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Construction Site Layout Evaluation by Intuitionistic Fuzzy TOPSIS Model

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Abstract. Effective construction site layout planning (CSLP) shall improve construction operations efficiently and enhance work environment safety. The majority researches works on CSLP focused on developing different algorithms and program to generate site layout alternatives using quantitative and qualitative factors involved in the interaction flows. However, some qualitative factors, such as security and noise control are not taken into consideration. This study proposed intuitionistic fuzzy TOPSIS method to evaluate and select the best site layout from site layout alternatives in terms of the project-specific attributes, which are neglected and hard to quantify in generating site layout alternatives. The results show that the proposed method improves the quality of decision making in evaluation and selection of the best construction site layout.

Introduction

An effective CSLP is vital to a construction project as it can improve efficient operations such as minimize travel time, decrease materials handling time by avoiding the obstruction of materials as well as plant movements and ensure safety of a site working environment. Hence, many researchers used many different algorithms and computer programs [1, 2, 3] to address the CSLP problems.

Artificial intelligence (AI), genetic algorithm (GA) and ant colony optimization (ACO) algorithm were being employed commonly to solve the CSLP problems in recent years. Tommelein [1] proposed an expert system (SightPlan) to layout out temporary facilities on construction sites and applied the SightPlan into two case studies concerning power plant construction. GA is the mostly used algorithm to solve CSLP problems. Li and Love [2] employed GA to solve equal-area and unequal-area CSLP problem respectively. The applications of ACO algorithm to solve CSLP problems started from 2006. Samdani, Bhakal and Singh [3] formulated CSLP problem as a combinatorial optimization problem with the objective function of minimizing the total cost of construction and interactive cost of assigning facilities into different locations.

In the research of CSLP problems, these algorithms commonly considered the quantitative factors, while other attributes of a good construction site layout, such as safety, security and noise control were generally neglected. Hence, the research gap i.e. how to evaluate and select the final construction site layout from the construction site layout alternatives generated by the advanced algorithms in terms of some qualitative attributes is neglected when generating the site layout alternatives. This study aims to propose a multiple attributes decision making (MADM) model using intuitionistic fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to evaluate and select optimal construction site layout alternatives from the generated construction site layout alternatives in terms of ten essential project-specific evaluation attributes. The results show that the proposed method improves the quality of decision making in evaluation and selection of the best construction site layout.

Intuitinistic Fuzzy TOPSIS

Intuitionistic fuzzy sets (IFS), which are the extension of traditional fuzzy sets [4], constitute a generalization of the concept of fuzzy sets. The merit of this method is conjoining intuitionistic fuzzy set to TOPSIS to overcome the limitations of traditional fuzzy set [5] in defining imprecise and uncertain situations by membership functions.

Based on the principle of choosing the best alternative which has the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative-ideal solution (NIS), TOPSIS was proposed by Hwang and Yoon [6] to solve MADM problems. Inspired by the work of Li [7], who use linear program to calculate optimal weights between the attributes instead of personnel preference to avoid evident preference on some alternatives and the research works of IFS and TOPSIS done by Tan and Zhang [8], the proposed Intuitionistic Fuzzy TOPSIS method adopted in this research can be realized by the following successive steps:

Step 1. Calculate intuitionistic fuzzy set decision-making matrix D.

$$\widetilde{D} = \begin{array}{c} \\ x_1 \\ x_2 \\ \cdots \\ x_n \end{array} \begin{array}{c} \begin{array}{cccc} a_1 & a_2 & \cdots & a_m \end{array} \\ \begin{bmatrix} \widetilde{r}_{11} & \widetilde{r}_{12} & \cdots & \widetilde{r}_{1m} \\ \widetilde{r}_{21} & \widetilde{r}_{22} & \cdots & \widetilde{r}_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{r}_{n1} & \widetilde{r}_{n2} & \cdots & \widetilde{r}_{nm} \end{bmatrix} \end{array}$$

$$= \begin{array}{c} \\ x_1 \\ x_2 \\ \cdots \\ x_n \end{array} \begin{array}{c} \begin{array}{cccc} a_1 & a_2 & \cdots & a_m \end{array} \\ \begin{bmatrix} (\mu_{11},\nu_{11}) & (\mu_{12},\nu_{12}) & \cdots & (\mu_{1m},\nu_{1m}) \\ (\mu_{21},\nu_{21}) & (\mu_{22},\nu_{22}) & \cdots & (\mu_{2m},\nu_{2m}) \\ \vdots & \vdots & \vdots & \vdots \\ (\mu_{n1},\nu_{n1}) & (\mu_{n2},\nu_{n2}) & \cdots & (\mu_{nm},\nu_{nm}) \end{bmatrix} \end{array} \tag{1}$$

$$\widetilde{W} = [\widetilde{w}_1 \quad \widetilde{w}_2 \quad \cdots \quad \widetilde{w}_m] \tag{2}$$

