Research on the Impact of the Olympic Games Based on AHP and EWM

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Abstract. In the face of the fierce competition for the right to host the Olympic Games, which is slowly diminishing, it is important to show the world the various impacts of hosting the Olympic Games to get out of the difficult situation and succeed a model is established. To solve this model, the most important Olympics Impact Measurement Model was first established. The Analytic Hierarchy Process Method and Entropy Weight Method were used to determine the weights of the main aspects and each small indicator, which were then used to derive corresponding indicators for the Summer and Winter Olympic Games. In both cases, the secondary indexes for sorting were economy, social psychology, and construction. The tertiary indicator with the highest weight was broadcasting revenue, while sponsorship revenue and tourism revenue followed closely. These indicators were found to be most effective in measuring the impact of hosting the Olympic Games. Overall, this model presents a comprehensive approach to measuring the impact of hosting the Olympic Games and provides a valuable tool for countries looking to secure the right to host this globally acclaimed event.

Keywords: Olympics, Olympics Impact, Entropy Weight Method, Analytic Hierarchy Process Method.

1. Introduction

The English poet, William Shakespeare, once wrote "All the world's a stage," which in modern times has evolved into a "Look at Me" attitude, making hosting mega sporting events, such as the Olympic Games, a perfect fit due to the long-term benefits for host cities. Hosting mega sporting events such as the Olympic games is in accord with this modern attitude due to the tangible and intangible long-term benefits for the host cities such as increased tourism and positive media attention [1-4]. Research has shown that hosting the Olympics can substantially increase a country's openness and have positive effects on trade due to the completed infrastructure and popularity [5]. However, financial dilemmas have been faced by some host cities, leading to arguments against hosting such costly events [6]. With the world economy being unstable, the number of countries bidding for the Olympics has decreased, making the benefits of hosting these games a continually debated issue. IOC (International Olympic Committee)'s sustainable legacy plans present a vision for the sustainability of Olympic Games hosting. Sustainability is often defined as "the capability to maintain a new way of working at a certain rate or level, often transforming existing systems to support the changes" [7]. Sustainability can be evaluated by considering multiple dimensions, such as economic, environmental, land use, and future improvements through a mathematical framework. As shown in Figure 1, it is a schematic diagram of the countries that hosted the previous Winter and Summer Olympic Games.

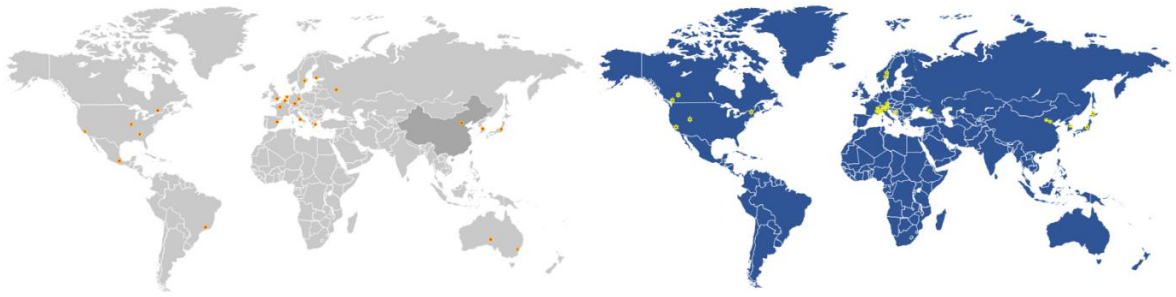


Figure 1. The highlighted cities (countries) that have hosted the Summer Olympic Games (left) and Summer Olympic Games (right)

2. Olympic Impact Measurement Model (OIMM)

2.1. Model Establishment

Many countries aspire to be hosts of the Olympic Games, which is very time consuming and costly but can have a profound impact on the host city. Therefore, a mathematical model is needed to establish to evaluate the overall impact when hosting the Olympic games. Behind this, three secondary indicators and many tertiary indicators should be considered, as shown in **Figure 2**.

