Site Selection and Optimization of Suburban Large Warehouse

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Abstract. Currently, various kinds of public security incidents occur frequently in society, and the problem of siting suburban silo bases is of great significance for post-disaster emergency relief. In order to conduct a reasonable study on the location of suburban silo base, this paper researches the location of suburban silo base for the needs of immediate deployment of supplies and guaranteeing the circulation of supplies in emergency situations. According to the general principles and influencing factors of suburban warehouse base site selection, the evaluation index system of suburban warehouse base site selection is determined. In view of the difficulty in assigning the index weights to the traditional site selection method, the partial order set decision method, which only needs to determine the order of index weights but not the exact value, is used to study the site selection of suburban warehouse bases, and the suburban warehouse base site selection evaluation model is constructed, and finally the feasibility of the method is verified by calculation, which provides a new idea for the suburban warehouse base site selection evaluation.

Keywords: suburban large warehouse base; partial order set; indicator weights; Hasse diagram

1 Introduction

The sudden outbreak of various public safety events has seriously affected the social order, especially the sudden outbreak of "COVID-19" at the end of 2019, which has brought significant impact on people's life safety as well as economic development, and the country is increasingly concerned about the improvement of infrastructure and the establishment of the guarantee system in emergency situations. 2022 April The General Office of the State Council proposed to build a number of suburban large warehouse bases integrating processing, storage and delivery in various large and small cities to guarantee the basic living needs of citizens in emergency situations. The site selection of suburban large warehouse bases is the key to the reasonable dispatch and optimal distribution of subsequent resources after an emergency event.

China started to establish the emergency material reserve system since 1988 and has been improving the emergency material reserve system since then, and the method of reconstruction of the emergency material reserve has also been clearly pointed out in the General Emergency Plan for National Public Emergencies. Although the emergency material reserve network system in China has been basically established so far, there are still some problems in the site selection of emergency material reserve bases, such as high construction costs, low distribution efficiency, and failure to efficiently meet people's needs. The site selection is one

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of the important tasks in the early stage of the project, and whether the site selection is reasonable or not will directly affect the reachability and timeliness of the emergency supplies and the delivery cost of the supplies in case of a disaster. Therefore, it is very meaningful to study the site selection of suburban warehouse bases for emergency management in China.

In 1909, weber and Alfred[1] first proposed the problem of site selection, and to date a wealth of research results have been generated both domestically and internationally. At the early stage of research, many scholars used quantitative analysis to conduct their studies. Mengjue Li et al.[2] (2011) constructed a site selection model for agricultural logistics distribution centers based on the mixed integer programming method. Zhou Gengui et al.[3] (2005) used genetic algorithm to solve the siting model of reverse logistics network. In recent years, more and more qualitative analysis methods have been applied to the site selection problem. Such as hierarchical analysis, fuzzy comprehensive evaluation, ideal solution method, data envelopment analysis, BP neural network evaluation, etc. Guo, Mina et al.[4] (2007) considered that the actual site selection of distribution centers is influenced by many uncertain factors such as local environment and government policies, and established a two-level objective opportunity constrained planning model based on expert evaluation method, which converts these qualitative-qualitative factors into quantitative factors and combines qualitative and quantitative factors. Yu Yan[5] (2009) considered the theory of economy of scale and combined the Delphi method with hierarchical analysis to avoid the complexity of the model. Chen Zhanbo et al.[6] (2015) gave a logistics center site selection evaluation method based on improved gray correlation analysis, which can solve the problem of uniqueness of correlation in gray correlation degree. Wang S. Y. et al.[7] (2013) established a hierarchical analysis model to solve the distribution center site selection problem by analyzing various factors affecting logistics and distribution. However, these methods, such as hierarchical analysis, gray correlation analysis, and fuzzy comprehensive evaluation method, have certain limitations, although they are simple in operation. Although they can give full play to expert opinions, they have a strong subjectivity. And some indicators have certain randomness, which cannot be described quantitatively.

