Article

Application of Multicriteria Decision Making and Multi-Objective Planning Methods for Evaluating Metropolitan Parks in Terms of Budget and Benefits

Wen-Chi Lo 1, Ching-Hua Lu 2, * and Ying-Chyi Chou 3

1 Academy Financial Technology Applications, Ming Chuan University, Taoyuan 33348, Taiwan; lowenchi@mail.mcu.edu.tw
2 Office of Institutional Research, Shih Chien University, Taipei 10433, Taiwan
3 Department of Business Administration, Tunghai University, Taichung 40704, Taiwan; ycchou@thu.edu.tw
* Correspondence: chlu725.ms97g@g2.nctu.edu.tw

Received: 16 July 2020; Accepted: 1 August 2020; Published: 6 August 2020

Abstract: Urbanization is inevitable in developed countries. This study investigated the design of metropolitan parks, which are essential for sustainable cities. The developed model examined the suitability of parks in Taichung City, Taiwan, and explored the three aspects of ecological, economic, and social indicators for park design using De Novo planning tools and the Decision Making Trial and Evaluation Laboratory-based Analytic Network Process. Because the De Novo programming method can redesign budget restrictions, this method can help managers arrange budget programming and reduce the impact of excessive investment on resource utilization in specific projects. After obtaining each factor’s price, the De Novo planning approach can reduce economic and ecological resource input and improve benefits relative to existing resource utilization methods. When assuming a fixed investment of resources, the De Novo planning method moves resources from the economic and ecological aspects of leisure and recreation, thus increasing the total benefit of metropolitan parks. Multicriteria decision-making and multi-objective planning methods can provide an effective solution for evaluating metropolitan parks.

Keywords: multicriteria decision making; Decision Making Trial and Evaluation Laboratory

1. Introduction

As an economy develops, the residents of the country tend to migrate into cities. For developed countries, urbanization is inevitable. According to the United Nations, by 2030, more than 1.7 billion people will be concentrated in metropolitan areas globally. In increasingly crowded urban areas, proper planning of urban green spaces will have a significant effect on the quality of life of citizens. In some densely populated cities, green space and leisure facilities are not planned, despite the cities’ growing populations [1–3]. Urban green space has a significant effect on the physiology, society, and environment of residents [4], and is a key factor affecting residents’ satisfaction [5,6]. The planning and implementation of an eco-city are crucial for achieving sustainability in a city; this depends on the government’s emphasis on environmental protection and environmental literacy improvement. The construction of metropolitan parks enables the government to plan and manage urban green space to protect the biological resources of the area, provide people with leisure and recreational places, improve the quality of life of residents, increase the economic value of neighborhoods close to metropolitan parks, and encourage environmental protection through ecotourism. The choice of metropolitan parks has a strong effect on urban sustainability and well-being in terms of environmental protection (e.g., biological habitats, reducing the greenhouse effect, and reducing energy use) and
residents’ quality of life (e.g., average green space allocated for residents, parks, and recreation areas) [7]. This study investigated the design of metropolitan parks. An evaluation model for a metropolitan park based on ecological, economic, and social factors was established to examine the suitability of parks in Taichung City, Taiwan.

2. Literature Review

Many factors in daily decision making are mutually influential rather than independent. This also applies to the design of metropolitan parks. For example, ecological factors, such as biological habitat planning and biodiversity, affect residents’ social satisfaction. Therefore, this study explored indicators for metropolitan park design using multicriteria decision making (MCDM). MCDM analysis is an optimal decision-making tool in a complex environment. It has been widely applied in the optimization of manufacturing [8–10] and the selection of supply chain partners [11,12]. The use of this method in environmental management has also gradually increased. For example, MCDM has been used to assess the environmental effect of locations selected for villages and towns [13], the distance between national parks and cities [14], and locations selected for urban forests and regional parks [15].

Indicators were selected through a literature review and an expert meeting; then, Decision Making Trial and Evaluation Laboratory (DEMATEL) was used to calculate the mutual influence between aspects and indicators for the design of metropolitan parks. After completing the influence model, the DEMATEL-based Analytic Network Process (DANP) method was used to convert the causal influence relationships of various aspects and indicators into influence weights. After the weight calculation, De Novo multi-objective planning was applied to combine the three aspects of park design, namely ecological, social, and economic factors, into a single cost factor. The current value of metropolitan parks and the optimal resource allocation under existing budget constraints, in addition to the weights of different aspects, were then calculated. The research process is shown in Figure 1.

![Figure 1. Research process.](image-url)
Integrated Design for Metropolitan Parks

As a population’s urbanization rate increases, metropolitan parks play a vital role in the quality of human life (QoL) and the natural ecosystem [16]. Therefore, the planning and design of these parks have been an important issue in recent years. Many studies have explored the functions or benefits of metropolitan parks from different angles, including spatial distribution evaluation, post-construction evaluation, and ecosystem services evaluation [17]. The value of metropolitan parks includes supply services (e.g., clean water, food), water regulation, and culture services (e.g., leisure) [18]. As a result, increasing research has also explored the setting of urban green space from multi-oriented, multi-standard models [19]. Research assessing metropolitan parks from an ecological point of view is abundant, but from a social perspective, cultural values, and even comprehensive assessments of the needs of urban eco-parks, is significantly less common [20,21]. Second, many previous studies of metropolitan parks have been planned using a multi-criterion assessment methodology that treats ecological, social, and cultural aspects and individual indicators as an independent [22,23]. In reality, indicators of the ecological value of a metropolitan park (e.g., park biodiversity), spatial location (e.g., distance from the metropolitan area), and cultural services (e.g., leisure service planning) influence each other. For example, highly ecological urban parks jointly enhance a park’s social services’ efficiency and reduce the impact of the utilization rate caused by space distance. Third, past studies have emphasized the assessment of metropolitan parks. These assessments are rarely linked to the planning and allocation of subsequent resource inputs. Based on the above, this study combined the DEMENTAL evaluation method with a De Novo planning method to explore how to optimize urban park design under resource constraints. The influence relationship weight between the three structures of ecology, economy, and social culture was first selected by the DEMENTAL assessment method. Then the budget allocation was optimized according to the weight and subject to resource limitation to maximize the park’s benefits.

