Preferred Parking Space Recommendation Method Based on Multi-attribute Decision-making Algorithm

Chen Fei¹, ², a*, Li Xiaolin¹, ², ³, b

¹School of Communication and Information Engineering, Chongqing University of Posts and Telecommunications
²Research Center of New Telecommunication Technology Applications, Chongqing University of Posts and Telecommunications
³Chongqing Information Technology Designing Co., Ltd, Chongqing, China
*aCorresponding author: ²2270647095@qq.com
bemail: cy20180708@163.com

Abstract—Based on a large parking lot with a large number of parking spaces and different parking space attributes, combined with the attributes of free parking spaces and the driver’s preference factors when choosing parking spaces, a preferred parking space recommendation method based on a multi-attribute decision-making algorithm is proposed. In the decision-making process, a new weighting method is proposed to avoid the shortcomings of subjective arbitrariness and ignoring subjective preferences, while reducing the deviation between the combined weight and the subjective and objective weights. Finally, the absolute deviation method is used to verify the new weighting method, the effectiveness of the algorithm will also be verified through examples.

1. INTRODUCTION

“Difficult parking” is an important transportation problem that is accompanied by my country’s economic development and the increase in the number of cars in my country [1]. At the same time, with the further enrichment of spiritual and material life, people's needs for convenience of life and convenience of travel have further emerged. When people park in a large parking lot with many parking spaces to choose from, they usually hope that the selected parking space can meet the driver's own needs. Therefore, combined with the driver’s needs and parking space attributes, the multi-attribute decision-making algorithm is used to sort and recommend the driver’s preferred parking spaces to provide the driver with effective decision-making information, which can satisfy the driver’s choice of parking spaces with different attributes from different degrees.

Ma Jing uses parking status and walking distance as the user’s preference index when choosing parking spaces [2], and assigns weights to different attributes through subjective weighting to obtain preferred parking space recommendations. The attribute weight of this weighting method reflects the intention and empirical judgment of the decision maker, but the decision or evaluation result has a large subjective arbitrariness, so the accuracy and reliability of the decision are slightly worse. Yang Yuzhong uses road congestion, parking difficulty, availability, etc [3], as user preference indicators when choosing parking spaces, and also uses subjective weighting method to directly determine differences based on the subjective intentions of decision makers. The weight and degree of attributes
generally do not violate human common sense, but their objectivity is poor and lacks the advantage of mathematical theory. Xu Yejun et al. considered the parking safety of parking spaces and the type of parking spaces as their preference indicators for parking space selection [4]. Through comprehensive target influencing factors, they proposed a subjective and objective weighting method based on ideal points. The calculation is large and the calculation process is complicated. The above articles have considered the driver’s preference research on different parking space attributes. At the same time, the weight assignment of attributes has been achieved to varying degrees through different weighting methods, but the subjective arbitrariness of the evaluation value, the amount of calculation and the subjective and objective weighting are ignored. The deviation between. In response to the above problems, the author considers the three parking space attributes most valued by users in parking space selection: the distance from the parking space to the elevator, the walking distance from the parking space to the exit, and the parking space type, combined with the accuracy and reliability of the subjective and objective combination weighting, and optimize the target The model minimizes the sum of squares of deviations of subjective weight and objective weight, and maximizes the comprehensive evaluation value of the decision-making scheme, and calculates the comprehensive attribute value of different attributes based on the improved multiple decision variables and the subjective and objective combination weighting method. First, the driver’s preference factors when choosing parking spaces are introduced, combined with the attributes and types of parking spaces to construct multi-attribute decision-making indicators, and the “cost-type” and "benefit" indicators are normalized to obtain a decision matrix. Secondly, the decision maker assigns the attributes by subjective weighting and entropy information objective weighting. By establishing an optimization target model, the indicators are combined subjectively and objectively and weighted to obtain weight coefficients; then, the comprehensive attribute values are obtained by multiplying the decision matrix and the weight coefficients to obtain the program ranking; the analysis of numerical examples shows that the combination of subjective and objective weighting method that minimizes the deviation of subjective and objective weights and maximizes the comprehensive attribute value can accurately reflect the driver’s preference for parking spaces, as well as the selection of the driver’s preference for attributes. Parking spaces are sorted and recommended.