The research on the siting of emergency logistics center facilities has only emerged in recent years, and most of them are aimed at public emergency facilities with certain application background such as hospitals. At present, there are two main ideas for siting emergency logistics center facilities in China: one is to establish a linear programming model to solve the siting problem considering demand, distance, cost, timeliness and other index factors[8, 9, 10] BOONMEE C[8] et al. classified the types of data modeling site selection into four types: deterministic, stochastic, dynamic, and stable, and combined the exact algorithm and heuristic algorithm to solve them respectively. GUO Yongmei[9] et al. construct a bi-objective mixed integer planning model considering the reliability elements of facilities and solve the model with the help of MATLAB. Yan Sen[10] et al. represent the uncertainty of material quantity with the help of triangular fuzzy numbers, then defuzzify the triangular fuzzy numbers, and finally solve the model with the help of genetic algorithm. There is another kind of multi-criteria decision making using qualitative research[11, 12] . pham t y[11] et al. combined with TOPSIS with the help of fuzzy comprehensive evaluation method, five aspects of freight demand, distance to market, origin, customer and transportation cost were selected to make decision on the candidate locations. LI G[12] et al. introduced the gray correlation analysis method for the determination of decision maker's preference degree, and the combination of qualitative and quantitative analysis provided a new idea for emergency logistics site selection.

In summary, most of the current research results on emergency facility reserves focus on the consideration of a single factor, and few studies have integrated the field conditions or considered the difficulty of obtaining realistic data. The purpose of site selection decision is to obtain the order of advantages and disadvantages of alternative points, and the fuzzy partial order method is precisely able to conveniently describe the uncertainty of comparing alternative objects with each other. Based on this, this paper proposes a siting evaluation model based on partial order set theory for suburban silo base selection, which mainly includes: constructing a suburban silo base siting evaluation index system; determining index weight ranking based on expert evaluation; ranking the siting options; and finally detailing the decision making method through case study.

2 Establishment of a site selection evaluation index system for peri-urban large warehouse bases

The site selection of suburban large warehouse base is a complex process with many complicated and difficult to quantify design factors, so this paper intends to use partial order set model to analyze the factors of site selection. According to the basic principles of large logistics center site selection, they are categorized into three aspects: social benefits, economic benefits and ecological benefits. After generalization, the suburban large warehouse base site selection evaluation index system is constructed as shown in Figure 1.

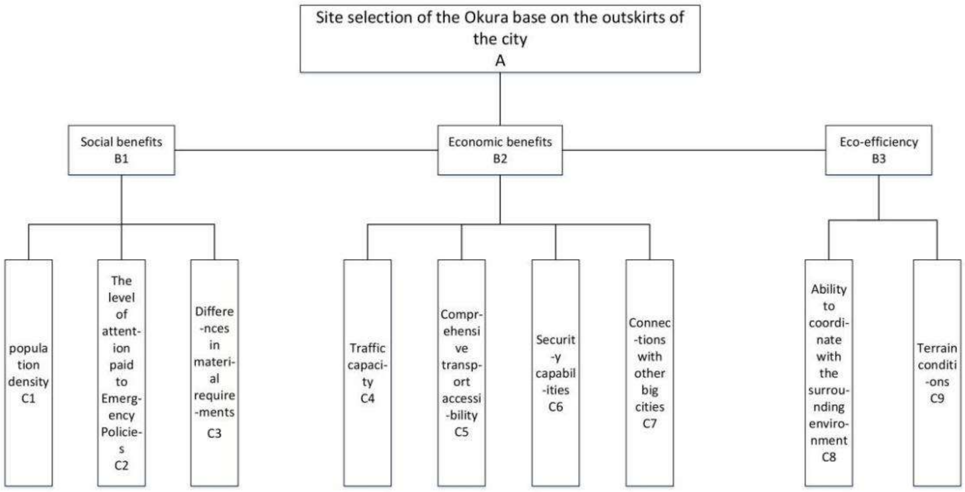

Figure 1 Suburban silo base site selection evaluation index system

3 Determination of the weights of the evaluation indexes for the site selection of suburban large warehouse bases

3.1 Basic principles of partial order sets

The partial-order set is a theoretical method with a strong hierarchy, which reveals the rank and position of each element in the set[13] . In the application, it is not necessary to know the exact weight value of each indicator, but only the weight order of each indicator can be known[14] .

Definition 1[15]

Let A be a non-empty set and R be a binary relation on A if it satisfies .

(1) Self-reflexivity: $\forall x \in A$, then xRx;

(2) Antisymmetry: $\forall x, \forall y \in A$, if xRy and yRx, then x = y;

(3) Transmissibility: $\forall x, \forall y, \forall z \in A$, if xRy , then yRz , then xRz .

