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A Hybrid MCDM Approach to Sports Center Site Selection in a Sustainable Environment

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Abstract: In order to achieve the goal of good health and well-being in Sustainable Development Goals (SDGs), the government has actively promoted the concept of sports and fitness. People expect the government could effectively build leisure facilities and sports centers that can provide high-quality services and activities. The purpose of this research is to establish a systematic model to help the government improve the quality of decision making and integrate various methods to expand the evaluation of site selection more objectively. This paper develops a hybrid MCDM model based on AHP, entropy and gray relational analysis methods to realize the location-selection process of sports centers. In this paper, a hybrid MCDM model was developed to realize the location-selection process of a sports center. Three perspectives and six major factors (including the 16 criteria) for the sports center location selection are presented. Among them, geographical conditions are the most important perspective, surrounding environment is the most important factor and the second most important factor is future development. The results of this research will provide reference for relevant government departments.

Keywords: SDGs; sports center; hybrid MCDM; site selection

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1. Introduction

In order to solve issues such as climate change, economic growth and social equality, in 2015, the UN announced the "2030 Sustainable Development Goals" (SDGs), which include 17 SDG goals such as no poverty, gender equality, clean water, sanitation, etc. They provide a blueprint for peace and prosperity for people and the planet, now and into the future. They also guide the world to work together towards sustainability. At that time, 193 countries agreed to strive to achieve 17 SDG goals by 2030. Among the 17 SDGs, the third goal is "Good Health and Well-Being". Target 3.4 in the third goal further states the following: Noncommunicable diseases and mental health: By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being. To achieve this goal, counties and cities in Taiwan have actively promoted sports education and built public sports centers to provide people with sports and develop good habits of exercise and fitness.

The main purpose of building a sports center is to cultivate a national sports atmosphere and a regular sports population. Of late, there has been a rise in people's awareness of the importance of regular physical activity and its benefits on one's health. A lot of people are hoping that the government could build more high-quality sports centers and operate the leisure facilities effectively to provide high-quality sports-related services. In recent years, the government has worked hard to promote a multi-sports policy to encourage everyone to exercise more, and the construction of many national sports centers was included in this policy. The government is planning to construct diversified sports facilities in metropolitan areas as part of the implementation of the policy to provide citizens with high-quality leisure sports venues. However, because the urban area is wide and has several completed buildings and residential houses, it is becoming more and more difficult

to find a good location for a sports center. The county and city governments are currently facing a lot of challenges in making their decisions especially in selecting a site for sports centers. Therefore, providing a complete and objective decision-making model is one of the motivations of this research.

In order to address the preferences of the citizens, the sports centers that will be built shall have facilities that will cater to indoor sports. The government is also planning to use these facilities to develop distinct sports and to provide support for regional sports competitions. Generally speaking, indoor sports facilities include six core installations, namely (1) fitness activity center, (2) rhythm classroom, (3) swimming pool, (4) comprehensive court, (5) badminton court and (6) billiard court [1]. In addition to providing basic facilities, public leisure and activity venues should uphold different local sports characteristics. According to the characteristics and needs of each county and city, the local governments should plan and build spaces that can meet local customs and characteristics [1]. For example, Taipei City launched the first National Sports Center in 2002. At that time, the combination of low-price entrance fees, diversified services and related leisure activities encouraged many people to use it. The construction of indoor sports facilities in the sports center will help individuals enjoy exercising without being affected by weather conditions [2]. Some of the reasons why the National Sports Center enhances people's participation in sports are the integrity of its facilities and the low cost of use. As for constructing a sports field, the factors that must be considered are the location of the sports center and the activity space. Because of these, identifying the decision-making factors for determining the best location of a sports center is also another motivation of this research.

MCDM can be used to solve complex problems related to business management. Since there are many different criteria in business-management decisions that may affect the final decision, these criteria must be considered [3]. The MCDM method is used to solve or assist in solving various problems related to decision-making. MCDM methods have been widely used in past research, and scholars have proposed a variety of MCDM methods in location selection or related decision-making processes. Commonly used techniques include the following: (1) combining prospect theory, DEMATEL and QUALIFLEX (qualitative flexible) methods for multi-attribute group decision-making [4]; (2) combining trapezoidal cloud and MULTIMOORA theory for multi-attribute group decision-making [5]; (3) utilizing DEA, TSP and interval-valued hesitant fuzzy constraint cone (IVHFCC) method for rescue route planning [6]; (4) extension of classification or scoring methods [7]; (5) analytical hierarchy process (AHP) [8–10]; (6) linear programming or LP [11,12]; (7) simulation [13]; (8) AFS clustering method and TOPSIS method [14,15] (9) combination of DEMATEL and ANP [16,17]. Among them, the analytical hierarchy process (AHP) combined with fuzzy theory is widely used in research involving decision-making process evaluation and is easier to implement, so the research will be conducted based on FAHP.

This research involves a very broad and complex topic because the assessment of investors' decisions in building a sports center consist of many evaluation criteria and sub-criteria related to the sports center's infrastructure including the surrounding environment, the number of guests it can hold and future development plans. To effectively evaluate the weightings of each criterion, it is important to consider the appropriateness of the alternatives and the aggregation of the decision-makers' estimated ratings which are important issues in a multiple DM problem. The weights of the evaluation criteria are greatly influenced by the final selection of the MCDM problem. According to Saaty (1980) [18], the AHP can be utilized to deal with complicated problems involving multiple criteria and sub-criteria as well as uncertain situations. Thus, this study used the AHP method to assess the relative importance of various investor decision criteria/sub-criteria. Further, Zeleng (1982) [19] suggested that the entropy weighting method can be employed to effectively measure the average essence of information quantity. Based on this, the larger the entropy value, the lower the information express quantity. In this paper, the entropy weighting method was utilized to solve the weight of sub-criteria under objective evaluation criteria to represent actual conditions of decision-making and express the explanation ability and

reliability of the sub-criteria. The gray theory proposed by Deng (1982) [20] was based on the fact that information is sometimes incomplete. The gray correlation model is based on development trends and is suitable for use when the sample size is small; therefore, the gray relation analysis can be effective in tackling the decision-making problem that exists in a gray decision environment [20–22].

At present, various counties and cities have begun to set up sports centers and are continuing to expand to promote sports and increase the residents' willingness to exercise. Once a sports center is completed, its use period will last for at least 20 years; thus, it will have a profound impact on regional development. Therefore, deciding the location is of high importance. The research questions of this study are as follows:

(1) How can a systematic framework be established to help the government and investors to improve the quality of their decision-making?
(2) How can the AHP, entropy method and gray relational theory be integrated to extend the decision-making evaluation of location selection to make it more objective in the decision-making process?

The method proposed in this research is unique in the following ways: (1) in the calculation process, the opinions of many professional decision-makers were integrated to establish a subjective weight comparison matrix to reduce the effect of bias, making the proposed method more realistic in the decision-making process; (2) the AHP and entropy technology for weight evaluation were integrated to make the results more objective; and (3) the integration weight and gray relation grade were combined to make the selection results more objective.