3. Methodology

This study explored the design and planning of metropolitan parks in a multi-faceted manner. First, experts and scholars studied the composition of ecological, economic, and social components in terms of 14 indicators for impact assessment. Then, according to the results of this assessment, the allocation of resources was determined. This composite approach to integrated planning and evaluation was also seen in Rodgers and George [24]. The study also confirmed the promotion of co-ordination between different structures and promoted overall effectiveness through proper systematic resource planning. Using the traditional linear planning approach, Rodgers and George identified system-feasible solutions or utility for optimizing resource allocation, based on resource constraints and resources that cannot be converted to each other. The De Novo planning approach used in this study assumes that all resources have a standard benchmark for measuring each other (e.g., money) and, therefore, can be substituted for each other (trade-off). Thus, the limitations of traditional linear planning were further relaxed, and better solutions to the differences in the research were identified.

3.1. Data Collection

By evaluation of metropolitan parks on the basis of budget and benefits, this study elucidated the methodology for constructing ecological parks and developed a reference for urban development management strategies. The design of ecological parks is proposed based on the analysis of a multicriteria evaluation. In DEMATEL and DANP questionnaires, experts were asked to provide their views on the construction of ecological parks and the design of metropolitan ecological parks. The results were used to evaluate the potential for the development of Taichung Metropolitan Park, Tunghai University, and Taichung Dadushan Wanli Great Wall Trail into ecological parks.
This research collected data in two parts. The first part invited 20 experts in the project management of ecological parks to confirm the construction, dimensions, and criteria for evaluating green lawns (the average tenure of these experts was seven years). By combining these expert suggestions, we confirmed the final framework for evaluating metropolitan parks with three dimensions and 14 criteria. In the second part of the research, a questionnaire was designed based on the DEMATEL and Analytic Network Process (ANP) methods (discussed in Section 3.2).

The survey distributed the questionnaires to 20 experts in the project management of ecological parks. After removing incomplete questionnaires, a sample of 16 complete questionnaires remained for analysis.

3.2. Integrated DEMATEL and ANP Method

Previous studies have detailed DEMATEL and ANP methods [25–29]. In this study, an integrated DEMATEL and ANP approach were used. ANP is a valuable conventional approach that helps decision-makers overcome the interdependence of the criteria and the indicators.

Because these criteria are often interdependent, individual weights are complex to obtain [20]. Consequently, this study used the DEMATEL method to find a causal network structure among all dimensions and green project management criteria. It then adopted the ANP approach to rank all criteria’s weights based on this causal network structure. The following steps describe the integrated DEMATEL and ANP approach [2].

The DEMATEL method: This method visualizes and presents interrelations between criteria through matrices and digraphs. The method can be summarized as follows:

Step 1: Find the initial average matrix. Each respondent indicates the degree of the direct impact that each criterion i exerts on each criterion j. Any pairwise comparisons between two criteria are denoted by \( a_{ij} \) and evaluated on a scale from 0 to 4, with 0 representing no influence and 4 representing very strong influence. Each respondent generates an \( n \times n \) nonnegative answer matrix, from which an average matrix \( A \) is obtained for each respondent. The following Equation presents the initial average matrix.

\[
A = \begin{bmatrix}
    a_{11} & a_{12} & \cdots & a_{1n} \\
    a_{21} & a_{22} & \cdots & a_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    a_{n1} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}
\] (1)

Step 2: Calculate the normalized initial influence matrix. The following normalized initial influence matrix \( D \) normalizes the average matrix \( A \).

\[
D = \frac{A}{S}
\] (2)

where

\[
S = \max( \max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}, \max_{1 \leq j \leq n} \sum_{i=1}^{n} a_{ij} )
\] (3)

Step 3: Compute the total-influence matrix, which shows a continuous decrease of the indirect effects of problems with \( D \)'s powers (e.g., \( D^2, D^3, \ldots, D^k \)), and \( \lim D^k = [0]_{nxn} \), where \( D = [d_{ij}]_{nxn} \), \( 0 \leq d_{ij} \leq 1 \) and \( 0 \leq \sum_i d_{ij} \) or \( \sum_j d_{ij} \leq 1 \) and where only one row or one column sum is equal to 1. The total-influence matrix \( T_{ij} \) is an \( n \times n \) matrix defined as follows:

\[
T = D + D^2 + \cdots + D^k = D(I + D + D^2 + \cdots + D^{k-1})(I - D)(I - D)^{-1} = D(I - D^k)(I - D)^{-1} = D(I - D)^{-1}
\] (4)
Let \( r \) and \( c \) represent vectors denoting the sum of rows and the sum of columns, respectively, of the matrix \( T \):

\[
\begin{align*}
    r &= [r_i]_{nx1} = \left[ \sum_{j=1}^{n} t_{ij} \right]_{nx1} \\
    c &= [c_j]_{nx1} = \left[ \sum_{i=1}^{n} t_{ij} \right]_{nx1}
\end{align*}
\]  

(5)

(6)

In this expression, \( r_i \) is the sum of the \( i \)th row in matrix \( T \) representing the total effects (both direct and indirect) of criterion \( i \) on the other criterion. Similarly, \( c_j \) denotes the \( j \)th column’s sum in matrix \( T \) and indicates the total effects (both direct and indirect) that criterion \( j \) receives from the other criterion.

When \( i = j \), the sum \( (r_i + c_j) \) (abbreviated as \( D + R \) as shown in Tables 1–4) indicates the strength of influences given and received by dimension or criterion \( i \). In other words, the sum \( (r_i + c_j) \) indicates the importance of dimension or criterion \( i \) in the problem. In addition, the difference \( (r_i - c_j) \) indicates the net effect of dimension or criterion \( i \) on the problem. If \( (r_i - c_j) \) (abbreviated as \( D - R \) as shown in Tables 1–4) is positive, then dimension or criterion \( i \) affects other dimensions or criteria, whereas if \( (r_i - c_j) \) is negative, then dimension or criterion \( i \) is affected by other dimensions or criteria.