Then R is said to be a partial order relation on A, denoted by "≤". The partial order relation "≤" together with the set A forms the partial order set, which is denoted as (A, ≤). If the evaluation set $M = (A, IC, E)$ there exists a partial order relation, then for $\forall x, y \in A$, there is:

$$x \leq y \Leftrightarrow C_j(x) \leq C_j(y), j = 1,2,3,\cdots\cdots n. \quad (1)$$

Definition 2[16]

Given the partial order set (A, ≤), let the evaluation set be M = (A,IC,D), for $\forall a_i, a_j \in A$, if $a_i \geq a_j$, then write $r_{ij} = 1$; if $a_i \leq a_j$ or a_i is incomparable with a_j is incomparable, denoted as $r_{ij} = 0$. $R = (r_{ij})_{m\times m}$ is the comparative relationship matrix of the partial order set (A, ≤). When the indicator weights satisfy $w_1 \geq w_2 \geq \cdots w_n$, Yue Lizhu et al. (2017)[13] gave a method for comparing multiple sample multiple indicator decision problems with the help of a matrix.

Given the upper triangular matrix E:

$$E = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 0 & 1 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}$$

$$D = X \cdot E = \begin{pmatrix} x_{11} & x_{11} + x_{12} & \cdots & x_{11} + x_{21} + \cdots + x_{n1} \\ x_{21} & x_{21} + x_{22} & \cdots & x_{21} + x_{22} + \cdots + x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m1} + x_{m2} & \cdots & x_{m1} + x_{m2} + \cdots + x_{mn} \end{pmatrix} \quad (2)$$

In the cumulative transformation matrix D, if the value of the first i each value of the row is greater than or equal to the value of the j value of the row, then it means that the first i solution is better than or equal to the j solution, which is denoted as $r_{ij} = 1$, otherwise $r_{ij} = 0$.

Denote$R = (r_{ij})_{m\times m}$ is denoted as the comparison relation matrix of the partial order set (A, ≤). Fan Yi (2003)[17] gives the transformation method of Hasse matrix, and Hasse diagram can be drawn according to Hasse matrix.

$$H_R = (R - I) - (R - I) * (R - I) \quad (3)$$

whereH_R denotes the Hasse matrix, R denotes the relation matrix, andI denotes the unit matrix, and * denotes the Boolean operation.

In any partial order set (A, ≤), the$O(x) = \{y \in A|x \le y\}$ denotes the lower set of the set A, the $F(x) = \{y \in A|x \ge y\}$ denotes the upper set of the set A, and $N(x)$ denotes the incomparable set.

$$N(x) = A - O(x) - F(x) \quad (4)$$

set$|O(x)|$, $|F(x)|$ and $|N(x)|$ denote the number of elements in each set, respectively, then for the partial order set (A, ≤) with m schemes, the number of elements satisfies:

$$|O(x)| + |F(x)| + |N(x)| = m + 1 \quad (5)$$

Given the partial order set (A, ≤), for $\forall x \in A$, the height of x in A can be expressed as:

$$hav(x) = \frac{|O(x)|}{|O(x)|+|F(x)|} * (|O(x)| + |N(x)|) + \frac{|F(x)|}{|O(x)|+|F(x)|} * (|O(x)|) \quad (6)$$

The partial order set decision method is to use the$hav(x)$ the size of the solution to rank the solutions.

3.2 Operation steps

(1) Obtain the data weight ordering, and arrange the data from left to right in the order of indicator weights.

(2) Normalization of the data.

(3) Summation of accumulation to obtain the accumulation transformation matrix.

(4) According to the biased order relationship, the solutions are compared two by two to build the biased order relationship matrix.

(5) The Hasse matrix is obtained from the partial order relationship matrix, and the Hasse diagram is drawn.

3.3 Constructing evaluation models

Based on the theory of partial order set, the suburban silo base site selection model is constructed, and the specific process is shown in the following figure.

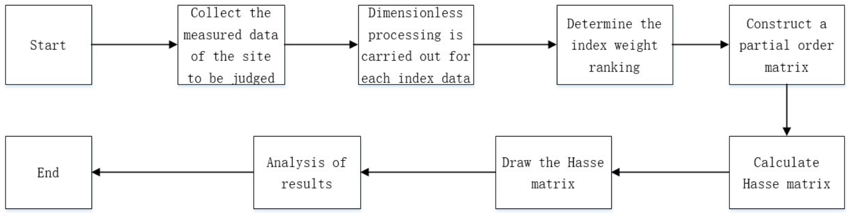

Figure 2 Processing flow of suburban silo base site selection

4 Application Examples

4.1 Data sources and optimization

Before determining the order of weights, the data of each indicator were normalized to the maximum value to eliminate the influence of the indicator scale on the output results. Experts are invited to qualitatively analyze the selected indicators. At the same time, some controversial indicators were analyzed and the order was adjusted in combination with the literature, and the weight order of each weight vector was finally obtained.