The purposes of this research are to integrate the AHP, entropy and gray relational methods to provide a systematic method for decision-makers during location selection, to propose a sports center location evaluation criterion based on relevant literature, to develop a systematic approach from the perspective of location selection to improve decision-making quality and to use actual cases to verify the feasibility of the proposed method. This article is organized as follows: firstly, it introduces the current situation of promoting the construction of sports centers in Taiwan in response to the development of SDGs; then, it uses literature review to construct the criteria and evaluation model for the site selection of sports centers; next, the importance of the criterion to the site selection is identified with fuzzy AHP and the entropy method; thereafter, the gray relational analysis method is used to compare each alternative; finally, the conclusions and suggestions of the research are proposed.

2. Literature Review

In this section, the selection elements of the sports center location are discussed. The relevant literature on the topic was limited; thus, it was not easy to confirm the developed criteria for the selection of a sports center location. Therefore, this study collected the criteria used in the research of location selection and applied them to the selection of a sports center location.

In past literature, the criteria for location selection generally cover the following aspects: population structure and needs, such as population density and the economic conditions of local residents; transportation network and infrastructure, including transportation convenience and complete infrastructure; and market competition conditions, environmental and natural conditions, etc. For example, Zhang et al. (2022) [23] designed the SpoVis system to analyze the location of sports facilities, and proposed the following evaluation criteria: population distribution, construction cost, existing sports facilities, traffic situation, and development potential. Erturan-Ogut and Kula (2023) [24] used the analytical hierarchy process (AHP) to evaluate multiple factors for the location of sports facilities. The evaluation criteria they proposed include ease of access, facility features, financial issues, neighborhood and market. The Sports Facilities Planning Guide proposed by the Abu Dhabi Sports Council (2023) [25] provides location-selection criteria for sports facilities, covering items such as population density, transportation convenience and

environmental impact. Others include Cabello (2019) [26] who proposed bank location-selection criteria, including population density and size, economic environment, degree of competition and transportation convenience. Li et al. (2011) [14] proposed an integrated approach to selecting logistics center locations. Standards include landform condition, water supply, communication, candidate land value, power supply, solid castoff disposal, traffic, candidate land area, candidate land shape, candidate land circumjacent, etc. Garcia et al. (2014) [9] proposed a model for evaluating the optimal location of new agricultural product warehouses and analyzed six general criteria, including accessibility to the area, distance, cost, security of the region, local acceptance of the company and its needs. Chou et al. (2008) [8] proposed a fuzzy multi-criteria decision-making (FMCDM) model for international tourist hotel location selection, and obtained a total of 21 criteria through literature review and actual investigation.

The criteria developed in the present study for the selection of a sports center location were based on three perspectives obtained from past literature. These are the geographical conditions (P2), traffic condition materials (P3) and operation management (P3). (as shown in Table 1)

Table 1. The hierarchical structure of the location-selection model.

Perspective	Factors	Criteria
P1 Geographical conditions	F1 Surrounding environment	C11 Population of the service circle
		C12 Size of the site
		C13 Economic income of the location
		C14 Public security
	F2 Future development	C21 Convenience of obtaining nearby land
		C22 Complementarity of adjacent facilities
		C23 Socio-cultural characteristics of the neighborhood
P2 Traffic conditions	F3 Convenience	C31 Intensity of public transportation frequency
		C32 Parking convenience
		C33 Diversification of public transportation
	F4 Access	C41 Proximity to public transportation facilities
		C42 The distance to the downtown area
P3 Operation management	F5 Human resource	C51 Sufficient human resources
		C52 Quality of manpower
	F6 Operating Conditions	C61 Land cost
		C62 License acquisition cost

Geographical conditions (P1)

Previous studies have shown that geographic location is an important indicator for developing the criteria for location selection. In this study, the geographical condition (P1) involves the surrounding environment (F1) and future development (F2). The surrounding environmental conditions (F1) include the population of the service circle (C11), the size of the site (C12), the economic income of the location (C13) and public security (C14); while future development (F2) includes the convenience of obtaining nearby land (C21), the complementarity of adjacent facilities (C22) and socio-cultural characteristics of the neighborhood (C23).

Surrounding environment (F1)

For a sports center to operate well, it must be located in a densely populated area. Therefore, the area of the sports center and the population of its service area should be considered as preliminary evaluation indicators of whether the sports center will operate

well. In addition to calculating the range of the core service circle based on the 15 min walking distance and extending the service circle based on the acceptable driving distance of consumers, studies found that most people are willing to spend 16 to 30 min driving to a sports center to exercise. Calculated based on the average driving speed of 40 km/h and 15 min of driving time in domestic cities, consumers within 10 km are considered potential customers of the sports center. In addition, according to the center of gravity theory, the core service circle has a population of approximately 10,000 and the extension service circle has a population of 150,000 [1].

The size of the venue determines the richness of the internal functions of the sports center. If the sports center provides diversified sports facilities, such as swimming pools, saunas, badminton courts, basketball courts and gymnasiums, the area of sports field required is larger [27,28].

Generally speaking, the lifestyle and family income of the fitness center's club members have a positive impact on consumers' participation in leisure sports. Therefore, the economic income of consumers in the service circle should be considered as a factor for location selection. Security refers to the protection of people's lives or property. When people walk outdoors or perform sports activities, the most direct consideration is safety. In addition to sports facilities, sports centers often provide related entertainment or parent–child facilities. Therefore, in this study, security and walking safety around the sports center were included in the development of the criteria. Based on these, the following four factors in the surrounding environment were considered in the criteria development of this study:

C11 Population of the service circle;

C12 Size of the site;

C13 Economic income of the location;

C14 Public security.

Future development (F2)

The establishment of a sports center involves the development of regional natural resources, human resources, catering resources and leisure resources. The more abundant the surrounding environment of the sports center is, the more diverse services the sports center can provide and the more consumers can engage in leisure and sports. Related living functions, the complementarity of facilities and the convenience of future land acquisition are all important considerations when building a sports center.

The construction of the sports center is a phased plan. The facilities are usually not completed all at once but are planned year by year. Therefore, the opportunities for future expansion and the ease of obtaining adjacent land must be considered for the future development of the sports center.

The area where the sports center is set up, the population of its neighboring areas, sports-related industries surrounding the area and educational institutions that cultivate talents can bring more economic opportunities for the sports center and the whole region as well. Therefore, the location selection of the sports center should be based on the consumer's daily life service circle and the actual local market survey should clarify the service circle and its market supply and demand conditions. If the complementary functions of the national sports center and neighboring facilities are strengthened, the effectiveness of regional integration, the willingness of private individuals to participate and operational feasibility will be enhanced.

Public facilities are a kind of welfare facility that provide residents with their needs, support the lifestyle that they lead and ensure the quality of their residence and environment.