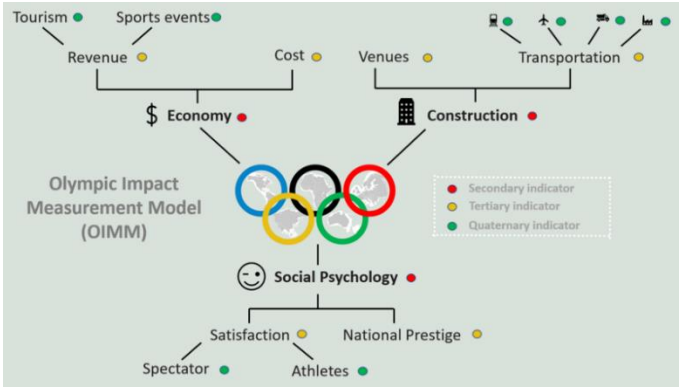


Figure 2. The indicators of OIMM

2.1.1 Economic Indicators

Hosting the Olympic Games implies that the host country needs a large amount of upfront money for the preparation of the event. This paper studied the economic indicator from the two dimensions of the Olympic Games' cost and revenue.

Cost

Initially, data concerning the cost of Summer Olympic games-hosting countries was collected from a website (https://olympstats.com/) and then was adjusted for inflation. The base year was selected for conversion and the resulting data is referred to as cost'(summer) (billions of dollars). The formula of Inflation Correction:

$$IC = history\ cost * (Price\ index\ of\ current\ year / Price\ index\ of\ historical\ year \quad (1)$$

Similarly, the corrected data about the cost of the Winter Olympic Games hosting country can be obtained from cfr.org, then the cost'(winter) (billions of dollars) was got.

Revenue

(1) Event Revenue

It was revealed by the analysis conducted on the source of revenue of the host country that sponsors and broadcasting revenue account for more than 80% of the revenue generated by the Olympic Games. Among them, TOP sponsors were found to give much more than others. Hence, the sum of **sponsorship** and **broadcast revenues** can be seen as the main income of the host country and the IOC, as shown in **Figure 3**.

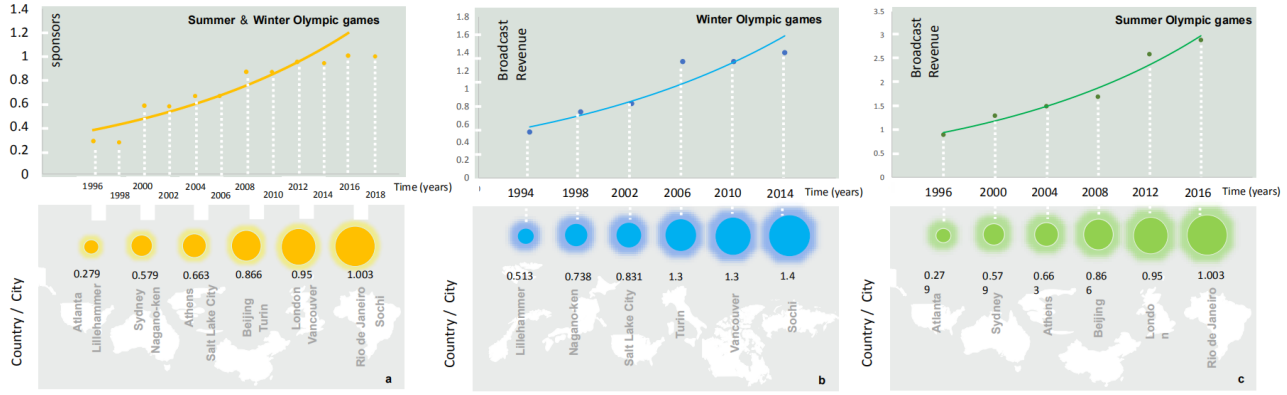


Figure 3. Revenue from sponsorship and broadcasting of the Winter Olympic Games and Summer Olympic Games

The above is denoted as:

$$e = k_1 SN + k_2 BR \tag{2}$$

Where e refers to the direct revenue from the Olympics hold, SN (billion) refers to the earning of sponsors, and BR (billion) refers to the income of broadcast. k_1 and k_2 are parameters greater than 0, according to the host country and IOC's different percentages of the decision?

(2) Tourism Revenue

The number of tourists during the Olympic Games is studied, and the expenditure that can measure the tourism expenditure is identified to calculate the overall relative tourism income.

First, the number of tourists: Data on the number of visitors from 2000 to 2018 were collected from the official websites of the host countries, and it was found that the data were relatively stable, except for 2016 when the data fluctuated for special reasons. The average number of tourists was taken, that is, NOT (S) =5.44, NOT (W) =1.2 (million).

Then, travel expenses: The Big Mac Index was introduced through economist.com to make a more direct standard comparison of travel income. The Big MAC Index serves as a tool to measure the reasonableness of the exchange rates of various currencies and can be used to compare the consumption levels of different regions.