Step 4: Set a threshold value and obtain the network relationship map. Reduce the complexity of information by filtering out negligible effects in matrix \( T \); a threshold value is necessary. The only criterion whose influence values are higher than the threshold can be selected and presented in the network relationship map. Thus, a new total influence matrix \( T_m \) can be derived (Equation (7)).

\[
T_m = \begin{bmatrix}
    t_{11} & t_{12} & 0 \\
    0 & t_{22} & t_{23} \\
    t_{31} & 0 & t_{23}
\end{bmatrix}
\]  

(7)

Pairwise comparisons are made between two criteria based on the question, “how much importance does a criterion have relative to another criterion regarding respondent’s preference?” The score is determined using a scale ranging from 1 to 4, with 1 representing equal importance and 4 representing extreme importance. One way of conducting this decision analysis is to set the alpha value and delete the low-impact indicators, similar to the expert meeting. The alternative is to delete the influence indicators that are too small without setting the alpha value. The selected indicators were repeatedly deleted and confirmed by the experts before the questionnaire was issued. Therefore, the study retained all criteria. The general form of the unweighted supermatrix was as shown in Equation (8).

Step 5: Find the unweighted supermatrix. The pairwise comparison matrices of criteria in the whole framework generates an unweighted supermatrix. Pairwise comparisons are made between two criteria and evaluated on a scale from 0 to 4 by asking, “how much importance does a criterion have relative to another criterion regarding respondent’s preference?” The score is determined using a scale ranging from 1 to 4, with 1 representing equal importance and 4 representing extreme importance. The general form of the unweighted supermatrix is as follows:

\[
\begin{array}{cccc}
    G_1 & G_2 & \cdots & G_n \\
    e_{11} & e_{11} & \cdots & e_{1n} \\
    \vdots & \vdots & \ddots & \vdots \\
    e_{n1} & e_{n1} & \cdots & e_{nn}
\end{array}
\]
where $W_j$ is the principal eigenvector of the influence of the criteria compared in the $j$th dimension to those compared in the $i$th dimension. If the $j$th dimension does not influence the $i$th dimension, then $W_{ij} = [0]$. $e_{nm}$ symbolizes the $m$th criterion in the $n$th dimension, $G_n$ characterizes the $n$th dimension.

Step 6: Compute the weighted supermatrix. Multiplying the normalized total-influence matrix $T_P$ and the unweighted supermatrix (Step 5) derives the weighted supermatrix. The normalized total-influence matrix $T_P$ is derived from the total influence matrix $T_m$ using the DEMATEL method (Step 4). The following matrix shows the normalized total-influence matrix $T_P$:

$$
T_P = \begin{bmatrix}
  t_{11}^p & \cdots & t_{12}^p & \cdots & t_{1n}^p \\
  \vdots & \ddots & \vdots & \ddots & \vdots \\
  t_{i1}^p & \cdots & t_{ij}^p & \cdots & t_{in}^p \\
  \vdots & \ddots & \vdots & \ddots & \vdots \\
  t_{n1}^p & \cdots & t_{nj}^p & \cdots & t_{nn}^p 
\end{bmatrix}
$$

where the normalized scores of the total-influence matrix $T_P$ are

$$
t_{ij}^p = t_{ij}^m / \sum_{i=1}^n t_{ij}^m 
$$

Then, the weighted supermatrix $W_s$ is calculated as follows:

$$
W_s = T_P \times W
$$

Step 7: Determine the limiting weighted supermatrix. The weighted supermatrix is developed to adequately high power, $k$, until it has converged and is stable; this is employed to access overall priority vectors:

$$
\lim_{k \to \infty} W_w^k
$$

Additionally, if the limited weighted supermatrix is not singular, it can be gauged by including $N$ supermatrices and dividing by $N$ ($N$ is the value of supermatrices) to obtain the final limiting weighted supermatrix.

According to the research process shown in the flow chart in Figure 1, the definitions of the notations of the integrated DEMATEL and ANP method are summarized step by step in the following Table 1.
Table 1. Definitions of the notations of the integrated Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP) method.

| Step | Formula | Notation | Definition |
|------|---------|----------|------------|
| Step 1 | \begin{align*} a_1 & = i \\ a_j & = j \\ a_{ij} & = \text{the pairwise comparisons between any two criteria taken as averages by experts} \\ A & = \text{initial average matrix} \end{align*} | i, j | one criterion, another criterion |
| Step 2 | \begin{align*} a_2 & = D \\ a_3 & = \max \sum_{j=1}^{n} a_{ij} \\ a_4 & = I \\ a_5 & = r_i \\ a_6 & = c_j \\ a_7 & = T_w \end{align*} | \[
\frac{\sum_{j=1}^{n} a_{ij}}{S} \]
| | | \[
S \text{ takes the bigger of the two as the upper boundary} \]
| Step 3 | \begin{align*} a_4 & = T \\ a_5 & = r_i \\ a_6 & = c_j \end{align*} | \[
\sum_{i=1}^{n} a_{ij} \]
| | | \[
T \text{ total-influence matrix} \]
| Step 4 | \begin{align*} a_7 & = T_w \end{align*} | \[
T_w \text{ matrix of total influence relation of criterion} \]
| Step 5 | \begin{align*} a_8 & = W \end{align*} | \[
W \text{ unweighted supermatrix} \]
| Step 6 | \begin{align*} a_9 & = T_p \end{align*} | \[
T_p \text{ normalized scores of the total-influence matrix} \]
| | | \[
W \text{ weighted supermatrix} \]
| | | \[
t_{ij} = \frac{r_i}{\sum_{i=1}^{n} r_i} \]
| | | \[
t_{ij} \text{ normalized total-influence matrix} \]
| Step 7 | \begin{align*} a_{12} & = \lim_{k \to \infty} W^k \end{align*} | \[
W^k \text{ limiting weighted supermatrix.} \]

Table 2. DEMATEL results for the ecological park.

| Economic Aspect | Ecological Aspect | Social Aspect | D + R | D – R |
|-----------------|------------------|---------------|-------|-------|
| Economic aspect | 0.3815           | 0.4284        | 0.3944| 2.4394| –0.0307|
| Ecological aspect| 0.4569                  | 0.4828        | 0.4656| 2.7566| 0.0539 |
| Social aspect   | 0.3967           | 0.4402        | 0.4108| 2.5184| –0.0232|