"Nearby avoidance" (Not-In-My-Back-Yard, NIMBY) is often regarded as the attitude of individuals or communities against certain facilities or land use. Therefore, residents' positive views and friendliness of the sports center will affect the communication cost of the facility. Based on these, the following three factors were considered in the present study for the development of the criteria for location selection of a sports center:

C21 Convenience of obtaining nearby land;

C22 Complementarity of adjacent facilities;

C23 Socio-cultural characteristics of the neighborhood.

Traffic conditions (P2)

In terms of traffic conditions (P2), this study considered convenience (F3) and accessibility (F4). Convenience includes the intensity of public transportation frequency (C31), the availability of parking space (C32) and the diversification of public transportation (C33), while accessibility includes proximity to public facilities (C41) and distance to the downtown area (C42).

Convenience (F3)

To achieve the sustainable operation of the sports center, it needs to provide various convenient facilities to attract consumers to use it. The service convenience model framework proposed by Berry et al. (2002) [29] is centered on service convenience, that is, when consumers use convenient services, they do not realize that they spend too much time and energy. Therefore, the present study considered customer convenience as an important factor for location selection.

The transportation cost should not be ignored to attract more consumers to use the sports center. It includes transportation time and transportation expenses. Low transportation costs will attract customers to spend more. In addition, under the social background where cars are the main means of transportation, large shopping facilities must be able to provide sufficient parking space to attract car users. Therefore, proper parking planning and renovation will help strengthen the competitiveness of the downtown business district. When discussing consumers' shopping street choice behavior, the variables related to the parking lot (e.g., area, distance from destination) are usually regarded as the model variable [30]. Therefore, this study considered the following three factors for the development of the criteria for location selection:

C31 Intensity of public transportation frequency;

C32 Parking convenience;

C33 Diversification of public transportation.

Accessibility (F4)

Accessibility represents how easy it is for the individual to reach the location where the activity will be held [31]. The ease of reaching the area through walking, by car or by public transportation is called accessibility. It is considered an important factor in determining the urban and regional spatial structure and the location of economic and residential activities. For sports consumers, if public transportation facilities are accessible and close to the sports center, it will save them time allotted for driving and is regarded as energy-saving and carbon-reducing. Therefore, the proximity to the city center or the central business district (CBD) and the distance from the public transport station will affect consumers' willingness to go to the sports center. Accordingly, the following are regarded in the present study's criteria development:

C41 Proximity to public transportation facilities

C42 The distance to the downtown area

Operation Management (P3)

In terms of operation management, if it is a public sector operation, it must consider the self-sufficiency of the operation center as the goal. However, if it is an outsourcing operation, it needs to consider whether the bidding company has a profit. Operational management mainly includes human resources (F5) and related operating costs (F6). Human resources include sufficient human resources and human quality, while operating conditions include land costs and license-acquisition costs.

Human Resources (F5)

Labor supply refers to the labor time that a family or individual is willing and able to provide under a certain market wage rate. The labor supply mainly includes fresh graduates, transferred or unemployed workers and on-the-job colleagues. If the nearby area has abundant human resources and better quality of human resources, it will reduce the pressure on the operators. Therefore, the following were included in the decision-making criteria:

C51 Sufficient human resources;
C52 Quality of manpower.
Operation status (F6)

Since sports centers demand a large area, the land size, as well as the acquisition cost of land use, are important considerations for location selection. For the sports center to be highly convenient and reduce restrictions in its accessibility, the cost of land acquisition must be high, which will affect the operation cost. Cost recovery refers to the social acceptance that the sports center is in the environment where it is supposed to be built. Therefore, the ease of access to building permits will help reduce operating costs.

C61 Land cost;
C62 License-acquisition cost.

3. Research Methodology

Some concepts and the construction of a hybrid MCDM model incorporating the AHP, entropy and gray relational analysis in this article are briefly introduced in this section. The proposed hybrid MCDM method of framework is shown in Figure 1.

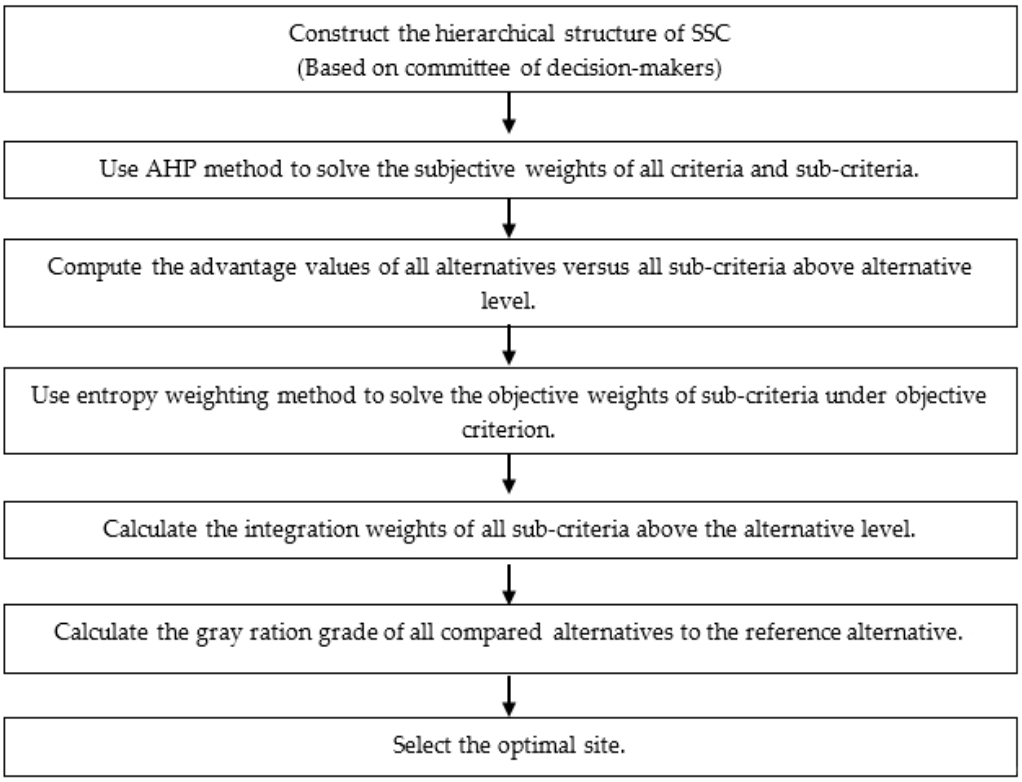


Figure 1. The framework of the proposed methodology.

3.1. Building a Hierarchical Structure

A hierarchical structure is the framework of a system structure. The complete hierarchical structure for the site selection of the sports center contained the k criteria, $n_1 + \cdots + n_t + \cdots + n_k$ sub-criteria and m alternatives.