In order to better verify the suitability of the partial-order set model for siting suburban silo bases, this paper selects the example in the Reference 19[19] to verify the effectiveness of the algorithm. The example includes 12 alternatives, the solution set $A = \{A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, A_9, A_{10}, A_{11}, A_{12}\}$; 5 evaluation criteria, the set of criterialC $= \{C_1, C_2, \cdots, C_5\}$ all of which are efficiency-based criteria with the weight vector $W = \{\omega_1, \omega_2, \cdots, \omega_5\}$ and the weight order is$w_3 > w_4 > w_2 > w_5 > w_1$. The specific data are shown in table 1.

Table 1 Program raw data table

	c_1	c_2	c_3	c_4	c_5
a_1	14.50	147.000	4.0	1014.000	5.25
a_2	13.25	199.125	4.0	1014.000	4.00
a_3	15.75	164.375	16.5	838.250	5.25
a_4	12.00	181.750	16.5	838.250	4.00
a_5	12.00	164.375	54.0	838.250	4.00
a_6	13.25	199.125	29.0	662.500	5.25
a_7	15.75	181.750	41.5	135.250	5.25

a_8	17.00	216.500	6.5	486.750	1.50
a_9	15.75	216.500	41.5	662.500	1.50
a_{10}	15.75	164.375	41.5	311.000	6.50
a_{11}	12.00	199.125	41.5	311.000	2.75
a_{12}	13.25	171.750	1.5	311.000	4.00

4.2 Data processing

Since there is a dimensional relationship between the indicators in the partial order set, in order to eliminate the influence between the data of different indicators, it is necessary to dimensionless the data. Since the indicators are all benefit-type indicators, equation (7) is used to dimensionless the data so that the data are all between [0,1], and the results are kept three decimal places to obtain table 2.

$$y = \frac{x_{max} - x_{ij}}{x_{max} - x_{min}} \tag{7}$$

Table 2 Dimensionless processing of raw data

Program Number	Evaluation Guidelines				
	c_1	c_2	c_3	c_4	c_5
a_1	0.500	1.000	0.952	0.000	0.250
a_2	0.750	0.250	0.952	0.000	0.500
a_3	0.250	0.750	0.714	0.200	0.250
a_4	1.000	0.500	0.714	0.200	0.500
a_5	1.000	0.750	0.000	0.200	0.500
a_6	0.750	0.250	0.476	0.400	0.250
a_7	0.250	0.500	0.238	1.000	0.250
a_8	0.000	0.000	0.905	0.600	1.000
a_9	0.250	0.000	0.238	0.400	1.000
a_{10}	0.250	0.750	0.238	0.800	0.000
a_{11}	1.000	0.250	0.238	0.800	0.750
a_{12}	0.750	0.644	1.000	0.800	0.500

4.3 Compare the relationship matrix

The data are arranged in the order of the criterion weights, and the data are processed using equation (2) to obtain the cumulative transformation matrix. Then, the data in the cumulative transformation matrix are compared row by row, and ifi each data in the row is greater than or equal to the value in thej in the first row, the value of $r_{ij} = 1$ otherwise$r_{ij} = 0$ The comparison relationship matrix$R = (r_{ij})_{m\times m}$ as shown in table 3.

Table 3 Comparative relationship matrix

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
a_1	1	1	1	0	1	1	0	0	1	0	0	0
a_2	0	1	0	0	1	1	0	0	1	0	0	0
a_3	0	0	1	0	0	1	0	0	1	0	0	0
a_4	0	0	0	1	1	1	0	0	1	0	0	0
a_5	0	0	0	0	1	0	0	0	0	0	0	0
a_6	0	0	0	0	0	1	0	0	0	0	0	0
a_7	0	0	0	0	0	0	1	0	1	0	0	0
a_8	0	0	0	0	1	1	0	1	1	0	0	0
a_9	0	0	0	0	0	0	0	0	1	0	0	0
a_{10}	0	0	0	0	0	0	0	0	1	1	0	0
a_{11}	0	0	0	0	1	0	0	0	1	0	1	0
a_{12}	1	1	1	1	1	1	1	1	1	1	1	1

4.4 Hasse matrix and Hasse diagram

The cumulative transformation matrix can be transformed into Hasse matrix by using equation (3), and the Hasse matrix can be converted into Hasse diagram by using the Hasse diagram drawing method given in the literature[17]. The Hasse diagram drawing method given in the literature is used to convert the Hasse matrix into the Hasse diagram, which is a streamlined version of the directed graph, and can reflect the sequential relationship between the schemes more intuitively, as shown in Fig. 3.