2. CONSTRUCTION OF PARKING SPACE EVALUATION INDEX BASED ON MULTI-ATTRIBUTE DECISION

The multi-attribute decision-making algorithm is applied to the preferred parking space recommendation, that is, the number of parking spaces is \( m \), and the optional parking space plan set is represented as \( S = \{s_1, s_2, \cdots, s_m\} \). Each parking space has \( n \) attributes, and the parking space attribute set can be represented as \( P = \{p_1, p_2, \cdots, p_n\} \). The attribute value of the \( j \) attribute of the \( i \) parking space is recorded as \( a_{ij} (i=1,2,\cdots,m; j=1,2,\cdots,n) \), and the parking space attribute decision matrix \( A = (a_{ij})_{m \times n} \) is constructed. Can be expressed as:

\[
A = \begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
a_{21} & a_{22} & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{m1} & a_{m2} & \cdots & a_{mn}
\end{bmatrix}.
\]

2.1 “Beneficial” Parking Space Index Construction

The benefit index is the bigger the better the index, also known as the positive index. This article studies the distance from the parking space to the elevator and the distance from the parking space to the exit. The distance from the parking space to the elevator refers to the walking distance from the current parking position to the elevator exit in the parking lot after the user completes the parking. The distance from the parking space to the exit refers to the distance from the parking space to the exit of the parking lot. The driving distance includes two parts, one is driving from the entrance of the parking lot to the parking space, and the other is driving from the parking space to the exit of the parking lot.
when leaving the parking lot. This study is based on the second situation, taking the distance from parking to the exit as another attribute of parking spaces. For "benefit" indicators, they can be normalized according to the following formula:

\[ b_{ij} = \frac{a_{ij} - a_{ij}^{\min}}{a_{ij}^{\max} - a_{ij}^{\min}} \quad (1) \]

Among them, \( a_{ij}^{\max} = \max\{a_{ij}, a_{2j}, \ldots, a_{mj}\} \) is the maximum value of the \( j \) index among the \( m \) candidate parking spaces, \( a_{ij}^{\min} = \min\{a_{ij}, a_{2j}, \ldots, a_{mj}\} \) is the minimum value of the \( j \) index among \( m \) candidate parking spaces, \( B = (b_{ij})_{mn} \) is the normalized vector, which is called the normalized decision matrix. Which represents the normalized attribute value of the \( j \) attribute of the \( i \) parking space plan \( S_i \). Obviously, the bigger the \( b_{ij} \) the better.

2.2 Construction of “Cost-Based” Parking Space Indicators

The cost index is the smaller the better index, also known as the negative index. This article studies the types of parking spaces available. There are different types of parking spaces in the parking lot, including inline parking spaces, non-shaped parking spaces and diagonal parking spaces. Each parking space has different parking methods and requirements for parking skills. Yes, so users have different preferences for these three types of parking spaces. For "cost-type" indicators, they can be normalized according to the following formula:

\[ b_{ij} = \frac{a_{ij}^{\max} - a_{ij}}{a_{ij}^{\max} - a_{ij}^{\min}} \quad (2) \]

Each symbol in the formula has the same meaning as above.

3. CONSTRUCTION OF A PREFERRED PARKING SPACE CALCULATION MODEL BASED ON MULTI-ATTRIBUTE DECISION MAKING

3.1 Multi-attribute Index Weight Calculation Based on Subjective and Objective Weighting

The subjective weighting method is based on the decision makers’ thinking ability, knowledge structure and knowledge level to give their own judgments on the plan. The relative importance of attributes generally does not violate people’s common sense, but ignoring the measured data, the decision or evaluation results have more large subjective arbitrariness, so the accuracy and reliability of decision-making is slightly worse. The objective weighting method has objective weighting standards. It uses various theoretical methods to determine the weights. It can make full use of the actual attributes of the indicators, but excessively relies on sample data, ignoring the subjective preference information such as the subjective knowledge and experience of the decision maker. Therefore, in view of the advantages and disadvantages of the subjective weighting method and the objective weighting method, a combined weighting method based on the minimization of subjective and objective deviations is used to optimize the weights of multi-attribute decision-making indicators. The evaluation results of parking space attributes not only meet the preferences of decision makers, but also conform to the actual situation.

1) The determination of the index weight of subjective weighting method

The subjective weighting method is to assign attribute weights based on the decision-maker’s cognitive level and consciousness judgment [5]. The attribute weights can usually be directly given by the decision-maker based on his preference for parking space attributes, and different parking space attribute evaluation indicators are obtained through subjective weighting method. The weight vector is
\( W_{ij} = (W_{i1}, W_{i2}, \ldots, W_{in})^T \), and satisfies \( \sum_{j=1}^n W_{ij} = 1.0 \leq W_{ij} \leq 1 \). In the formula, \( W_{ij} \) is the weight of the \( j \) importance evaluation index.