Table 3. DEMATEL results for the economic aspect.

|                           | A1   | A2    | A3    | A4    | D + R | D – R |
|---------------------------|------|-------|-------|-------|-------|-------|
| A1 Park capacity          | 0.3491| 0.3962| 0.4610| 0.4745| 3.1012| 0.2603|
| A2 Artificial building area ratio | 0.3711| 0.3136| 0.4456| 0.4249| 2.9714| 0.1391|
| A3 Construction and maintenance cost | 0.3621| 0.3748| 0.3381| 0.4034| 3.1034| –0.1464|
| A4 External benefits      | 0.3381| 0.3315| 0.3803| 0.3394| 3.0316| –0.2530|

Table 4. DEMATEL results for the ecological aspect.

|                           | B1   | B2    | B3    | B4    | B5    | D + R | D – R |
|---------------------------|------|-------|-------|-------|-------|-------|-------|
| B1 Land use patterns near the park | 0.3698| 0.3982| 0.4790| 0.4826| 0.4712| 4.4902| –0.0888|
| B2 Park size              | 0.4482| 0.3576| 0.4879| 0.5025| 0.4950| 4.4140| 0.1685 |
| B3 Environmental protection| 0.4812| 0.4386| 0.4956| 0.5484| 0.5346| 5.0100| –0.0853|
| B4 Biodiversity           | 0.4983| 0.4629| 0.5630| 0.4845| 0.5566| 5.1462| –0.0155|
| B5 Park green coverage    | 0.4920| 0.4654| 0.5583| 0.5628| 0.4713| 5.0786| 0.0210 |

3.3. De Novo Multicriteria Planning Method

After establishing the influence weights of the indicators for the ecological park design, the De Novo method was used to evaluate the benefits of the ecological park. Conventional multi-objective
planning determines the optimized resource allocation based on fixed total resources. The mathematical formula for the De Novo multicriteria planning method used in this study is as follows:

\[
\text{Max } Z = Vx
\]  
(13)

s.t. \( pUx \leq pb \)  
(14)

\( pb \leq B \)  
(15)

\( x \geq 0 \)  
(16)

Symbol description:

\( V \): \( m \times n \) matrix, \( V = \begin{vmatrix} V_{kj} \end{vmatrix} \)  
(17)

\( U \): \( m \times n \) matrix

\( Z \): objective function; \( k \) objective functions: \( Z = z_1, z_2, \ldots, z_k \),

where \( Z_k = \sum_{j=1}^{n} V_{kj} \times x_j \), \( k = 1, 2, \ldots, k \)

\( p \): the unit price of \( m \) types of resource, \( p = p_1, p_2, \ldots, p_m \)

\( b \): vector of \( m \) types of resource, \( b = (b_1, b_2, \ldots, b_m)^T \)

\( x \): the output of \( n \) types of products, \( x = (x_1, x_2, \ldots, x_n)^T \)

\( B \): total budget

By changing the reallocation of resource input price \( p^* \) and the number of input resources \( b^* \) for each of the objective functions, this study determines the cost of the input elements \( p^* \) and \( b^* \) that optimizes the objective function \( Z_k^* = \text{Max} Z_k \), \( k = 1, 2, \ldots, n \), and calculates the Pareto optimality with limited resources. The objective function calculates as follows:

\[
\text{min} B = pUx^*
\]  
(18)

s.t. \( Vx \geq Z^* \)  
(19)

\( x \geq 0 \)  
(20)

Solving Equations (18)–(20) yields the meta-optimal solution for the change of each total resource under the lowest total budget \( B^* \), total input \( b^* \), and a total output \( x^* \). Because the optimal total budget is usually higher than the actual budget, the maximum utility \( \text{max} Z \) can be recalculated using the ratio of the actual budget to the optimal budget \( r \) based on the constraints of the optimum path ratio.

\[
r = \frac{B}{B^*}
\]  
(21)

4. Empirical Results and Analysis

4.1. DEMATEL Analysis of Ecological Parks

The ANP questionnaire was administered to experts to obtain their views on the construction of ecological parks and the design of a metropolitan ecological park. Ecological parks have three important design indicators, namely, economic, ecological, and social factors.

A higher correlation value indicates a stronger correlation between aspects. If an aspect affects other aspects or is affected by other aspects, it is considered to have causality. \( D - R > 0 \) indicates that the aspect affects other aspects, whereas \( D - R < 0 \) indicates that the aspect is affected by other aspects.
The analysis results shown in Table 2 reveal that the correlation \((D + R)\) and causality \((D − R)\) values of ecological aspects are the highest.

Table 2 presents the correlation \((D + R)\) and causality \((D − R)\) results of the economic, ecological, and social aspects. These results are presented in a scatter plot in Figure 2.

![Figure 2](image_url)

**Figure 2.** Scatter plot of the correlation \((D + R)\) and causality \((D − R)\) results for the economic, ecological, and social aspects.

As shown in Figure 2, the results of the ecological aspect are distinct from those of the other two aspects. This indicates that improving the quality of the ecological park will enhance its economic and social benefits.

4.2. **DEMATEL Analysis of the Economic Aspects**

In the economic aspect, the definition of each indicator is as follows:

- **Park capacity**: The optimal number of people in the ecological park per unit time. The artificial building area ratio is the ratio of artificial buildings in the park to the total area. Park land is selected based on urban conditions, geographical conditions, and the convenience of the surrounding environment. Accordingly, construction and maintenance cost is the cost of acquiring and constructing on the land. External benefits refer to the ability of metropolitan parks to promote the development of the surrounding economy, improve job opportunities, and facilitate the reuse of idle urban land.

Table 3 shows that the highest correlation \((D + R)\) and causality \((D − R)\) results were observed for the ecological aspect of A4 External benefits.

Table 3 shows the correlation \((D + R)\) and causality \((D − R)\) results for the four economic indicators of park capacity, artificial building area ratio, construction and maintenance cost, and external benefits. The scatter plot is presented in Figure 3.