So, relative tourism income (RTI): Various MAC data were collected, and the actual local cost of a Big MAC was figured out. Therefore, the following formula can be used to obtain the relative tourism revenue of each host country.

$$RTI = MAC * NOT \tag{3}$$

2.1.2 Construction Indicators

Regarding the infrastructure of the Olympic Games, pre-construction impact analysis and post-construction prospect analysis should also receive sufficient attention. The Olympic games work as triggers for the construction of many infrastructures such as stadiums and transportation systems [8]. A construction model was applied to assess the impacts of Olympic land use and transportation.

Land Use-Venue Area Index

The "number of venues" was abstracted as an indicator of Olympic land use and based on the number of venues for the Olympic Games from 2000 to the present, it was found that the number of venues in summer and winter varies greatly, but not significantly between the same seasons.

Transportation

Four indicators of **total railway mileage**, **total road mileage**, **number of airlines**, and **number of airports** was selected in each country to establish the model.

The idea of clustering, utilizing a **combination algorithm of system clustering**, was used to classify countries according to the four indicators selected above using SPSS. In the first clustering, only three data were separated, and only the best data was found in the first clustering analysis. The

rest were eliminated and re-clustered. Finally, all countries were classified into five categories, and different points were assigned to the different categories, as shown in **Table 1**.

Table 1 Grading results of each country

10 points	CHN, USA, IND
8 points	RUS, JPN, FR, CAN, AUS, BR
6 points	ZA, SE, DE
4 points	FIN, ID, ITA, MX, POL, TR, UK
2 points	Others

2.1.3 Social Psychological Indicators

Some social impacts of hosting the Olympic Games need to be taken into account [9-11]. This psychological concept was decomposed into two sub-factors, namely, **degree of satisfaction** and **national prestige**.

Degree of Satisfaction

The indicator degree of satisfaction can be divided into **spectator satisfaction** represented by attendance and **athlete satisfaction** shown in some data from the IOC questionnaire.

(1) Spectator Satisfaction

Considering the claim that ticket purchasing represents an intersection of enthusiasm and love is accepted, it is believed that the attendance rate can reflect the spectator satisfaction degree. The ticket sales for the Olympic Games were collected from the website (https://data.iimedia.cn/). The formula of Attendance was calculated as follows, and the results are shown in **Figure 4**.

$$Attendance = (Ticket\ sales\ /\ Total\ number\ of\ tickets\ released) \times 100\% \quad (4)$$

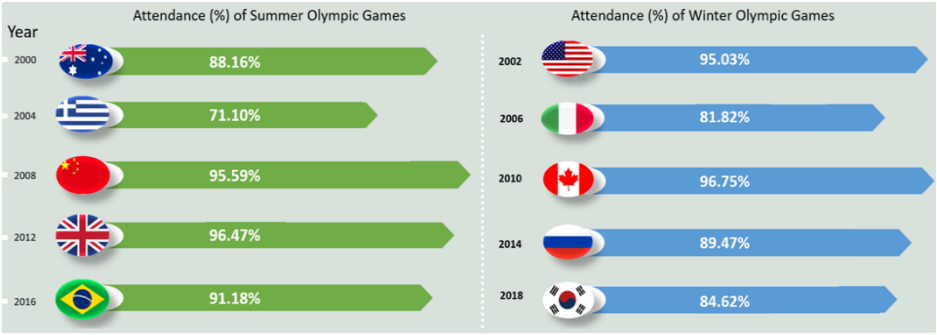


Figure 4. Attendance for the five Summer Olympics (green) and Winter Olympics (blue)

Overall, they are all above 70%. It can be further believed that hosting the Olympic Games will often win the satisfaction and recognition of the audience and improve the image of the host country.

(2) Athlete Satisfaction

The IOC questionnaire showed that 88% of the athletes are satisfied with the Tokyo Olympic Games and that the messages in the media are mostly positive. Therefore, it can be assumed that a high evaluation is always left. On the other hand, the athletes are a "small sample" compared to the audience, and the subjective nature of the questionnaire may bring fluctuations to our model. Hence, there is no need to analyze it further.

National Prestige

According to *The Theory of Money and Credit*, the stronger the country and the higher its international influence, the better the stability of its currency and exchange rate. Hence, the prestige of the country can be expressed in terms of the exchange rate of the country in question.