Where an alternative set $X = [x_1, x_2, \ldots, x_n]$ consists of n alternative candidates in which the most preferred alternative need to be selected, a attribute set A can be expressed as $A = [a_1, a_2, \ldots, a_m]$, which is based on m attributes, each alternative candidate's performance is evaluated; $\widetilde{r}_{ij}, (i = 1,2,\ldots,n, j = 1,2,\ldots,m)$ is the rating of alternative candidate x_i with respect to the attribute a_j; μ_{ij} , ($0 \le \mu_{ij} \le 1$) and ν_{ij} ($0 \le \nu_{ij} \le 1$) are the degree of membership and the degree of non-membership of the alternative candidate x_i with respect to the attribute a_j under the concept of intuitionistic fuzzy set respectively, where $0 \le \mu_{ij} + \nu_{ij} \le 1$. $\widetilde{w}_j (j = 1,2,\ldots,m)$ is the weight of the attribute a_j. $\widetilde{D}$ and $\widetilde{W}$ are the intuitionistic fuzzy decision matrix and weight vector respectively.

Step 2. Calculate the attribute weight.

The evaluation of alternatives in term of attribute is an IFS, which can be denoted as $X = \{< x_i, \mu_{ij}, \nu_{ij}, \pi_{ij} >\}$, where intuitionistic index $\pi_{ij} = 1 - \mu_{ij} - \nu_{ij}$ is the uncertainty membership of alternative candidate x_i with respect to the attribute a_j, which will bias decision maker's choice. The best result of μ_{ij} will increase to $\mu_{ij} + \pi_{ij}$ if the decision maker considers the situation in an optimistic way. So the decision maker's 'positive' evaluation will fall into the interval $[\mu_{ij}, \mu_{ij} + \pi_{ij}]$. Similarly, the decision maker's 'negative' evaluation will fall into the interval $[\nu_{ij}, \nu_{ij} + \pi_{ij}]$.

As for the attribute weight, let α_j, β_j and τ_j to be the degree of membership, the degree of non-membership and intuititonistic index of the fuzzy concept of 'importance' of the attribute a_j respectively, where $\tau_j = 1-\alpha_j-\beta_j$. The weight $\widetilde{w}_j$ ($0 \le \widetilde{w}_j \le 1, \sum_{j=1}^{m}\widetilde{w}_j = 1$) lies in the closed interval $[\alpha_j, \alpha_j+\tau_j]$ if the decision maker takes into consideration of τ_j.

In order to get PIS, the alternative should fulfill the following equations:

$$\max\{\sum_{j=1}^{m}(\mu_{ij}+\pi_{ij})\cdot\widetilde{w}_j\}$$
$$s.t\ \begin{cases}\alpha_j \le \widetilde{w}_j \le \alpha_j+\tau_j, j=1,2,\ldots,m \\ \sum_{j=1}^{m}\widetilde{w}_j = 1\end{cases} \tag{3}$$

$$\min\{\sum_{j=1}^{m}\nu_{ij}\cdot\widetilde{w}_j\}$$
$$s.t\ \begin{cases}\alpha_j \le \widetilde{w}_j \le \alpha_j+\tau_j, j=1,2,\ldots,m \\ \sum_{j=1}^{m}\widetilde{w}_j = 1\end{cases} \tag{4}$$

Where π_{ij} =1-μ_{ij}-ν_{ij}, is the degree of hesitation of the alternative candidate x_i with respect to the attribute a_j under the concept of IFS.

Integrate equation (3) with (4), we have the following equation

$$\max\{\sum_{j=1}^{m}(\mu_{ij}+\pi_{ij}-\nu_{ij})\cdot\widetilde{w}_j\}$$
$$s.t\ \begin{cases}\alpha_j \le \widetilde{w}_j \le \alpha_j+\tau_j, j=1,2,\ldots,m \\ \sum_{j=1}^{m}\widetilde{w}_j = 1\end{cases} \tag{5}$$

Based on the equation (5), the attribute weight problem can be solved by transforming into a linear programming.