The evaluation value of every available alternative should be obtained to represent the attractiveness of alternatives in terms of criteria values. In this paper, the criteria were classified into two sorts: (1) subjective criteria, which is qualitative (e.g., surrounding environment, convenience); and (2) objective criteria, which is quantitative (e.g., population, travel time).

3.2. Use the AHP Method to Solve the Weights of the Evaluation Criteria and Sub-Criteria

In this paper, the analytic hierarchy process (AHP) was utilized to assess the weights of the criteria and sub-criteria that affect investors' decisions in the construction of a sports center. The steps involved in this method based on Liao et al. (2016) [32] are summarized below.

3.2.1. Establish the Pair-Wise Comparison Matrices for All Criteria and Sub-Criteria

The fundamental scales shown in Table 2 were used to assess the relative importance of the criteria and sub-criteria; then, the pair-wise comparison matrices containing all criteria and sub-criteria were established.

Table 2. The fundamental scale of AHP.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities equal to the objective
3	One has weak importance over the other	Judgment slightly favor one activity over another
5	Essential or strong importance	Judgment strongly favor one activity over another
7	Very strong or demonstrated very strong importance	An activity is favored very strongly over another
9	Absolute importance	The evidence favoring one activity over another
2, 4, 6, 8	Intermediate values between adjacent scale values	When compromise is needed

Source: [18].

Assume that there are f experts in a committee. These experts are responsible for assessing the relative importance of k criteria and the relative importance of sub-criteria under each criterion.

Let $b_{pqr}, \forall p < q,\ r = 1, 2, \cdots, f$ and $p,\ q = 1, 2, \cdots, k$ be the relative importance of criteria C_p to C_q given by expert E_r. The pair-wise comparison matrix B_r of the relative importance of criteria C_p to C_q given by expert E_r can be obtained.

$B_r = \left[b_{pqr}\right]$,

where

$$b_{pqr} = 1, \forall p = q, b_{pqr} = \frac{1}{b_{qpr}}, if\ p\ >\ q.$$

By using similar steps, pair-wise comparison matrices of the relative importance of sub-criteria under each criterion given by expert E_r can be obtained.

3.2.2. Conduct Consistency Testing

The consistency test is an important issue and can be carried out using the consistency ratio (C.R.), which is defined by Saaty (1980) [18] as:

$$C.R. = {C.I.}\Big/{R.I.} \quad (1)$$

where

C.I. is the consistency index;

R.I. is the random index.

$$C.I. = {(\lambda_{max}^{r} - k)}\Big/{k} \quad (2)$$

where

k is the number of criteria compared;

λ_{max}^{r} is the maximum eigenvalue of the pair-wise comparison matrix $B_r = [b_{pqr}]$.

The *R.I.* value is shown in Table 3. When the *C.R.* is less than or equal to 0.1, the consistency test is regarded as successful [18].

Table 3. Random index.

k	**1**	**2**	**3**	**4**	**5**	**6**	**7**
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32

Source: [18].

3.2.3. Calculate the Weights of All Criteria and Sub-Criteria

Let there be s $\leq$ f experts whose evaluation results pass the consistency test. Let a_{ijt}, $t = 1, 2, \cdots, s$; $\forall\, i, j = 1, 2, \cdots k$ be the relative importance of criteria C_i to C_j given by expert E_r. The pair-wise comparison matrix A can now be obtained by all s experts.

$$\mathrm{A} = [a_{ij}],$$

where:

$$a_{ij} = \left[\prod_{t=1}^{s} a_{ijt}\right]^{1/s},\ if\ i < j, \tag{3}$$

$$a_{ij} = 1, \forall i = j,\ a_{ij} = {}^{1}/_{a_{ij}},\ if\ i > j.$$

Using the same method, the pair-wise comparison matrix of the relative importance between sub-criteria under each criterion given by all s experts can also be obtained.

Allowing $\mathrm{w} = (w_1, w_2, \cdots, w_g, \cdots, w_k)$ as the eigenvector of the pair-wise comparison matrix $A = [a_{ij}]$, the weight w_g of criterion C_g can then obtain by using the average of the normalized columns method [18].

$$w_g = \left(\sum_{j=1}^{k} \left(a_g / \sum_{g=1}^{k} a_{gj}\right)\right)/_{k}, \mathrm{g} = 1, 2, \cdots, \mathrm{k}. \tag{4}$$

The weights of all sub-criteria can be obtained using similar steps.

3.2.4. Calculate the Final Aggregation Ratings and Determine the Priorities of All Sub-Criteria

Let $w_g, \mathrm{g} = 1, 2, \cdots, \mathrm{k}$ be the weight of criterion C_g. Let v_{gh}, $g = 1, 2, \cdots, k$; $h = 1, 2, \cdots, n_g$ be the weight of sub-criterion C_{gh}. The aggregate ratings u_{gh} of sub-criterion C_{gh} can be calculated as:

$$u_{gh} = w_g \times v_g, \mathrm{g} = 1, 2, \cdots, \mathrm{k}; \mathrm{h} = 1, 2, \cdots, n_g \tag{5}$$

3.3. Compute the Advantage Values of All Alternatives Versus All Sub-Criteria Above the Alternative Level

In this paper, the seven-point Likert-type scale based on the level of appropriateness was used to evaluate the superiority of alternatives versus various subjective criteria.

Allow x_{iuhr}, $i = 1, 2, \cdots, m$; $u = 1, 2, \cdots, k$; $h = 1, 2, \cdots, n_u$; $r = 1, 2, \cdots, f$ to be the evaluation value of alternative A_i versus sub-criterion C_{uh} under objective criterion C_u given by expert E_r. The geometric mean was used to integrate experts' evaluations; thus, the appropriateness rating x_{iuh}, $i = 1, 2, \cdots, m$; $u = 1, 2, \cdots, k$; $h = 1, 2, \cdots, n_u$ of alternative A_i versus sub-criterion C_{uh} under criterion C_u can be calculated by:

$$x_{iuh} = \left(x_{iuh1} \times x_{iuh2} \times \cdots \times x_{iuhr} \times \cdots \times x_{iuhf}\right)^{\frac{1}{f}}. \tag{6}$$

3.4. Use Entropy Weighting Method to Solve the Weights of Sub-Criteria Under Objective Criterion

In this paper, the entropy weighting method was used to solve the weights of the sub-criteria under the objective criterion. The steps involved in this method are summarized below:

3.4.1. Build the Close Strength Matrix D

Let C_k (the last criterion) be the objective criterion. Allow x_{ikh}, $i = 1, 2, \cdots, m$; $h = 1, 2, \cdots, n_k$ to be the evaluation value of alternative A_i versus sub-criterion C_{kh} under objective criterion C_k. Define $x^*_{kh} = \max\limits_i\{x_{ikh}\}$ and $x^{\sim}_{kh} = \min\limits_i\{x_{ikh}\}$. Then the degree of closeness, denoted by d_{ikh}, of x_{ikh} to an ideal value can be defined using the following:

(1) For positive sub-criterion C_{th}

$$d_{ikh} = {x_{ikh}}/{x^*_{kh}} \tag{7}$$

(2) For negative sub-criterion C_{th}

$$d_{ikh} = {x^{\sim}_{kh}}/{x_{ikh}} \tag{8}$$

(3) For goal sub-criterion C_{th}

$$d_{ikh} = {\min\{x_{ikh}, g_{th}\}}\Big/{\max\{x_{ikh}, g_{th}\}} \tag{9}$$

where g_{th} is the goal value of sub-criterion C_{th}.
Define $\mathrm{D} = [d_{ikh}]$, $i = 1, 2, \cdots, m$; $h = 1, 2, \cdots, n_k$,
$D_{kh} = \sum_{i=1}^{m} d_{ikh}, \mathrm{h} = 1, 2, \cdots, n_k$.