The exchange rate data was collected for the year of hosting the Olympics and five years after the Olympics, and through ANOVA, it was found that the exchange rates fluctuated both before and after the Olympics, but the data differed significantly, which means it only needs to focus on the direction of fluctuations. Therefore, it can be concluded that the international influence of the host country is benefited by hosting the Olympic Games.

2.2. Model Solving

2.2.1 Analytic Hierarchy Process Method (AHP)

First, a criterion-level judgment matrix on the target layer is constructed based on the importance of the judgment matrix and the characteristics of the judgment matrix.

To determine the weights among the elements of each layer, i.e., secondary indicators, the importance of these Second-level Indicators were judge as accurately as possible by comparing these factors with each other, as shown in **Table 2**.

Table 2 The Scale of the Judgement Matrix

Scale	Implication
1	**equal** important
3	**slightly** more important
5	**significantly** more important
7	**strongly** more important
9	**extremely** more important
2, 4, 6, 8	The median of the above two adjacent judgments
reciprocal value	If the scale of A compared to B is 4, then B compared to A is 1/4

Where a_{ij}, a_{jk}, a_{ik} are presented by the following formula (i represents a row, j represents column).

$$a_{ij} = \frac{the\ importance\ of\ i}{the\ importance\ of\ j} \tag{5}$$

$$a_{jk} = \frac{the\ importance\ of\ j}{the\ importance\ of\ k} \tag{6}$$

$$a_{ik} = \frac{the\ importance\ of\ i}{the\ importance\ of\ k} = a_{ij} \times a_{jk} \tag{7}$$

By analyzing many kinds of literature, the following judgment matrix was constructed (**Table 3**).

Table 3 Judgment Matrix

Olympics Impact	**Economy**	**Construction**	**Social Psychological**
Economy	1	4	3
Construction	1/4	1	3/4
Humanity	1/3	4/3	1

This judgment matrix is also a positive reciprocal matrix. By the Perron-Frobenius theorem, this matrix must have a maximum eigenvalue λ_{max}. To measure the quantitative index of the degree of inconsistency, the consistency index CI is introduced as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{8}$$

Where n is the order of this matrix.

But it is not enough to rely on CI alone to determine whether the matrix has a satisfactory consistency criterion. For this reason, Saaty proposed the average random consistency index RI:

$$RI = \frac{\lambda'_{max} - n}{n-1} \tag{9}$$

Where λ'_{max} is the average of the maximum eigenvalues of the randomly constructed positive reciprocal inverse matrix. The value of RI is also given by Saaty.

The consistency ratio CR is introduced as:

$$CR = \frac{CI}{RI} \tag{10}$$

When $\boldsymbol{CR < 0.1}$, the judgment matrix is considered to have satisfactory consistency; otherwise, it is necessary to adjust the judgment matrix to make it satisfactorily consistent.

Then the weights are calculated according to the arithmetic mean method, geometric mean method, and eigenvalue method.

(1) Arithmetic average method

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{ij}} \tag{11}$$

(2) Geometric averaging method

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{(\prod_{j=1}^{n}a_{ij})^{1/n}}{(\prod_{j=1}^{n}a_{ij})^{1/n}} \tag{12}$$

(3) Eigenvalue method: If the judgment matrix consistency is found to be acceptable, the weights can be calculated using the consistency matrix method. The maximum eigenvalue of the judgment matrix and its corresponding eigenvector can then be determined and the eigenvector can be normalized to obtain the weights.

Ultimately, the average of the three methods was used as our measure. The results are in **Table 4**.

Table 4 Second-level Indicators Results

Secondary Indicator	**Economy**	**Construction**	**Humanity**
Weight	0.6321	0.1580	0.2098

2.2.2 Entropy Weight Method (EWM)

From the data mentioned above, **cost, sponsor (SN), broadcasting revenue (BR), tourism income, venues, traffic score, spectator attendance, and exchange rate**, this paper weighs them by the **Entropy Weighting Method**. EWM is a comprehensive evaluation method that can be used for multiple objects and multiple indicators, and its evaluation results are mainly based on objective information. The weighting analysis for these indicators can be performed using this method, specific steps are as follows.

Step 1: Data normalization. Since the units of measurement of each index are not uniform, they need to be normalized before calculating the comprehensive weight.