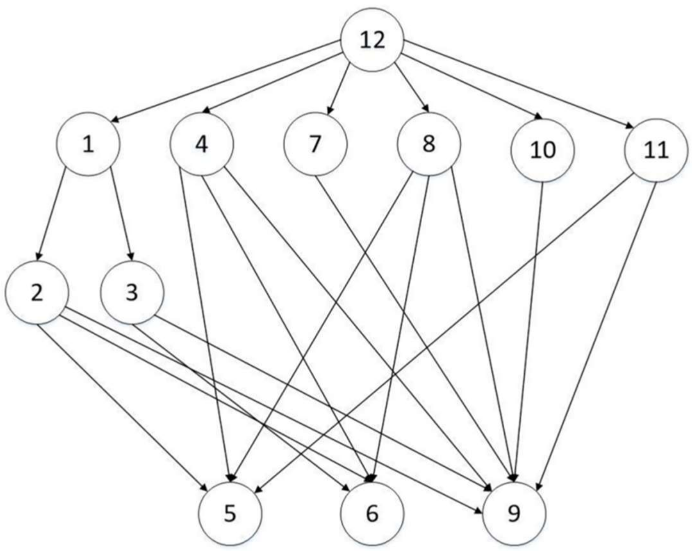

Figure 3 Hasse diagram

4.5 Structured interpretation of Hasse diagrams

Observing the Hasse diagram, it is clear that the 12 solutions are divided into four hierarchical levels. According to the partial order set theory, the upper level of the hierarchy scheme is superior to the lower level. The first hierarchy is $\{A_{12}\}$, the second hierarchy is $\{A_1, A_4, A_7, A_8, A_{10}, A_{11}\}$, the third level is $\{A_2, A_3\}$, and the fourth level is $\{A_5, A_6, A_9\}$. Based on the comparative relationship matrix, the alternatives are calculated using equation (5)$hav(x)$, and the specific results are shown in the table 4. With the help of$hav(x)$ it is possible to rank the advantages and disadvantages of the options in the same tier. According to$hav(x)$ linear ranking, the results of ranking different options are$a_{12} > a_{10} = a_7 > a_{11} > a_8 = a_4 > a_1 > a_3 > a_2 > a_9 > a_6 = a_5$.

Table 4 Linear ranking results

Serial number	Programs	$hav(x)$
1	a_1	9.75
2	a_4	8.67
3	a_8	8.67
4	a_{11}	7.80
5	a_2	7.43
6	a_3	6.50
7	a_7	6.50
8	a_{10}	6.50
9	a_5	1.86
10	a_6	1.86
11	a_9	1.18
12	a_{12}	1.00

4.6 Analysis of evaluation results

The data were processed using the method in literature 19 and the results obtained were $a_8 \geq a_9$,$a_1 \geq a_2$,$a_3 \geq a_4 \geq a_5$,$a_{10} \geq a_{12}$,$a_{10} \geq a_{11}$. The method in that paper can only produce a comparison of the advantages and disadvantages of some of the programs, while the partial order set used in this paper can produce the evaluation results of all the programs. Comparing the ranking results obtained in this paper with those in the paper, it can be found that the overall evaluation results obtained by the two methods are basically the same, and only some of the evaluation results of the program are slightly different, which is due to the fact that the method in this paper is only to obtain the weight ranking, without the specific weight value, the partial order structure is more stable, and the original comparable relationship allows the weight value to be slightly changed, and the model is more elastic and robust for the evaluation of the uncertainty and fuzzy problems, such as the evaluation of the program. The model is more flexible and robust. In addition, the method in this paper can also be used to calculate the height value of the method of the same level of samples to realize the re-ordering, and its sorting identification is more robust and reliable. The accuracy and reliability of the prediction results of the partial order set method also proves that it is feasible and effective to apply the partial order set theory to the siting of the suburban barn base program.

5 Conclusions

(1) The partial-order set decision evaluation method eliminates the complicated and tedious process of determining indicator weights, and also avoids the situation that the indicator weights cannot be determined due to various factors, and is able to determine the stability of the weight order of the evaluation criteria with the help of more methods, which has good robustness and can reflect the hierarchical information of the candidate solutions and better meets the needs of actual site selection.

(2) The site selection of suburban silo bases is carried out by using partial order set. The effectiveness of the method is verified by arithmetic examples, and the resulting Hasse diagram can visually reflect the advantages and disadvantages of each alternative, which provides an effective new method for siting suburban silo bases.

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