3.4.2. Calculate the Contrast Intensity Entropy Measure of the Sub-Criterion C_{kq}

$$e_{kh} = -t\sum_{i=1}^{m} \frac{d_{ikh}}{D_{kh}} ln \frac{d_{ikh}}{D_{kh}}, where\ t = {1}/{\ln m}, 0 \le e_{kh} \le 1. \tag{10}$$

3.4.3. Calculate the Objective Weight λ_{kh} of Sub-Criterion C_{kh}

$$\lambda_{kh} = {1 - e_{kh}}\Big/{\sum_{h=1}^{n_k}(1 - e_{kh})} \tag{11}$$
$$0 \le \lambda_{kh} \le 1, \sum_{h=1}^{n_k} \lambda_{kh} = 1.$$

By combining the objective weight λ_{kh} and the subjective weight u_{kh} of sub-criterion C_{kh}, the integrated weight λ^*_{kh} of sub-criterion C_{kh} can be obtained.

$$\lambda^*_{kh} = {\lambda_{kh} u_{kh}}\Big/{\sum_{h=1}^{n_k} \lambda_{kh} u_{kh}},\ h = 1, 2, \cdots, n_k. \tag{12}$$

The integration weights β_{gh} of all sub-criteria C_{gh} above an alternative level can be calculated by:

$$\beta_{gh} = \begin{cases} u_{gh},\ g = 1, 2, \cdots, k-1;\ h = 1, 2, \cdots, n_g \\ \lambda^*_{kh},\ g = k;\ h = 1, 2, \cdots, n_k \end{cases} \tag{13}$$

3.5. Calculate the Gray Ration Grade of All Compared Alternatives to Reference Alternative

Herein, the gray relational analysis was used to calculate the gray ration grade of all compared alternatives to the reference alternative. Let

$$x_i = \left(x_{i11,}, \cdots, x_{i1n_1}, x_{i21}, \cdots, x_{i2n_2}, \cdots, x_{ig1}, \cdots, x_{igh}, \cdots, x_{ign_g}, \cdots, x_{ik1}, \cdots, x_{ikn_k}\right),\ \mathrm{i} = 1, 2, \cdots, \mathrm{m},$$

denote the original message sequences based on k criteria, $n_1 + \cdots + n_g + \cdots n_k$ sub-criteria and m alternatives. Next, assume that

$y_i = \left(y_{i11,}\cdots, y_{i1n_1}, y_{i21}, \cdots, y_{i2n_2}, \cdots, y_{ig1}, \cdots, y_{ighh}, \cdots, y_{ign_g}, \cdots, y_{ik1}, \cdots, y_{ikn_k}\right)$, i $= 1, 2, \cdots,$ m are the normalized message sequences transferred from x_i by using the effectiveness measure method. That is,

(1) For positive (benefit) sub-criterion C_{th}

$$y_{igh} = {}^{x_{igh}}\Big/ \max_i\left\{x_{igh}\right\} \tag{14}$$

(2) For negative (cost) sub-criterion C_{th}

$$y_{igh} = \min_i\left\{x_{igh}\right\}\Big/ {}_{x_{igh}} \tag{15}$$

(3) For goal sub-criterion C_{th}

$$y_{igh} = min\left\{x_{igh}, z_{gh}\right\}\Big/ max\left\{x_{igh}, z_{gh}\right\} \tag{16}$$

where z_{gh} is the goal value of sub-criterion C_{gh}.

Define $y_{0gh} = \max_i\left\{y_{igh}\right\}$. Let

$y_0 = \left(y_{011}, \cdots, y_{01n_1}, y_{021}, \cdots, y_{02n_2}, \cdots, y_{0g1}, \cdots, y_{0ghh}, \cdots, y_{0gn_g}, y_{0k1}, \cdots, y_{0kn_k}\right)$ and $y_i = \left(y_{i11}, \cdots, y_{i1n_1}, y_{i21}, \cdots, y_{i2n_2}, \cdots, y_{ig1}, \cdots, y_{ighh}, \cdots, y_{ign_g}, y_{ik1}, \cdots, y_{ikn_k}\right)$ represent the referential sequence and the comparative sequence, respectively. Then the gray relation coefficient $\gamma\left(y_{0gh}, y_{igh}\right)$ of these elements at sub-criterion C_{gh} under criterion C_g can be calculated by:

$$\gamma\left(y_{0gh}, y_{igh}\right) = \left(\min_i\min_h\Delta_{0igh} + \xi\max_i\max_h\Delta_{0igh}\right)\Big/\left(\Delta_{0igh} + \xi\max_i\max_h\Delta_{0igh}\right) \tag{17}$$

where $\Delta_{0igh} = \left|y_{0gh} - x_{igh}\right|$ and ξ ($\xi \in [0, 1]$) is the distinguished coefficient).

The coefficient ξ can be used to change the dimension of the relative value of $\gamma\left(y_{0gh}, y_{igh}\right)$. It can be varied depending on the uncertainty in the data [33]. If the value of ξ is smaller, the distinguishability between the data sequences is larger and if the value of ξ is larger, the distinguishability is smaller [34]. After obtaining all gray relation coefficients, the gray relation grade $\gamma(y_0, y_i)$ between y_0 and y_i can be calculated using:

$$\gamma(y_0, y_i) = \sum_{g=1}^{k}\left(\sum_{h=1}^{n_g}\beta_{gh}\gamma\left(y_{0gh}, y_{igh}\right)\right), \tag{18}$$

where β_{gh} is the integration weight of sub-criterion C_{gh}.

Through Equation (18), the gray relation grades of the m candidates y_i $(i = 1, 2, \cdots, m)$ with the referential sequence y_0 can be obtained. Based on these gray relation grades, the investor can easily make the best site selection.

3.6. Contributions of This Paper

The method proposed in this research provides the following theoretical and practical contributions for decision-makers when choosing a sports center location:

(1) The application of the proposed integrated evaluation model in the selection of sports center location was a novel one.
(2) When the decision-maker or management team wants to make an objective location selection, the proposed model could be utilized as an objective reference basis.