2) Determination of the index weights of the objective weighting method

The entropy weighting method is a commonly used weighting method in the objective weighting method [6]. The entropy weighting method uses information entropy to calculate the decision attribute weight according to the degree of variation of the parking space attribute evaluation index value. According to the definition of information entropy, the information entropy of the \( j \) index in the evaluation matrix \( B = (b_{nj})_{m \times n} \) is:

\[
\begin{align*}
    e_j &= -\left( \sum_{i=1}^m z_{ij} \ln z_{ij} \right) \left( \ln m \right), \quad j = 1, 2, \ldots, n \\
    z_{ij} &= \frac{a_{ij}}{\sum_{i=1}^m a_{ij}}
\end{align*}
\]

Therefore, the entropy weight of the \( j \) decision index is, \( W_{2j} = \frac{1-e_j}{n-\sum_{j=1}^n e_j} \), \( j = 1, 2, \ldots, n \). And satisfied \( \sum_{j=1}^n W_{2j} = 1.0 \leq W_{2j} \leq 1 \). Where \( w_{2j} \) is the entropy weight of the \( j \) preference evaluation index.

3) Weight determination of subjective and objective combination weighting method

Due to the complexity and uncertainty of parking space attributes and users’ difficulty in evaluating preferred parking spaces, there is often a big gap between the weights obtained by subjective weighting and the weights obtained by objective weighting. In order to make the decision result more reasonable and reduce the deviation between subjective and objective weights, a comprehensive attribute weight vector \( W_j = (\alpha W_{1j} + \beta W_{2j})_{m \times n} \), \( j \in n \) is introduced, Combine \( W_{1j}, W_{2j} \) to ensure that the combination weight \( W_j \) is close to \( W_{1j}, W_{2j} \) as much as possible. Therefore, construct an optimization model that minimizes the sum of squared deviations of subjective weights and objective weights:

\[
\min Z = \sum_{j=1}^n (\alpha W_{1j} - \beta W_{2j})^2, \alpha + \beta = 1, (\alpha \geq 0, \beta \geq 0)
\]

(3)

According to the characteristics of the multi-attribute decision-making algorithm, the solution with the larger comprehensive attribute value is the best solution, and the best solution is reflected by ranking. Therefore, the weight should be determined so that the comprehensive evaluation value of the program is as large as possible. Obtain the comprehensive evaluation value vector through linear weighted evaluation model \( U = (u_1, u_2, u_3, \ldots, u_m)^T \cdot u_i = \sum_{j=1}^n b_{ij} W_j (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n) \cdot W_j \)
represents the comprehensive attribute value, \( W_j = (w_1, w_2, \ldots, w_n)^T \). Therefore, construct an optimization model that maximizes comprehensive attribute values:

\[
\max G = \sum_{i=1}^n u_i = \sum_{i=1}^n \sum_{j=1}^m b_{ij} (\alpha W_{1j} + \beta W_{2j}), \alpha + \beta = 1, (\alpha \geq 0, \beta \geq 0)
\]

(4)

Generally speaking, it is impossible to optimize the objective function multiple times to achieve their respective goals and achieve the best value at the same time. There is more or less conflict between them. Therefore, in order to solve the above two problems, the optimization model is based on the objective and subjective combination of weighted deviation By minimizing the sum of squares (3)
and maximizing the comprehensive attribute evaluation value of the objective function (4), the following optimization models can be synthesized:

$$
\min Q = \sum_{j=1}^{n} (aW_{ij} - \beta W_{ij})^2 - \sum_{i=1}^{n} b_i (aW_{ij} + \beta W_{ij}), \alpha + \beta = 1, \alpha \geq 0, \beta \geq 0
$$

(5)

3.2 Calculation of Preferred Parking Spaces Based on Combined Weighting Method

The subjective and objective combination of weighted preferred parking space attribute calculation is to treat each parking space as a solution, and the multi-attribute index values that can reflect the parking space attributes are regarded as input variables, and the ranking of recommended parking spaces is calculated to obtain the corresponding driver preference attributes. For parking spaces, the comprehensive attribute value expression formula is as follows:

$$
\max G = \sum_{i=1}^{n} u_i = \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} (aW_{ij} + \beta W_{ij}), \alpha + \beta = 1, \alpha \geq 0, \beta \geq 0
$$

(6)

