-loss percentage are available in Table 5. However, the quantitative criteria of organizational capability, management capability, race command capability and performance in league matches are unavailable. Based on the fuzzy mathematics and questionnaire survey, the obtained data is also listed in Table V [19].

Considering that each criterion is associated with each other and it may have different effects on the final evaluation results, the aforementioned grey relational algorithm is adopted to calculate each criterion's relational coefficient with respect to the reference data for each coach. The calculated results are listed in Table VI. Following the steps in section 3, we obtain the comprehensive evaluation results and ranking as listed in Table VII. Through the analysis of original data, we find that the reason for top ranking of *A* is due to his/her excellent performance in matches, great team achievements, and good social reputation. This implies that the ranking is very reasonable and credible.

Table VII. Final ranking of the five representative coaches

Coach	Integrated grey relational grade	Rank
A	0.738414	1
B	0.690673	2
C	0.357852	5
D	0.368938	4
E	0.525051	3

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B. Sensitivity Analysis

According to Eq.(6), the resolution ratio ρ is a key parameter to correlate the coefficients, which is highly related to the correlation. If ρ is too small, the differences of correlation coefficients will be too large and fail to provide the correlation of every evaluation criterion and reference data series. On the other hand, if ρ is too large, the differences of correlation coefficients are too small and the absolute differences have little impact on the evaluation results. Therefore, the value of ρ is crucial to the final evaluation results. In the process of calculation, a constant value of ρ =0.5 is selected. In order to analyze its sensitivity, we take the aforementioned coaches as examples. For 10 representative resolution ratios, we evaluate the effect of resolution ratio value. The final scores for coaches with respect to different resolution ratios are shown in Fig.3, where the horizontal coordinate represents the resolution ratio and the vertical coordinate represents the final scores.

From the results in Fig.3, it can be observed that the evaluation results change with respect to the change of resolution ratio. When $\rho \leq 0.5$, scores of coaches change greatly indicating that the control capability of a small resolution is weak. When $\rho > 0.5$, scores of coaches are approximately unchanged. Meanwhile, all the ranks are consistent. Therefore, ρ=0.5 is well justified and the results are stable.

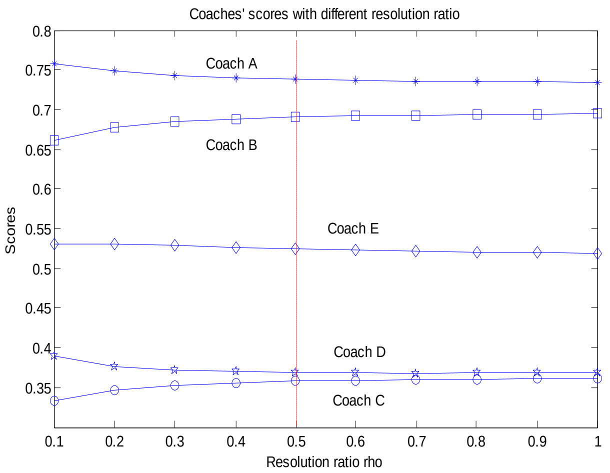

Fig. 3. Coaches' scores with respect to different ρ.

V.DISCUSSIONS AND CONCLUSIONS

Theoretically speaking, ranking coaches is a complicated multiple objective decision-making problem. Uncertainty, complexity and hierarchy are the most important characteristics. It is very important to select an optimal method and rank certain objects by considering multiple performance attributes in our daily life and work environments. In this paper, we adopt an innovative method to analyze and rank coaches' performance. As a novel solution, the AHP and GRA are combined to evaluate and rank coaches. First, the AHP is used to determine the final evaluation criteria and weights. Then, based on a questionnaire survey, the fuzzy mathematic theory is taken into account to quantify the qualitative criteria. Finally, the GRA is adopted to evaluate coaches and provide a unified quantitative criterion for ranking. By combining those methods, the progress of rank and evaluation is more hierarchically comprehensive and scientifically sound.

The effectiveness of the proposed method is demonstrated by a realistic case study. The study indicates that such an approach can provide a useful tool for complicated multiple objective decision-making to obtain scientific and reasonable results for decision makers. If the optimization approach is integrated into computing software and the information databases are available, the efficiency of the proposed method can be further improved and artificial error can be reduced during decision-making. Furthermore, the proposed approach can be applied to other fields where there is an optimization problem of multi-objective decision-making, such as university evaluation and ranking, etc.

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