(3) The evaluation criteria adopted in this research were developed based on relevant important documents and experts' suggestions.
(4) This study used actual cases to verify the proposed method, which could enable decision-makers to plan operational strategies based on the location advantages of the results obtained.
(5) The objective weights obtained in this research were adjusted flexibly in response to the external environment to accurately grasp environmental changes.

When establishing the evaluation criteria, this study not only referred to sports-related location-selection criteria, but also referred to relevant literature on location selection. These research documents can make the establishment of the criteria more complete. Furthermore, the results of this study cannot only be applied to the selection of sports center locations. It can also be used for practical applications in a variety of situations across many industries. In addition to the completeness of the criteria, this research method can not only help decision-makers objectively decide on their options, but also help understand the performance of alternatives when formulating future operating strategies. At the same time, it is also verified that the comprehensive application of the MCDM method, entropy and gray relational theory will be an effective method to evaluate alternatives in the site-selection process.

4. Empirical Study

In this section, the developed criteria were used in selecting the most appropriate sites for the construction of a sports center to demonstrate the computational process of the proposed hybrid MCDM algorithm. The steps are as follows.

Step 1: Form a committee of decision-makers, then select the evaluation criteria and identify the prospective alternatives.

Five experts (two gym operators and three government officials; the operators have more than 5 years of experience and the officials also have many years of experience in planning work in the sports department) and five scholars familiar with the industry were invited to establish the committee. This committee confirmed three perspectives and six major factors (surrounding environment, future development, convenience, access, human resource and operating conditions), including the 16 criteria for the sports center location selection summarized and explained in Table 4.

Table 4. The evaluation criteria for sports center location selection.

Perspective	Factors	Criteria
P1 Geographical conditions	F1 Surrounding environment	C11 Population of the service circle
		C12 Size of the site
		C13 Economic income of the location
		C14 Public security
	F2 Future development	C21 Convenience of obtaining nearby land
		C22 Complementarity of adjacent facilities
		C23 Socio-cultural characteristics of the neighborhood
P2 Traffic conditions	F3 Convenience	C31 Intensity of public transportation frequency
		C32 Parking convenience
		C33 Diversification of public transportation
	F4 Access	C41 Proximity to public transportation facilities
		C42 The distance to the downtown area
P3 Operation management	F5 Human resource	C51 Sufficient human resources
		C52 Quality of manpower
	F6 Operating conditions	C61 Land cost
		C62 License-acquisition cost

There were three alternatives available for this empirical study, which are described below.

Alternative 1: This site is located in the green area of Pinglin Forest Park, Taiping District, Taichung City. The area is adjacent to a university, a military hospital and dense residential areas. The transportation is convenient, with multiple bus routes and frequent trips. A paid parking lot is attached to the nearby park, which is convenient for parking. Because there is a university, there are sufficient human resources. The surrounding land has almost been fully developed. People living in this area are older.

Alternative 2: The site is located in the newly developed area of Taichung, Beitun District, Taichung City. Due to the newly rezoned area, the site is surrounded by new buildings and the population is mostly young and middle-aged. It is close to the MRT station, but there is no bus to reach it. Because it is a new community, life functions are not convenient. The surrounding land will be well developed in the future.

Alternative 3: This location is in the Wuri High-speed Railway Special Zone, which is considered to be a more remote area, but it has frequent bus trips. Although the quality of public safety is moderate, the relative land price is low. The surrounding land has not been fully developed and it will be easier to obtain land for future development. There are no competitors near this location.

Step 2: Establish a hierarchical structure (as shown in Figure 2).

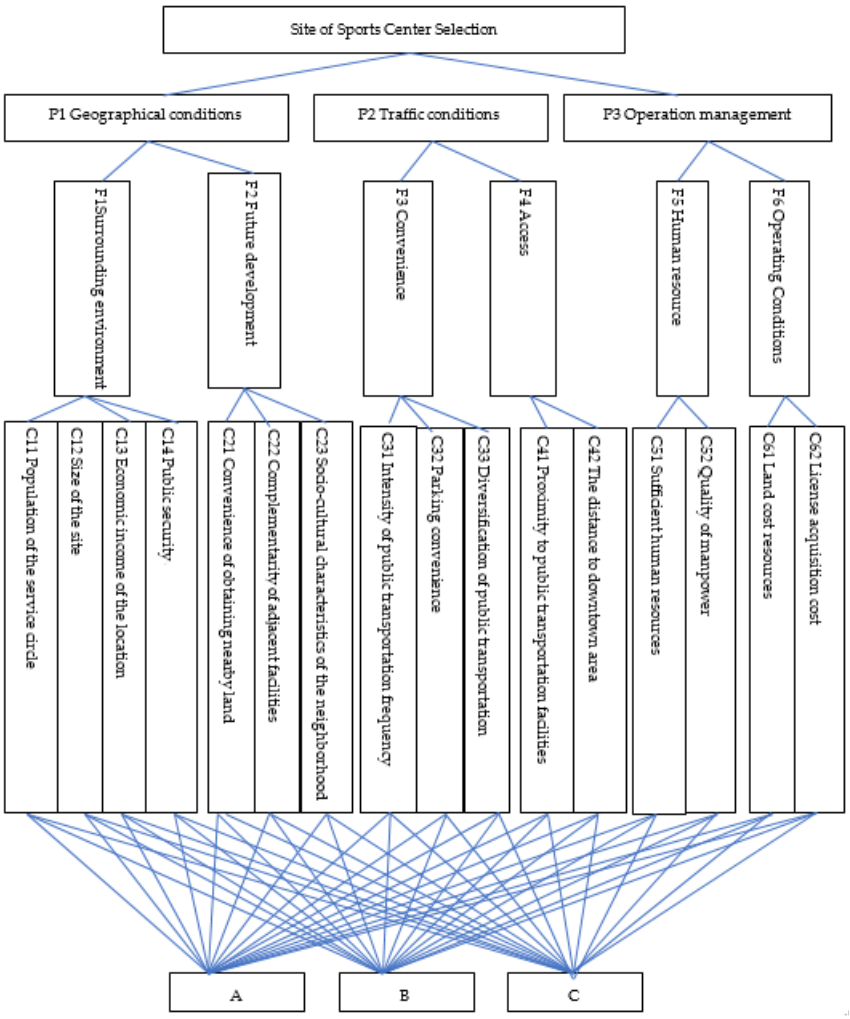


Figure 2. Sports center location-selection-evaluation model.

Based on the factors and criteria obtained by the above committee, this study established a sports center location-selection evaluation model which is shown in Figure 2.

Step 3: Use the AHP method to solve the subjective weights of all criteria and sub-criteria.

In this section, the second phase of AHP data collection and analysis was implemented. Data were collected through a survey administered to the committee members, government officials, academics and consumers. A total of 50 questionnaires were distributed, and 35 of them were collected and considered valid, with a recovery rate of 70%.