According to formula (4) and formula (5), construct the Lagrangian function, and use the Lagrangian multiplier method to solve the problem under the constraint condition of the extreme value model, and obtain:

$$
F(W_1, W_2, W_3, \ldots, W_n, \lambda) = \sum_{j=1}^{n} (aW_{ij} - \beta W_{ij})^2 - \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} (aW_{ij} + \beta W_{ij}) + \lambda (\alpha + \beta - 1)
$$

(7)

In the formula, $\lambda$ represents the Lagrangian operator. Differentiate 1, 2, and 3 in the formula, and finally get:

$$
\alpha = \frac{1}{2} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} (W_{ij} - W_{ij}) + \sum_{j=1}^{n} W_{ij} (W_{ij} + W_{ij})}{\sum_{j=1}^{n} (W_{ij} + W_{ij})^2}
$$

(8)

$$
\beta = \frac{\sum_{i=1}^{n} W_{ij} (W_{ij} + W_{ij}) - \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} (W_{ij} - W_{ij})}{\sum_{j=1}^{n} (W_{ij} + W_{ij})^2}
$$

(9)

4. Evaluation of Preferred Parking Spaces Based on Improved Multi-attribute Decision-making Algorithm

Considering the calculation of preferred parking spaces based on the multi-attribute decision-making algorithm, a case of the underground parking garage of a large shopping mall in Chongqing is introduced. There are a total of 540 parking spaces in the parking lot, and 10 parking spaces are randomly selected at a certain moment for user preference parking space recommendation. The specific data of the attributes of these 10 parking spaces can be obtained through the CAD drawings and legends of the parking lot, as shown in Table 1. Show. The problem is expressed by a multi-attribute decision-making algorithm, that is, the decision maker currently has ten parking spaces to choose from $S_1, S_2, \ldots, S_{10}$, the scheme set is $S = \{S_1, S_2, \ldots, S_{10}\}$, and each parking space has 3 attributes, namely $P_1, P_2, P_3$, the attribute set is $P = \{P_1, P_2, P_3\}$, and each is parking space. The distance to the elevator (m), the distance from the parking space to the exit of the parking lot (m), the type of parking lot (score). Here, the parking spaces are divided into non-character, straight and diagonal, and the three types of parking spaces are defined as 1, 0.7, and 0.5 according to the difficulty of parking. Among them, is the cost type attribute and the benefit type attribute. Table 1 is the original decision matrix of the problem.
Table 1. Parking space plan of preferred attributes

| Parking | Attributes | $p_1$ | $p_2$ | $p_3$ |
|---------|------------|-------|-------|-------|
| $s_1$   | 100        | 105   | 1     |
| $s_2$   | 90         | 102   | 1     |
| $s_3$   | 95         | 103   | 0.7   |
| $s_4$   | 84         | 105   | 0.5   |
| $s_5$   | 80         | 110   | 0.7   |
| $s_6$   | 85         | 100   | 0.5   |
| $s_7$   | 87         | 103   | 0.7   |
| $s_8$   | 80         | 120   | 1     |
| $s_9$   | 98         | 114   | 0.7   |
| $s_{10}$| 65         | 101   | 0.5   |

According to Table 1, the original decision matrix is $A = (a_{ij})_{10 \times 3}$ . According to formulas (1) and (2), the normalized decision matrix is $B = (b_{ij})_{10 \times 3}$ , as shown below:

$$A = \begin{bmatrix} 100 & 105 & 1 \\ 90 & 102 & 1 \\ 95 & 103 & 0.7 \\ 84 & 105 & 0.5 \\ 80 & 110 & 0.7 \\ 85 & 100 & 0.5 \\ 87 & 103 & 0.7 \\ 80 & 120 & 1 \\ 98 & 114 & 0.7 \\ 65 & 101 & 0.5 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0.75 & 1 \\ 0.2857 & 0.9 & 1 \\ 0.1429 & 0.85 & 0.4 \\ 0.1714 & 0.75 & 0 \\ 0.5714 & 0.5 & 0.4 \\ 0.4286 & 1 & 0 \\ 0.3714 & 0.85 & 0.4 \\ 0.5814 & 0 & 1 \\ 0.0571 & 0.3 & 0.4 \\ 1 & 0.95 & 0 \end{bmatrix}$$

