Hierarchy Analysis Technique in Solving the Problem of Choosing a Place to Build the Incinerator Plant

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Abstract. Approach to choose a place for the incinerator plant is considered in the paper. One of the ways to solve the problem of continuous growth of household and industrial waste in the world is construction of incinerators. In Russia, there is still a great fear that the incineration of waste will dramatically worsen the environmental situation. It is significant to take into consideration the cost of construction, the necessary conditions for construction and the opinion of citizens when choosing the appropriate location of the plant. Since this problem is multi-criterion, the method of hierarchy analysis was suggested to consider the site selection. This approach refers to the problem of decision-making in conditions of certainty, but in a situation when the quantitative indicators are determined on the basis of the scale of preferences and on the basis of feelings and emotions. The stages of solving problem with the help described method are described. The hierarchy analysis technique was demonstrated by the example of the task to find a place for the location of the waste incineration plant

1. Introduction

Modern cities, both in the world and in Russia, are choking on huge volumes of garbage produced. According to statistics, an average of 250 kg of garbage accumulates per inhabitant per year. The city with a million people accumulates up to 250 million kg of garbage a year [1, 2]. Thus, the issue of waste disposal is a very pressing issue. The overwhelming amount of household waste is taken to special landfills, which are located near the city. Some of them are located even on the territory of the city. Such landfills have many disadvantages, such as air and groundwater pollution, and the spread of unpleasant odors, infections and fire hazards. One of the modern approaches to solve the problem of increasing large landfills city is the construction of incinerators. When choosing a site for construction of the incinerator, it is needed to take into account a number of criteria. The main ones are availability of the required area and appropriate infrastructure. Also a distance to residential buildings according to standards and regulations is a strongly required factor. So a multicriteria problem is gotten to solve.

2. Problem setting

The decision maker must consider a variety of factors when solving the task of choosing a site for the construction of an incinerator because of necessity to consider the set of criteria. Thus, when considering the task of construction of the incinerator, one has to be guided not by one criterion, but by some set \( L_i \), \( i=1,\ldots,k \). Each of criteria can tend to either the maximum or minimum value [3, 4]. It is most likely impossible to achieve extreme values for each objective function, in this case some kind of compromise is needed, allowing for the deterioration values of some criteria in comparison with others.
[5-8]. There are various methods to solve multi-criteria tasks that are reduced to two groups [9, 10]. The first group includes methods which are based on the transformation the set of criteria into a single criterion. This can be done by highlighting the main criterion or by convolving all specific criteria into some global one [10]. For example it may be represented by expression (1), where values of coefficients are set by experts and should satisfy the condition (2).

\[ F(x) = \sum_{i=1}^{k} a_i \cdot f_i(x). \]  

(1)

\[ \sum_{i=1}^{k} a_i = 1 \]  

(2)

The second group includes the methods which are based on the search for solutions based on the Pareto set [10, 11]. Usually, they are the techniques which use method of compromises, search for an ideal point, and method of analyzing hierarchies. During the construction of the incinerator, it is necessary to take into account opinion of experts [12, 13]. The set of criteria is exposed to comparative assessment using the scale of preferences. In this case, hierarchy analysis technique is the most suitable for decision making. When this method is used, estimates of criteria or alternatives are considered which are represented in a matrix form. This is a square matrix of pair wise comparisons of alternatives or criteria. Elements of the matrix have the property of inverse symmetry (3).

\[ a_{ij} = 1/a_{ji} \]  

(3)

The element \( a_{ij} \) of matrix represents criteria number \( i \) assessment relatively to criteria number \( j \). Elements of matrix are evaluated by numbers from 1 to 9 [11, 12]. They are set by experts. The value equal to 1 signifies that criteria number \( i \) and criteria number \( j \) have equal importance. If the value is equal to 9, it means that criteria number \( i \) has maximal superiority relatively to criteria number \( j \). Then the values \( a_{ij} \) are considered according to (4). Suppose there are \( C_1, C_2, \ldots, C_m \). If they represent some set of criteria, then the preference matrix is set according to each criteria [13, 14]. Calculated values become the elements of the matrix.

\[ a_{ij} = w_i / w_j \]  

(4)

The values of weights are set by experts using the scale of preferences both on types of criteria or on alternative offers in accordance with a given goal. After that the preferences table is made [15, 16]. The vector \( K \) is defined on the base expressions (5) and (6).

\[ d_i = \prod_{j=1}^{n} a_{ij}, \quad i = 1, 2, \ldots, n \]  

(5)

\[ K_i = \sqrt[n]{d_i}, \quad i = 1, 2, \ldots, n \]  

(6)

The elements of vector \( V \) are defined using formula (7).

\[ V_i = \frac{k}{\sum_{i=1}^{n} K_i} \]  

(7)
The result of hierarchy analysis technique is a tree of goals, which can have several levels of hierarchy [17,18], as it is shown in Fig.1. There elements $R_i$ are solutions and $V_{ij}$ are weights. Evaluation of an alternative solution $R$ in general form is made according to the formula (8).

$$R_i = \sum_{j=1}^{n} P_i \cdot V_{ij}, \quad i = 1, n; \quad j = 1, m$$

3. Site selection for construction incineration plant

Let’s consider implementation of hierarchy analysis technique to choose the place for location to build incinerator in Kazan city. Previously, three accommodation options A, B and C were chosen. The first of them (A) is the square nearby Osinovo settlement. It was the most suitable for the investor because of convenient road connection with waste dumps and garbage sorting station in the Levchenko settlement. But exactly this case caused the most population protests. The Reds offered to arrange the plant at the distance more than 10 kilometers from the city (case $B$), but it would raised the cost of the construction. The third location (C) is placed nearby old dump in Samosyrovo. However, this site is located close to the city and the runway of the aviation plant passes here. Among these three cases the most appropriate site should be defined. The criteria are shown in Fig.2.