This study evaluated the consistency of paired matrices, including 3 constructs, 6 dimensions, 16 criteria and the CI value. According to Saaty (1980) [18], if C.R. $\leq$ 0.1, it indicates that the consistency of paired matrices is satisfactory, so the decision-making behavior can continue. From the consistency results, the C.I. and C.R. values of each dimension and each item were less than 0.1, indicating that the hierarchical framework of the study and the paired matrix constructed have good consistencies.

In this paper, the pair-wise comparison matrix of the relative importance of all criteria and sub-criteria under each criterion given by all experts was obtained using Equations (4) and (5). The top five standardized weight item were as follows: C22. Complementarity of adjacent facilities; C12. Size of the site; C11. Population of the service circle; C13. Economic income of the location; and C23. Socio-cultural characteristics of the neighborhood (as shown in Table 5).

Table 5. The weight and integrated weight of the criteria and sub-criteria.

Perspective	Wt(1)	Criteria	Cr-wt(2)	Int. cr-wt (3) = (1) × (2)	Sub-Criteria	Sub-wt(4)	Int. Sub-wt (3) × (4)	Rank
P1 Geographical conditions	0.62590	F1 Surrounding environment	0.60823	0.38069	C11 Population of the service circle	0.25580	0.09738	3
					C12 Size of the site	0.27598	0.10506	2
					C13 Economic income of the location	0.24845	0.09458	4
					C14 Public security	0.21977	0.08366	6
		F2 Future development	0.39177	0.24521	C21 Convenience of obtaining nearby land	0.45517	0.04414	11
					C22 Complementarity of adjacent facilities	0.36484	0.11161	1
					C23 Socio-cultural characteristics of the neighborhood	0.46429	0.08946	5
P2 Traffic conditions	0.24679	F3 Convenience	0.64504	0.15919	C31 Intensity of public transportation frequency	0.24418	0.07391	7
					C32 Parking convenience	0.29155	0.03887	13
					C33 Diversification of public transportation	0.34407	0.04641	10
		F4 Access	0.35496	0.08760	C41 Proximity to public transportation facilities	0.65594	0.03014	14
					C42 The distance to the downtown area	0.48316	0.05746	8
P3 Operation management	0.12731	F5 Human resource	0.70914	0.09028	C51 Sufficient human resources	0.51696	0.04362	12
					C52 Quality of manpower	0.65084	0.04667	9
		F6 Operating Conditions	0.29086	0.03703	C61 Land cost	0.34919	0.02410	15
					C62 License acquisition cost	0.25581	0.01293	16

Step 4: Compute the values of all alternatives versus all sub-criteria above the alternative level.

In this study, the method used to measure the strengths of each criterion included objective data calculations and grade conversions. The results were used for the next calculation. Lines 2 to 4 in Table 6 show the scores of each sub-criterion for each alternative.

Through this, the maximum value of positive sub-criterion x_{kh}^{*} and the minimum value of negative sub-criterion $x_{kh}^{\sim}$ were found (as shown in Table 6).

Table 6. The values of all alternatives versus all sub-criteria.

Criteria	C11	C12	C13	C14	C21	C22	C23	C31	C32	C33	C41	C42	C51	C52	C61	C62
A	12,764.0	40,000.0	727.0	6.0	8.0	6.0	7.0	6.0	4.0	1.0	6.0	5.9	9.0	8.0	5.0	6.0
B	54,781.0	30,000.0	925.0	7.0	4.0	4.0	7.0	3.0	8.0	3.0	3.0	8.9	6.0	8.0	5.0	5.0
C	16,606.0	25,000.0	807.0	5.0	5.0	3.0	8.0	9.0	6.0	2.0	2.0	8.8	5.0	6.0	2.0	4.0
x_{kh}^{*}	54,781.0	30,000.0	925.0	7.0	8.0	6.0	8.0	9.0	8.0	3.0	3.0		9.0	8.0		
$x_{kh}^{\sim}$												5.9			2.0	4.0

Step 5: Use the entropy weighting method to solve the objective weights of sub-criteria under objective criteria.

This step consisted of two stages. In the first stage, according to the calculation method proposed in Section 3.4.1, Equations (7)–(9) were employed to obtain the degree of closeness. After, the close strength matrix D was built (as shown in Table 7).

Table 7. The close strength matrix D.

Criteria	C11	C12	C13	C14	C21	C22	C23	C31	C32	C33	C41	C42	C51	C52	C61	C62
A	0.233	1.00	0.78595	0.85714	1.0	1.00000	0.875	0.66667	0.50	0.33333	1.00000	1.00000	1.00000	1.00	0.4	0.66667
B	1.000	0.75	1.00000	1.00000	0.5	0.66667	0.875	0.33333	1.00	1.00000	0.50000	0.66292	0.66667	1.00	0.4	0.80000
C	0.30313	0.625	0.87243	0.71429	0.625	0.50000	1.000	1.00000	0.75	0.66667	0.33333	0.67046	0.55556	0.75	1.0	1.00000

In the second stage, this study calculated the contrast intensity entropy measure (e_{kh}) of the sub-criterion using Equation (10) and then the objective weight (λ_{kh}) of the sub-criterion was obtained through Equation (11) (as shown in Table 8).

Table 8. Contrast intensity entropy measure and objective weight of the sub-criterion.

Criteria	e_{kh}	λ_{kh}	Criteria	e_{kh}	λ_{kh}
C11	0.806253	0.257903	C32	0.965634	0.045746
C12	0.982630	0.023122	C33	0.920620	0.105666
C13	0.995543	0.005933	C41	0.905619	0.125634
C14	0.991532	0.011272	C42	0.982136	0.023780
C21	0.960395	0.052720	C51	0.971311	0.038189
C22	0.962947	0.049322	C52	0.992215	0.010363
C23	0.998146	0.002468	C61	0.905713	0.125509
C31	0.920620	0.105666	C62	0.987449	0.016707

Step 6: Calculate the gray ration grade of all compared alternatives to the reference alternative and select the optimal site.

In this step, the gray relational analysis was used to calculate the gray ration grade of all compared alternatives to the reference alternative. The effectiveness-measure method calculated through Equations (14)–(16) was employed to normalize the message sequences. Then, the gray relation coefficients $\gamma\left(y_{0gh}, y_{igh}\right)$ of these elements at sub-criterion C_{gh} under criterion C_g were calculated using Equation (17). The distinguished coefficient ξ in this research was 0.5.

After obtaining all gray relation coefficients, the gray relation grade $\gamma(y_0, y_i)$ can be calculated by Equation (18). Ranking the gray relation grades of the candidates, the referential sequence can be obtained (as shown in Table 9).

Table 9. Gray relation coefficient $\gamma\left(y_{0gh}, y_{igh}\right)$.