Table 3 reveals that the highest correlation \((D + R)\) and causality \((D − R)\) results were for A1 Park capacity. Thus, A1 Park capacity affects the artificial building area ratio, construction and maintenance cost, and external benefits.

4.3. **DEMATEL Analysis of the Ecological Aspect**

The definitions of indicators in the ecological aspect are as follows:

- **Land use patterns near the park**: The land use status adjacent to the park (i.e., residential land, buffer reserve, commercial land, industrial land, military land, and agricultural land). Park size refers to the area covered by the park. The size of the park influences whether it can provide animal and plant habitats and diverse ecological features. Environmental protection indicates whether the...
park has environmental protection functions (e.g., reducing air pollution and preventing flooding). Biodiversity refers to the types and numbers of animals and plants in the area and whether the park can be a habitat for more than two kinds of animals (e.g., multiple ecological functions, good soil permeability, and topsoil thickness). Green coverage refers to the ratio of the green area of the park to the total area of the park (including rivers, lakes, marshes, and fishing land).

![Economic Aspect](image-url)

**Figure 3.** Scatter plot of correlation ($D + R$) and causality ($D - R$) for economic indicators.

Table 4 shows that among ecological indicators, the highest correlation ($D + R$) and causality ($D - R$) results were obtained for B2 Reduce air pollution.

Table 4 presents the correlation ($D + R$) and causality ($D - R$) results for the five ecological indicators of land use patterns near the park, park size, environmental protection, biodiversity, and green park coverage. The scatter plot is presented in Figure 4.

![D-R](image-url)

**Figure 4.** Scatter plot of the correlation ($D + R$) and causality ($D - R$) results for the ecological aspect.
Table 4 reveals that the highest correlation \((D + R)\) and causality \((D - R)\) results were obtained for B2 Park size, indicating that the size of the park affects land use patterns near the park, environmental protection, biodiversity and green coverage.

4.4. DEMATEL Analysis of the Social Aspect

The definitions of indicators in the social aspect are as follows:

The environmental education field indicates that the park can be used as a space for environmental education. Promote urban ecotourism suggests that the park includes an environmental education (e.g., an information system detailing flora and fauna in various parts of the park) or tour guides with a background in environmental conservation who can increase public awareness of ecotourism. Increase the public’s attitude, and behavior toward ecotourism indicates that parks can promote the consciousness of urban ecotourism, improve quality of life and leisure, develop urban leisure and recreation activity networks, and maintain natural and cultural tourism resources. Cultural value and landscape beauty indicate that the park can combine local culture, construction facilities with cultural value, and construction facilities with historical value. Transportation indicates that the park features a clear traffic guide webpage and convenient public transportation.

Table 5 shows that the correlation \((D + R)\) and causality \((D - R)\) results of C5 Transportation were the highest.

| C1 Environmental education field | C2 Promote urban ecotourism concept | C3 Increase the public’s attitude and behavior towards ecotourism | C4 Cultural value and landscape beauty | C5 Transportation and means of transport | D + R        | D - R     |
|---------------------------------|-----------------------------------|---------------------------------------------------------------|--------------------------------------|----------------------------------------|--------------|-----------|
| 0.4070                          | 0.4882                            | 0.4752                                                        | 0.4342                               | 0.3769                                 | 4.3773       | -0.0142   |
| C2 Promote urban ecotourism concept | 0.4711                           | 0.3953                                                        | 0.4584                               | 0.4195                                 | 4.3264       | -0.0787   |
| C3 Increase the public’s attitude and behavior towards ecotourism | 0.4489 | 0.4580 | 0.3818 | 0.4009 | 0.3620 | 4.2261 | -0.1229 |
| C4 Cultural value and landscape beauty | 0.4418 | 0.4334 | 0.4352 | 0.3286 | 0.3345 | 3.9266 | 0.0204 |
| C5 Transportation and means of transport | 0.4269 | 0.4276 | 0.4239 | 0.3699 | 0.2911 | 3.6836 | 0.1953 |

Table 5 presents the correlation \((D + R)\) and causality \((D - R)\) results of the five indicators of cultural value, awareness of environmental protection, promote urban ecotourism, and basic urban conditions and convenience. The scatter plot is as shown in Figure 5.

![Figure 5](image)
Table 5 reveals that the correlation (D + R) and causality (D − R) results of C5 Transportation were the highest, indicating that C5 Transportation will affect environmental education field, promote urban ecotourism concept, increase the public's attitude and behavior towards ecotourism and cultural value, and landscape beauty.

4.5. Ranking of Indicator Importance

This study obtained an unweighted supermatrix from the total influence matrix of DEMATEL. This technique was performed using the influence degree of each criterion to obtain a weighted supermatrix and limited supermatrix to obtain each criterion’s overall weight. The weight of the factor was then obtained under the evaluation framework (importance).

Upon obtaining the limited matrix, the calculating step was conducted to identify the weight and overall ranking of the criteria (Table 6). The importance ranking of each indicator is shown as follows:

| Aspects          | Indicators | Contents                              | Importance | Weight |
|------------------|------------|---------------------------------------|------------|--------|
| Economic Aspect  | A1         | Park capacity                         | 4          | 0.0737 |
| (0.308)          | A2         | The artificial building area ratio     | 6          | 0.0726 |
|                  | A3         | Construction and maintenance cost      | 2          | 0.0771 |
|                  | A4         | External benefits                     | 1          | 0.0851 |
| Ecological Aspect| B1         | Land use patterns near the park        | 10         | 0.0640 |
| (0.351)          | B2         | Park size                             | 14         | 0.0639 |
|                  | B3         | Environmental protection              | 3          | 0.0743 |
|                  | B4         | Biodiversity                          | 5          | 0.0736 |
|                  | B5         | Park green coverage                   | 8          | 0.0701 |
| Social Aspect    | C1         | Environmental education field          | 9          | 0.0693 |
| (0.341)          | C2         | Promote urban ecotourism concept      | 12         | 0.0670 |
|                  | C3         | Increase the public’s attitude and behavior towards ecotourism | 13 | 0.0656 |
|                  | C4         | Cultural value and landscape beauty    | 11         | 0.0687 |
|                  | C5         | Transportation and means of transport  | 7          | 0.0702 |

4.6. Application of De Novo Multicriteria Planning Method

According to the results of the DANP analysis in Section 3.3, the three goals of De Novo multi-objective planning in the design of an ecological park are as follows:

1. The highest economic benefit: The park can accommodate most people, create the most ecological and economic benefits, and require the lowest maintenance cost.
2. The greatest ecological benefit: The park has the largest area, the highest ecological value, the most optimized biological species and quantity, the highest optimized green space ratio, and the most diverse ecological functions.
3. The greatest social benefit: The park is integrated with local culture, has the optimal park content (animals and plants, recreation, and education), can increase the public’s willingness to engage in ecotourism, and has the most convenient transportation.