![Figure 1. Solution tree.](image1)

![Figure 2. Criteria structuring.](image2)

The choice was made three criteria taking into consideration. They were the cost of building, the number of people, who could suffer from adverse ecologic influence and the distance to deliver the waste. The last factor was represented like the time which is needed to convey the waste from the city to the incinerator. Then, using the scale of relative importance, the criteria were compared among themselves. Table 1 confirms that the cost of building and environmental cleanliness are the prefer criteria, to the detriment of the time of garbage collection. According to formulas (6) and (7) vector $K$ and the weights of the criteria were calculated.

| Alternative | Criteria evaluation | $K$ | Weight |
|-------------|---------------------|-----|--------|
| $C1$        | 1                   | 3   | 1.44   | 0.43   |
| $C2$        | 1/3                 | 1   | 0.47   | 0.14   |
| $C3$        | 1                   | 3   | 1.44   | 0.43   |

After that the alternatives were compared according to each criterion. The minimal cost is the main criteria for the investor. The comparison results are shown in the table 2. Estimation of the weight equal
to 0.77 substantiated that the site A is more preferable. The same result was gotten for the time criteria in table 3. Table 4 shows the result of comparison for ecological criteria. In this case the site B became more valuable with the estimation 0.65. Obviously, the farness from the city caused this value.

**Table 2. Result on criteria C1.**

| Alternative | Criteria evaluation | Weight |
|-------------|---------------------|--------|
| A           | 1                   | 7      | 3     | 2.76  | 0.77  |
| B           | 1/7                 | 1      | 1/3   | 0.36  | 0.10  |
| C           | 1/3                 | 1/3    | 1     | 0.47  | 0.13  |

**Table 3. Result on criteria C2.**

| Alternative | Criteria evaluation | Weight |
|-------------|---------------------|--------|
| A           | 1                   | 5      | 2     | 10.00 | 0.43  |
| B           | 1/3                 | 1      | 1/3   | 0.10  | 0.14  |
| C           | 1/2                 | 1/5    | 1     | 0.20  | 0.18  |

**Table 4. Result on criteria C3.**

| Alternative | Criteria evaluation | Weight |
|-------------|---------------------|--------|
| A           | 1                   | 1/3    | 2     | 0.87  | 0.23  |
| B           | 3                   | 1      | 5     | 2.47  | 0.65  |
| C           | 1/2                 | 1/5    | 1     | 0.46  | 0.12  |

At the last stage the hierarchical structure was built. It is represented in Fig. 3. The formula (8) is used to estimate the importance coefficients. The hierarchical structure as result of the synthesis of the coefficients of importance is presented in Fig. 3.

The resulting values of evaluation are the following

\[
R_A = 0.43 \times 0.67 + 0.14 \times 0.63 + 0.43 \times 0.24 = 0.3735
\]

\[
R_B = 0.43 \times 0.63 + 0.14 \times 0.03 + 0.43 \times 0.34 = 0.2887
\]

\[
R_C = 0.43 \times 0.23 + 0.14 \times 0.65 + 0.43 \times 0.12 = 0.1102
\]

The result have shown that the site A became the most suitable to locate the incinerator for Kazan city.
4. Conclusion
The problem of clogging up modern cities with huge volumes of garbage produced and leading to pollution of the environment, in many developed countries is solved with the help of waste incineration plants. This concept has been adopted in Russia to implement in the cities Moscow, St. Petersburg and Kazan. The appearance in the vicinity of the city of high-tech, energy-intensive incinerators are a new unexplored factor, which causes active protests from the population because of fear for environmental degradation. Therefore, an important task is to select the appropriate site for the construction of the incinerator. Since the construction task is multicriteria, the hierarchy analysis technique was chosen to support decision-making. Using the example of construction of an incinerator in Kazan, an analysis and selection of a suitable site was carried out based on three criteria - cost, time of garbage collection and the number of people who may be in a zone of unfavorable environmental conditions.

Thus, the hierarchy analysis method is applicable in the case when the solution of the optimization problem fails to use classical exact mathematical methods. Usually, these are situations where the outcome of the decision is influenced by the opinion of the interested or protesting persons, competitors, political situations, ambitions of officials and etc. In this case, it is more appropriate to use the methods of the analytical hierarchy based on expert assessments in combination with analytical calculations. On the basis of this method and the considered above problem of the incinerator construction, this approach can be proposed for solving such tasks as choosing a place for building a new industrial centre shopping center, building a new industrial center, a sports ground, a school and others.

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