Criteria	C11	C12	C13	C14	C21	C22	C23	C31	C32	C33	C41	C42	C51	C52	C61	C62
A	0.33333	1	0.64178	0.72859	1	1	0.75418	0.53499	0.4347	0.36518	1	1	1	1	0.38993	0.53499
B	1	0.60537	1	1	0.43407	0.53499	0.75418	0.36518	1	1	0.43407	0.53221	0.53499	1	0.38993	0.65724
C	0.35497	0.5056	0.75039	0.57306	0.5056	0.43407	1	1	0.60537	0.53499	0.36518	0.53783	0.46320	0.60537	1	1

Finally, the gray relation grade $\gamma(y_0, y_i)$ was calculated using Equation (18). To rank the gray relation grades of the candidates, the referential sequence was obtained. The order of alternative selection was B, A and C. (as shown in Table 10).

Table 10. Ranks of the gray relation grades.

Alternative	A	B	C
Gray relation grade γ	0.595832	0.688141	0.579419
Rank	2	1	3

Discussion and Comparison with Other Research

The evaluation model proposed in this study could provide the government or enterprise companies with two types of information: one is to know the subjective and objective reference criteria for the location of a sports center, which is of great help to the evaluators; and the other is to build a complete evaluation model, which is used as a reference for decision-makers. Based on this information, government departments or enterprises could formulate appropriate location selection and operational strategies. In addition to improving operational efficiency, it could also improve service quality or create new service items so that citizens can enjoy a comfortable and pleasant sports environment.

The alternatives with the best performance in the various criteria are marked with an asterisk (*) and are summarized in Table 11. The performance of alternative A in the 16 evaluation criteria and 6 criteria was better than the other two alternatives. Option B had seven advantages and Option C had four superior performances. As mentioned in the case introduction, alternative A is a dense residential area. It is close to a forest park and a university. Therefore, it performs better in terms of the number of people served, the complementarity of nearby facilities, the distance from the urban area and sufficient human resources. Meanwhile, alternative B is located in the newly developed area of Taichung, the population is mostly young and middle-aged and the consumption capacity is relatively strong. Therefore, it has relative advantages in terms of location area, economic income, parking convenience and transportation facilities. Compared with the other two alternatives, alternative C has a weaker comparative advantage. Because the area is considered to be relatively remote, even if buses run frequently and the land prices are low, the advantages are still not as good as the other options.

According to the integrated weights in Table 5. For the selection of sports center location, the top three important criteria were C22 Complementarity of adjacent facilities (0.11161); C13 Size of the site (0.10506); and C11 Population of the service circle (0.09738). All three advantages belong to the P1 Geographical conditions and the factors F2 Future development and F1 Surrounding environment. This means that the sports center in the case study can be constructed from the alternatives if it has an advantageous performance in Geographical conditions.

Combining the entropy method and GRA for decision-making offers a robust approach, particularly in scenarios with uncertainty or incomplete information. The advantages of this article compared with Chou et al. (2008) [8] are as follows:

1. Handling uncertainty and incomplete information: The entropy method calculates the weights of each criterion based on data variability, making the analysis more objective and reducing reliance on subjective expert opinions. GRA effectively compares alternatives with an ideal solution even when data are incomplete or samples are limited.

2. Scientific and objective MCDM: The entropy method automatically assigns weights, avoiding bias from subjective weight assignment, leading to more scientifically sound results.
3. Avoiding limitations of a single method: While the entropy method focuses on weighting criteria, GRA emphasizes evaluating the performance of alternatives. Combining the two methods compensates for the shortcomings of using just one, resulting in more comprehensive decision support.
4. Simplicity and efficiency: Both methods have simple calculation processes and can obtain results quickly, especially in situations with limited time or resources.

Table 11. The alternatives with the best performance in the various criteria.

Criteria \ Alternative	A	B	C
C11 Population of the service circle	*		
C12 Size of the site		*	
C13 Economic income of the location		*	
C14 Public security		*	
C21 Convenience of obtaining nearby land	*		
C22 Complementarity of adjacent facilities	*		
C23 Socio-cultural characteristics of the neighborhood			*
C31 Intensity of public transportation frequency			*
C32 Parking convenience		*	
C33 Diversification of public transportation		*	
C41 Proximity to public transportation facilities		*	
C42 The distance to the downtown area	*		
C51 Sufficient human resources	*		
C52 Quality of manpower	*		
C61 Land cost			*
C62 License-acquisition cost			*

Note: * refers to alternatives with the best performance.

5. Conclusions

This research combined AHP, entropy weighting and gray relational analysis to establish an objective and consistent evaluation model to assist managers' decision-making. It also used real data to assist government units or private enterprises in understanding the performance of each pre-selected alternative. In addition, calculations based on a systematic and objective model performed in this study would allow managers to make informed decisions and formulate strategies based on various advantageous criteria to enhance service competitiveness.

The AHP was employed in this research to systematize complex problems. Through the opinions of experts, scholars and decision-makers, a hierarchical structure with mutual influence was established, which enabled complex issues or different opinions to be consistent and comprehensive evaluation was carried out through quantitative judgments. This method could provide sufficient information and reduce the risk of failure during decision-making. The entropy method is an objective weighting method, which was utilized in this study to determine the weight of the criteria according to the amount of information provided by the various indicators of the observation to avoid the bias caused by human subjective factors. Finally, in this research, the gray correlation analysis method was used to determine the gray correlation sequence of the proposed alternative in the model.

The empirical research proved the validity of the proposed evaluation model of sports center location selection. The results showed that F1 Surrounding environment and F2 Future development were the two most important factors in selecting the location for a sports center. The top five criteria were as follows: C22 Complementarity of adjacent facilities, C13 Size of the site, C11 Population of the service circle, C13 Economic income of the location and C23 Socio-cultural characteristics of the neighborhood. These are the indispensable key criteria for the selection of a sports center location.

This study has the following two limitations. First of all, because there are few studies in the literature on the site selection of sports centers or gyms, it is recommended that the site-selection criteria of chain enterprises can be incorporated in the future. Secondly, it is recommended that when government departments make site-selection decisions, the committee can add more members from the sustainable development department to participate in the discussion to link up with the promotion of sustainable development policies. Recommendations for further research follow. First, this paper only applies the proposed method to site selection and should be able to try to make practical applications in more fields. Secondly, the environmental impacts were not considered in the study and it is recommended that environmental sustainability be considered as a criterion in future studies. Third, a sensitivity analysis can be performed to test the impact on the priority order of sports centers when the weight of the evaluation criteria is changed. Finally, this study uses fuzzy theory as a computational tool to design methods, which can then be performed using rough theory or neural network methods.

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Institutional Review Board Statement: The study's approach, utilizing anonymous surveys, presented exceedingly little danger to participants. Furthermore, no personally identifying information was gathered, guaranteeing total anonymity during the study. Research operations that preserve anonymity and entail low risk are free from Taiwan AREE. Based on the regulations of academic review, it was confirmed that this research meets the third category: exempt from review. Available online: https://ethics-p.moe.edu.tw/static/ethics/u28-2/p02.html (accessed on 16 September 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is available on request from corresponding author.

Conflicts of Interest: The author declares no conflicts of interest.

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