When the driver considers the attributes of the parking space, the subjective weight is given as $W_{ij} = (0.5, 0.3, 0.2)^T$ . According to the entropy method, the objective weight is $W_{ij} = (0.4318, 0.2760, 0.2448)^T$ . Then based on subjective weight $W_{ij}$ and objective weight $W_{ij}$, solve the values of $\alpha$ and $\beta$ by formulas (8) and (9) as $\alpha = 0.4744$, $\beta = 0.5085$ . According to the values of coefficients $\alpha$ and $\beta$, as well as subjective weight $W_{ij}$ and objective weight $W_{ij}$, the combined subjective and objective weight values are as follows:

$$W_j = \alpha W_{ij} + \beta W_{ij} = (0.4660, 0.2948, 0.2220)^T$$

Since the result of each weighting method is an estimate of reasonable weight, if it is assumed that the result calculated by each weighting method is reasonable, then each weighting result should be distributed on both sides of the reasonable weight. We take the average of the three weight calculation methods as the approximate value of the reasonable weight. Here, the concept of absolute deviation is introduced [7]. According to the subjective weight, objective weight and the deviation range of the combination weight and the average weight value, the accuracy of the combination weight weight based on the minimum deviation is tested. The combination weights and comparison results of the preference parking space evaluation index are obtained, as shown in Table 2.
Table 2. Preference parking space evaluation index combination weight result

| Index | Subjective -weighting | Objective -weighting | Combination -weighting | Average -value | Absolute deviation |
|-------|------------------------|----------------------|------------------------|---------------|-------------------|
|       |                        |                      |                        |               | Subjective -weighting | Objective -weighting | Combination -weighting |
| $P_1$ | 0.5                    | 0.4318               | 0.4660                 | 0.4659        | 0.0732            | 0.0732               | 0.0002               |
| $P_2$ | 0.3                    | 0.2760               | 0.2948                 | 0.2903        | 0.0334            | 0.0493               | 0.0155               |
| $P_3$ | 0.2                    | 0.2448               | 0.2220                 | 0.2223        | 0.1003            | 0.1012               | 0.0013               |
|       |                        |                      |                        |               | 0.2069            | 0.2237               | 0.017                |

It can be seen from the table that the absolute deviation range of the subjective weighting method calculation result is 0.0334–0.1003, the absolute deviation range of the objective weighting method calculation result is 0.0493–0.1012, and the absolute deviation range of the deviation minimization combined weighting method calculation result is 0.0002–0.0155. It can be seen that the absolute deviation range of the weight result obtained by the deviation minimization combined weighting method is the smallest, and the cumulative absolute deviation result is the smallest 0.017. Therefore, the combination weighting method based on the subjective and objective weight minimization is closer to the reasonable weight, and the comprehensive evaluation result obtained is more accurate.

Substituting the combined weight vector $W_j$ into formula (6), the comprehensive attribute value of each parking space is obtained, and the results are shown in Table 3.

Table 3. Evaluation value of each parking space

| Weighting method       | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $S_9$ | $S_{10}$ |
|------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|
| Combination weighting  | 0.4432| 0.6206| 0.4060| 0.3011| 0.5026| 0.4946| 0.5126| 0.4883| 0.2039| 0.7462   |

When the driver assigns weights to the three attributes, the objective weighting method is combined to minimize the sum of squared deviations between the subjective and objective weights and maximize the comprehensive attribute value. According to Table 3, according to the driver's preference and the actual theoretical situation, the preferred parking space recommended to the driver is the 10th parking space.

5. CONCLUSIONS

The importance of preferential parking space recommendation in the smart parking management system is gradually emerging, and reasonable weight is the key to evaluation. Aiming at the characteristics of the subjective, objective and subjective and objective evaluation methods, through comparative analysis of the subjective weighting method, objective weighting method, and deviation minimization combination weighting method results, we can see that the absolute deviation of the indicator weight obtained by the deviation minimization combination weighting method Minimal, and get the user's preferred parking space through the combination of weighting method through example verification. Therefore, the combined weighting method of minimizing deviation can be selected to calculate the weight of the user's preference parking space evaluation index. In this article, two weighting methods are recently selected for combined research. If more reasonable weighting methods can be selected in combination with the characteristics and target requirements of the parking lot, the reasonableness of the indicator combination weight can be further improved, and the evaluation accuracy and scientific. In addition, the evaluation index system also has an important impact on the recommendation results of preferred parking spaces. Each parking space has many attributes and different users prefer different attributes. The corresponding evaluation index system should be adjusted accordingly. For example,
parking spaces can be further considered. The safety, width of the parking space, whether there are other vehicles on both sides and other factors, more comprehensively characterize the characteristics of the parking space. It is hoped that in the following research, China and Russia can propose a more comprehensive and reasonable evaluation index system to improve the accuracy of the evaluation results of preferred parking spaces.

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