Step 3. Calculate weighted IFS decision-making matrix $\widetilde{D}$ (See equations (1) and (2))

$$\bar{r}_{ij} = r_{ij}\cdot\widetilde{w}_j, i=1,2,\ldots,n; j=1,2,\ldots,m. \tag{6}$$

Step 4. Identify the positive-ideal intuitionistic fuzzy solutions (A^+) and negative-ideal intuitionistic fuzzy solutions (A^-)

$$A^+ = \{(\max_j \mu_{ij},),(\min_j \nu_{ij}), j=1,2,\ldots,m | i=1,2,\ldots,n\} \tag{7}$$

$$A^- = \{(\min_j \mu_{ij},),(\max_j \nu_{ij}), j=1,2,\ldots,m | i=1,2,\ldots,n\} \tag{8}$$

Step 5. Calculate the distance of each alternative to positive-ideal and negative-ideal intuitionistic fuzzy solutions

In this research, the distances between alternative candidates and positive-ideal and negative-ideal intuitionistic fuzzy solutions are measured by Euclidean distance. The distances from positive-ideal and negative-ideal intuitionistic fuzzy solutions are denoted as E^+ and E^- respectively.

Step 6. Calculate the closeness coefficient of each alternative

The closeness coefficient C_i of each alternative can be calculated by

$$C_i = E_i^- /(E_i^+ + E_i^-), i = 1,2,\dots,n. \tag{9}$$

Step 7. Rank the preference order of alternatives

A set of alternatives shall be ranked in accordance to the descending order of C_i. The best alternative is the one with the highest relative C_i.

Case Study

The residential building project was employed to verify the proposed MADM model using intuitionistic fuzzy TOPSIS. There were four residential building (building 1, building 2, building 3 and building 4) in the construction site. The temporary facilities located in the construction site are sample room, equipment maintenance plant, electrician hut, tool shed, reinforcement bending yard, carpentry workshop, site office, security hut at site entrance, security hut at exit, two material lay-down areas, two tower cranes, three material hoists. In this case study, the management team needed to select the best site layout from the final six site layout alternatives. The 'best' construction site layout needed to be evaluated and selected in terms of the project-specific attributes (See Table 1). The ten essential attributes were deduced from 23 attributes commonly found in literatures via the 5-point scale questionnaire, which was sent to the key personnel in the selected building project. It was designed to capture the perception of the extent to which the respondents considered these attributes were important in evaluating construction site layouts of the building project.

Table 1 Importance index and rank order of the attributes for the case of residence building used in this case.

Attribute No.	Attributes
1	Efficient movement of materials
2	Tie-in with external transportation
3	Good space utilization and configuration
4	Ease of expansion
5	Safety
6	Effective movement of personnel
7	Efficient operations
8	Frequency and seriousness of potential breakdowns
9	Security
10	Easy supervision and control

In terms of the surveyed under ten essential attributes, IFS of the ten attributes of the construction site layout alternatives was determined. According to the IFS of construction site layout alternatives, A^+ and A^- under the ten essential attributes were determined in accordance with equation (7) and (8) respectively. Having A^+ and A^- determined, the proposed intuitionistic fuzzy TOPSIS method is employed to find the optimal solutions. The optimal construction site layout alternative is the one which has the highest C_i (See Table 2).

Table 2 Rank the alternatives in terms of closeness coefficient of case study

Alternatives	Distances from positive-ideal intuitionistic fuzzy solutions E^+	Distances from negative-ideal intuitionistic fuzzy solutions E^-	Closeness coefficient of each alternative C_i	Ranking
L1	0.093	0.249	0.727	3
L2	0.011	0.310	0.966	1
L3	0.030	0.295	0.908	2
L4	0.270	0.053	0.165	6
L5	0.122	0.205	0.628	5
L6	0.109	0.226	0.675	4

The results of the preference ranking order of the six alternatives is in descending order of L2>L3>L1>L6>L5>L4. Therefore, Alternative L2 (See Fig. 1), which has the highest closeness coefficient (0.966) among the six alternatives, was selected as the output of the proposed CSLP decision-making system. In L2, the 1# and 2# material lay-down areas are located around Building 3 and Building 4, and Building 1 and Building 2, respectively. Thus the #1 material lay-down area could service Building 3 and Building 4 and the #2 material lay-down area could service Building 1 and Building 2 effectively. The centralized locations for all the facilities in the middle area between the four buildings should boost the construction operation efficiency. The compact arrangement of the facilities should facilitate the construction site expansion on the left-hand side area of the construction site.