For very large indicators

$$x_{ij}^{*} = \frac{x_{ij} - \min\limits_{1\le i\le n} x_{ij}}{\max\limits_{1\le i\le n} x_{ij} - \min\limits_{1\le i\le n} x_{ij}} \tag{13}$$

For very small indicators

$$x_{ij}^{*} = \frac{\min\limits_{1\le i\le n} x_{ij} - x_{ij}}{\max\limits_{1\le i\le n} x_{ij} - \min\limits_{1\le i\le n} x_{ij}} \tag{14}$$

Step 2: Calculate the $\boldsymbol{j-th}$ I term's entropy $\boldsymbol{e_j}$

$$e_j = -\frac{1}{ln(n)}\sum_{i=1}^{n} p_{ij} ln(p_{ij}) \tag{15}$$

where p_{ij} is the characteristic of specific gravity.

$$p_{ij} = -\frac{x_{ij}^{*}}{\sum_{i=1}^{n} x_{ij}^{*}} \tag{16}$$

The greater the difference between the observed values of the j-th index, the greater is e_j; conversely, the smaller e_j.

Step 3: Calculate the difference coefficient of the $\boldsymbol{j-th}$ index, that is, the information entropy redundancy $\boldsymbol{g_j}$

$$g_j = 1 - e_j \tag{17}$$

If the observed values of the j-th index are more different, the larger g_j is, and the more important the j-th index.

Step 4: Calculate the weight coefficient w_j of the $j-th$ index.

$$w_j = -\frac{g_j}{\sum_{k=1}^{m} g_k} \tag{18}$$

2.2.3 Final Index (OI)

Finally, we will integrate the second-level indicators and get one indicator, which is the first-level indicator.

$$\begin{aligned} \boldsymbol{OI} = (economy)\sum(econindicators) * \text{weight} \\ +(construction\,weight)\sum(con\,indicators) * \text{weight} \\ +(social\,psychological\,weight)\sum(sp\,indicators) * \text{weight} \end{aligned} \tag{19}$$

3. Results

3.1. Analytic Hierarchy Process Method (AHP)

The AHP algorithm is applied to our data in Table 3 to get the result of the secondary index which are Economy, construction, and humanity, and the weights are 0.6321, 0.1580, and 0.1580, respectively (Table 4). Our secondary index is suitable for the Winter and Summer Olympic Games.

3.2. Entropy Weight Method (EWM)

The Cost, Sponsor, and other data of six Olympic Games from 2000 to 2020 have been collected, and the following tables have been obtained for winter and summer through the EWM algorithm. The results are shown in **Table 5.**

Table 5 Third-level Indicators for Summer and Winter Olympics

Summer Olympics

Cost'	Sponsor (SN)	Broadcasting revenue (BR)	Tourism income
0.12728	0.12661	0.16901	0.10937
Venues	**Traffic score**	**Spectator attendance**	**Exchange rate**
0.18794	0.09686	0.11468	0.06925

·Winter Olympics

Cost'	Sponsor (SN)	Broadcasting revenue (BR)	Tourism income
0.09254	0.11505	0.15156	0.13973
Venues	**Traffic score**	**Spectator attendance**	**Exchange rate**
0.10282	0.12878	0.13476	0.13476

3.3. Final index (OI)

OI will be our final index for Olympic impacts on the host country, which contains all the information for the three levels we have chosen. Impact metrics of the Winter and Summer Olympics are listed below:

$$\begin{aligned} \boldsymbol{OI}(\boldsymbol{summer}) = 0.6321 * (-0.13cost' + 0.13SN + 0.17BR + 0.11TI) \\ +0.1580 * (0.19VE + 0.10TS) + 0.2098 * (0.11SA - 0.07ER) \end{aligned} \tag{20}$$

$$\begin{aligned} \boldsymbol{OI}(\boldsymbol{winter}) = 0.6321 * (-0.09cost' + 0.12SN + 0.15BR + 0.14TI) \\ +0.1580 * (0.10VE + 0.13TS) + 0.2098 * (0.13SA - 0.13ER) \end{aligned} \tag{21}$$

4. Conclusions

A model of measurement indicators has been proposed based on the above-mentioned data. The model uses clever and intuitive three-level indicators and comprehensive and important two-level indicators. With this model, it is only necessary to understand the meaning of the relevant indicators and collect data of tertiary indicators to make judgments regarding the post-Olympic impact. It is believed that the method can provide helpful consultations for the Olympic Games.

In addition, potential improvements have been identified in the previous multiple regression model. It is suggested that more independent variables, such as the population of the host city and other factors, can be added to the model to further improve its predictive ability and explanatory power.

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