This study cooperated with the Taichung Metropolitan Park and the Taichung City Government to obtain the annual budget of the park and the values of some parameters from the Taichung City Budget of the Metropolitan Park. For the parameters without secondary data or nonqualitative data, in-depth interviews were conducted with park managers and academic experts, and the values of parameters were thus estimated and quantified. The parameters and values required for this study are shown in Table 7 below.
Table 7. Indicator importance rankings.

| Parameter                                | Unit          |
|------------------------------------------|---------------|
| The total area of the park (S)           | m²            |
| Annual budget (B)                        | NT$1000/m²    |
| Floor areas of facilities and buildings (x₁) | m²            |
| Maintenance cost for facilities and buildings | NT$1000/m²   |
| Area of the ecological environment (x₂)  | m²            |
| Design planning and construction cost of the ecological environment | NT$1000/m²   |
| Area of landscape architecture in the social aspect (x₃) | m²            |
| Design planning and construction cost in the social aspect | NT$1000/m²   |
| Weights in economic, ecological, and social aspects (w₁, w₂, w₃) | Refer to Table 6 |

The Equation for multi-objective planning of eco-park design is as follows:

\[ \text{Max } Z_1 = w_1x_1 \]  \hspace{1cm} (22)
\[ \text{Max } Z_2 = w_2x_2 \]  \hspace{1cm} (23)
\[ \text{Max } Z_3 = w_3x_3 \]  \hspace{1cm} (24)
\[ \text{s.t. } x_1 + x_2 + x_3 \leq S \]  \hspace{1cm} (25)
\[ pUx \leq B \]  \hspace{1cm} (26)
\[ x_1, x_2, x_3 \geq 0 \]  \hspace{1cm} (27)

In this study, the correlation parameters for the design and planning of the metropolitan park were as follows:

1. Investigate the mutual influence of the three aspects of Economy (Z₁), Ecology (Z₂), and Leisure and Entertainment (Z₃) using DANP and convert the influence and causality results into weights through mathematical programming.
2. Total annual budget: NTD $1.5 million
3. Table 8 inputs elements for the design of metropolitan parks should include Land maintenance, building maintenance, software and hardware equipment investment, manpower cost, and biological maintenance. Different design aspects have different demand units for these five elements.
4. The manager should prepare different budgets (e) for each element, which cannot be diverted for other projects.

Table 8. Planning and restraint of budget.

| Item                      | Unit Price (a) | Economy (b) | Ecology (c) | Leisure and Entertainment (d) | Resource Constraints (e) | Resource Planning for De Novo Redesign |
|---------------------------|----------------|-------------|-------------|-------------------------------|-------------------------|---------------------------------------|
| Land maintenance          | 3              | 2           | 4           | 3                             | 50                      | 13.7                                  |
| Building maintenance      | 4              | 2           | 0           | 4                             | 20                      | 10.2                                  |
| Software and hardware equipment | 2              | 2           | 1           | 4                             | 10                      | 11.1                                  |
| Manpower                  | 1              | 0           | 5           | 3                             | 5                       | 5.1                                   |
| Biological maintenance    | 2              | 2           | 5           | 4                             | 50                      | 14.8                                  |

The mathematical equations used in this study are shown in Equations (28)–(31):

\[ \text{Max } Z_1 = 6x_1 + x_2 + 3x_3 \]  \hspace{1cm} (28)
\[ \text{Max } Z_2 = x_1 + 7x_2 + 2x_3 \]  \hspace{1cm} (29)
\[ \text{Max } Z_3 = 4x_1 + 2x_2 + 4x_3 \]  \hspace{1cm} (30)
\[ \text{s.t.} \]
\[22x_1 + 29x_2 + 44x_3 \leq 150 \quad (31)\]
\[x_1, x_2, x_3 \geq 0 \quad (32)\]

5. Conclusions

Table 9 revealed the simulation results that the budget calculated using traditional linear programming was NTD $1.39 million, and the benefit created by the metropolitan park was 61.5. The De Novo programming method was used to redesign entire budget restrictions. It can thus assist managers in arranging budget programming and reducing the impact of excessive investment on resource utilization. From the perspective of minimum resource consumption, after obtaining the price of each factor, the De Novo method can reduce economic and ecological resource input and create higher benefits compared with existing resource utilization methods. By contrast, when assuming fixed resources, the De Novo planning method moved resources from the economic and ecological aspects to leisure and recreation, thus increasing the total benefit of the metropolitan park to 63.07.

Table 9. Comparison of analysis results.

| Method of Programming                  | Total utility \(Z_k\) | Optimal budget allocation for each aspect | De Novo redesign of the budget restrictions |
|---------------------------------------|-----------------------|------------------------------------------|---------------------------------------------|
| Values of Parameters                  | Traditional Linear Programming | De Novo (Minimal Budget) | De Novo (fixed Budget Constraints) |
| \(Z_k = \sum_{j=1}^{n} w_j c_{kj} x_j\) | 61.5 | 62.77 | 63.07 |
| (110, 29, 0)                          | (106.5, 27.6, 0)      | (104.7, 26.4, 7.9)                     |
| (−3.5, −1.4, 0)                       | (−5.3, −2.6, 7.9)     |                                          |

In practice, when planning and designing or maintaining the budget for a metropolitan park, managers must rely on experience or existing principles for the use of funds, and they ignore diminishing marginal benefits resulting from the excessive investment of resources and the mutual influence between various aspects of the parks. For example, the construction of the Ecological Interpretation Hall in the park not only enhanced the park’s leisure and recreational functions but also generated economic benefits (e.g., selling of related products). This study explored the mutual influences of the three aspects of park design by using De Novo planning tools and optimized the resource investment with the DANP method to provide managers with a reference method for budget planning.