The merits of TOPSIS are simplicity, easy-understanding, easy-implement, no goal formulation and need not aware of goals and priority. Moreover, in TOPSIS, there is no need to compare the relative importance degree and figure out the exact numerical value to express the relative importance degree.

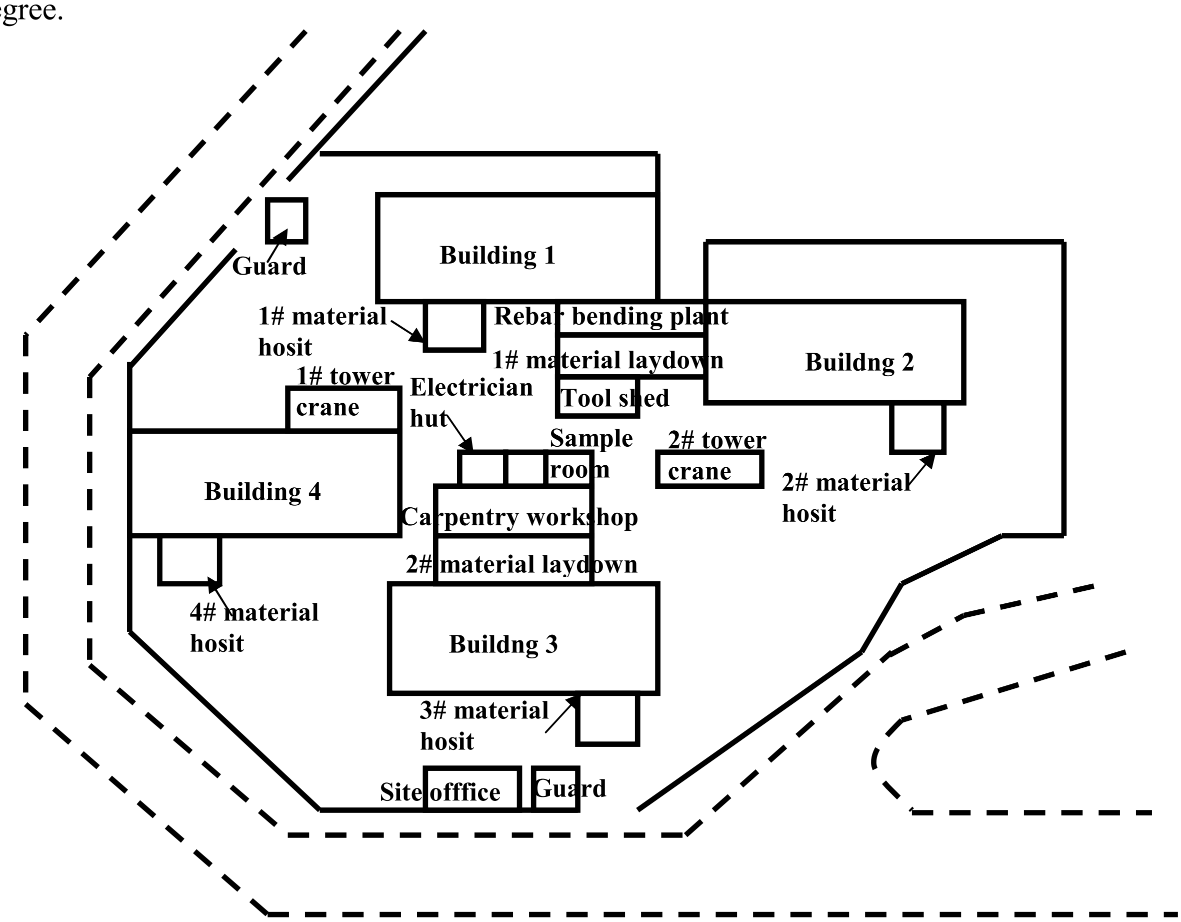

Fig.2 Construction site layout alternative-L2

Conclusion

This paper proposed the modified intuitionistic fuzzy TOPSIS to evaluate and select the optimal construction site layout from the six construction site layout alternatives in terms of the ten essential project-specific attributes, which are out of consideration during site layout alternative generating process. A residential building was used to verify the applicability of the intuitionsitic fuzzy TOPSIS to quantitatively evaluate site layout alternatives. Finally, construction site layout L2 was selected for its ranking top one among the total six site layout alternatives. Integration of intuitionistic fuzzy set and TOPSIS can magnify the advantage of intuitionistic fuzzy set and TOPSIS. Intuitionistic fuzzy TOPSIS is employed in order to reveal the potentiality of this method to improve the efficiency and quality of decision making involved in the field of construction management.

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