6. Research Limitation and Future Research

This study was undertaken as academic research. Although the process involved the production, officials, and academic experts for metropolitan park design advice and weights, it lacked specific input for metropolitan park planning resources and the related budget, and the analysis was conducted using analog numbers. This study used group decision making based on expert questionnaires and formulated evaluation criteria for urban park design. However, during the completion of the questionnaire, linguistic terms may have different interpretations due to personal factors. For example, one expert who perceived a “slightly less important” degree, may define this as lying somewhere between “very unimportant” to “slightly less critical,” while another expert’s perception of “slightly less important” may differ. Therefore, for the same project, for future study, it is recommended to add the vague-word approach to expert decision making (Rodgers and George [24]), considering the differences in respondents’ feelings about meaning. For example, using the fuzzy method of triangulation processing, Expert 1’s “a little unimportant” can be converted to (0, 25, 50), and Expert 2’s “a little unimportant” can be converted to (25, 50, 50). This transformation allows a more accurate assessment of the questionnaire. The weight evaluation operation can be carried out using mathematical methods to derive the fuzzy number for comparison with the present study’s results. The steps for the fuzzy method are as follows:
Step 1 Derive the triangular fuzzy number: The mathematical expression is as follows:

$$\bar{T}_{k_{avg}} = \frac{\sum_{i=1}^{n} T_{k}^{i}}{n} = \left(\frac{\sum_{i=1}^{n} a_{kl}^{i} \sum_{i=1}^{n} a_{km}^{i} \sum_{i=1}^{n} a_{ku}^{i}}{n}\right)$$

for $i = 1, 2, \ldots, n; k = 1, 2, 3, 4, 5$

$T_{k_{avg}}$: the five linguistic terms’ triangular fuzzy number.

$i$: the number of experts

$K$: linguistic terms. Including very unimportant, a little unimportant, just as important, slightly important, and very important.

Step 2 Arithmetic Average of Evaluation Criterion $j$:

$$\bar{T}_{j_{avg}} = \frac{\sum_{i=1}^{n} T_{j}^{i}}{n} = \left(\frac{\sum_{i=1}^{n} a_{jl}^{i} \sum_{i=1}^{n} a_{jm}^{i} \sum_{i=1}^{n} a_{ju}^{i}}{n}\right)$$

for $i = 1, 2, \ldots, n; j = 1, 2, \ldots, m$

$T_{j_{avg}}$: the $ith$ expert in the triangular fuzzy value of the $jth$ metropolitan park evaluation criterion.

$a_{jl}^{i}, a_{jm}^{i}, a_{ju}^{i}$: lower-bound, median, and upper bound values, respectively, of the linguistic items.

$m$: all evaluation criteria.

Step 3 Average for all expert opinions:

$$\bar{O}_{avg} = \frac{\sum_{i=1}^{n} O^{i}}{n} = \left(\frac{\sum_{i=1}^{n} o_{1}^{i} \sum_{i=1}^{n} o_{2}^{i} \sum_{i=1}^{n} o_{3}^{i}}{n}\right)$$

$O^{i}$: the average of fuzzy values of the linguistic items of $n$ experts’ opinions.

$o_{1}^{i}, o_{2}^{i}, o_{3}^{i}$: Lower-bound, median, and upper bound fuzzy values, respectively, of the linguistic items.

**Step 4 Defuzzification**

The mathematical formula of triangular fuzzy number resolution is as follows:

$$V_{A}^{-} = (a_{1} + 2a_{2} + a_{3})/4$$

$V_{A}^{-}$ is the triangle fuzzy number $\vec{A}$ after defuzzification.

Then the expert opinion value after defuzzification can be used in the DEMETAL analysis method to be calculated and compared with this study’s results.
Author Contributions: Conceptualization, Y.-C.C.; Methodology, C.-H.L.; Software, C.-H.L.; Formal analysis, C.-H.L.; Investigation, Y.-C.C. and W.-C.L.; Resources, W.-C.L.; Writing—original draft preparation, C.-H.L. and W.-C.L.; Supervision, Y.-C.C.; Project administration, Y.-C.C.; Funding acquisition, Y.-C.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Science and Technology (MOST) grant number MOST.104-2621-M-029-005.

Acknowledgments: For the third author, this project was financially supported by the Ministry of Science and Technology (MOST), grant number Republic of China, Taiwan, grant number MOST.104-2621-M-029-005.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gül, A.; Gezer, A. Modelling proposal for selection of urban forest location and its evaluation using Isparta city example. In Proceedings of the I. Ulusal Kent Ormancılığı Kongresi (First National Urban Forestry Congress in Turkey), Ankara, Turkish, 9–11 April 2004.

2. Chou, Y.-C.; Yang, C.-H.; Lu, C.-H.; Dang, V.T.; Yang, P.-A. Building Criteria for Evaluating Green Project Management: An Integrated Approach of DEMATEL and ANP. Sustainability 2017, 9, 740. [CrossRef]

3. Coşkun, A.; Velioglu, N. Definition and legal aspect of urban forest. In Proceedings of the 1st National Urban Forestry Congress Proceedings Book, Ankara, Turkish, 9–11 April 2004.

4. Gül, A.; Gezer, A.; Kane, B. Multi-Criteria Analysis for Locating New Urban Forests: An Example from Isparta, Turkey. Urban For. Urban Green. 2006, 5, 57–71. [CrossRef]

5. Bonaiuto, M.; Aiello, A.; Perugini, M.; Bonnes, M.; Ercolani, A.P. Multidimensional Perception of Residential environment Quality and Neighbourhood Attachment in the Urban Environment. J. Environ. Ment. Psychol. 1999, 19, 331–352. [CrossRef]

6. Bonaiuto, M.; Fornara, F.; Bonnes, M. Perceived Residential Environment Quality in Middle- and Low-Extension Italian Cities. Eur. Rev. Appl. Psychol.-Rev. Eur. Psychol. Appl. 2006, 56, 23–34. [CrossRef]

7. Chiesura, A. The Role of Urban Parks for the Sustainable City. Landsc. Urban Plan. 2004, 68, 129–138. [CrossRef]

8. Azadeh, A.; Kor, H.; Hatefi, S.M. A Hybrid Genetic Algorithm-TOPSIS-Computer Simulation Approach for Optimum Operator Assignment in cellular Manufacturing Systems. J. Chin. Inst. Eng. 2011, 34, 57–74. [CrossRef]

9. Braglia, M.; Frosolini, M.; Montanari, R. Fuzzy TOPSIS Approach for Failure Mode, Effects and Criticality Analysis. Qual. Reliab. Eng. Int. 2003, 19, 425–443. [CrossRef]

10. Chang, C.-W. Collaborative Decision Making Algorithm for Selection of Optimal Wire Saw in Photovoltaic Wafer Manufacture. J. Int. Manuf. 2012, 23, 533–539. [CrossRef]

11. Boran, F.E.; Genc, S.; Kurt, M.; Akay, D. A Multi-Criteria Intuitionistic Fuzzy Group Decision Making for Supplier Selection with TOPSIS Method. Expert Syst. Appl. 2009, 36, 11363–11368. [CrossRef]

12. Bottani, E.; Rizzi, A. A Fuzzy TOPSIS Methodology to Support Outsourcing of Logistics Services. Supply Chain Manag. Int. J. 2006, 11, 294–308. [CrossRef]

13. Joerin, F.; Musy, A. Land Management with GIS and Multicriteria Analysis. Int. Trans. Oper. Res. 2000, 7, 67–78. [CrossRef]

14. Sharifi, M.; Van den Toorn, W.; Rico, A.; Emmanuel, M. Application of GIS and Multicriteria Evaluation in Locating Sustainable Boundary between the Tunari National Park and Cochabamba City (Bolivia). J. Multi-Criteria Decis. Anal. 2002, 11, 151–164. [CrossRef]

15. Zucca, A.; Sharifi, A.M.; Fabbri, A.G. Application of Spatial Multi-Criteria Analysis to Site Selection for a Local Park: A case Study in the Bergamo Province, Italy. J. Environ. Manag. 2008, 88, 752–769. [CrossRef]

16. Heubach, K.; Lambini, C.K. Distribution and Selection of Experts in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES): The Case of the Regional Assessment for Africa. Innov. Eur. J. Soc. Sci. Res. 2018, 31, S61–S77. [CrossRef]

17. Zulian, G.; Stange, E.; Woods, H.; Carvalho, L.; Dick, J.; Andrews, C.; Baró, F.; Vizcaino, P.; Barton, D.N.; Novell, M. Practical Application of Spatial Ecosystem Service Models to Aid Decision Support. Ecosys. Serv. 2018, 29, 465–480. [CrossRef] [PubMed]
18. Li, F.; Guo, S.; Li, D.; Li, X.; Li, J.; Xie, S. A Multi-Criteria Spatial Approach for Mapping Urban Ecosystem Services Demand. *Ecol. Indic.* **2020**, *112*, 106119. [CrossRef]

19. Song, S.; Christian, A.; Martin, P. Exploring Integrated Design Guidelines for Urban Wetland Parks in China. *Urban For. Urban Green.* **2020**, *53*, 126712. [CrossRef]

20. Ala-Hulkko, T.; Kotavaara, O.; Alahuhta, J.; Helle, P.; Hjort, J. Introducing Accessibility Analysis in Mapping Cultural Ecosystem Services. *Ecol. Indic.* **2016**, *66*, 416–427. [CrossRef]

21. Zhang, L.; Peng, J.; Liu, Y.; Wu, J. Coupling Ecosystem Services Supply and Human Ecological Demand to Identify Landscape Ecological Security Pattern: A Case Study in Beijing–Tianjin–Hebei region, China. *Urban Ecosys.* **2017**, *20*, 701–714. [CrossRef]

22. Shariat, R.; Roozbahani, A.; Ebrahimian, A. Risk Analysis of Urban Stormwater Infrastructure Systems Using Fuzzy Spatial Multi-Criteria Decision Making. *Sci. Total Environ.* **2019**, *647*, 1468–1477. [CrossRef]

23. Zavadskas, E.K.; Bausys, R.; Mazonavičiūtė, I. Safety Evaluation Methodology of Urban Public Parks by Multi-Criteria Decision Making. *Landscape Urban Plan.* **2019**, *189*, 372–381. [CrossRef]

24. Rodger, J.A.; George, J.A. Triple Bottom Line Accounting for Optimizing Natural Gas Sustainability: A Statistical Linear Programming Fuzzy ILOWA Optimized Sustainment Model Approach to Reducing Supply Chain Global Cybersecurity Vulnerability through Information and Communications Technology. *J. Clean. Prod.* **2017**, *142*, 1931–1949.

25. Saaty, T.L. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*; McGraw-Hill International Book Co.: New York, NY, USA; London, UK, 1980.

26. Yang, Y.-P.O.; Shieh, H.-M.; Leu, J.-D.; Tzeng, G.-H. A Novel Hybrid MCDM Model Combined with DEMATEL and ANP with Applications. *Int. J. Op. Res.* **2008**, *5*, 160–168.

27. Yang, J.L.; Tzeng, G.-H. An Integrated MCDM Technique Combined with DEMATEL for a Novel Cluster-Weighted with ANP Method. *Expert Syst. Appl.* **2011**, *38*, 1417–1424. [CrossRef]

28. Baviera-Puig, A.; Gómez-Navarro, T.; García-Melón, M.; García-Martínez, G. Assessing the Communication Quality of CSR Reports. A Case Study on Four Spanish Food Companies. *Sustainability* **2015**, *7*, 11010–11031. [CrossRef]

29. Caballero-Luque, A.; Aragonés-Beltrán, P.; García-Melón, M.; Dema-Pérez, C. Analysis of the Alignment of Company Goals to Web Content Using ANP. *Int. J. Inf. Technol. Decis. Mak.* **2010**, *9*, 419–436. [CrossRef]

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).