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APPLICATION OF A HYBRID MCDM METHOD IN CONSTRUCTION LOGISTICS

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Abstract: Construction industry is one of the world leading industries that is why optimizing its processes is indispensable. Layout planning is an essential and determinative task of construction logistics. This paper is devoted to this problem and it is organized as follows: a chapter unfolds the criteria of site layout planning considered relevant by the authors. Then survey is conducted on Multi-criteria decision making (MCDM), fuzzy theory and their construction related researches. Next the authors propose a new method which is appropriate for solving the layout selection problem in construction sites, based on the mixture of hesitant fuzzy sets and well-known KIPA method, called HFS-KIPA. After the detailed description of the technique and its advantages, it is illustrated with an example taken from a close related article. Finally, results and future research directions are summarized.

Keywords: Construction logistics, Layout planning, MCDM, fuzzy

1. Introduction

Construction site layout planning (CSLP) has been recognized as a critical step in construction planning by practitioners and researchers. Most construction resources require space on site. This is the case for materials and equipment, support facilities (e.g., trailers or parking lots), and demarcated areas (e.g., laydown areas, roads, or work space), but also for obstacles (e.g., trees or existing buildings). Layout planning is to allocate site space to resources so that they can be accessible and functional during construction. CSLP involves identifying, sizing, and on-site-positioning of temporary facilities which may include security fences, access roads, storage sheds, field offices, fabrication shops, sanitary facilities, electric power service, stockpiles of excavation, and batch plants [1]. It is recognized that a good layout has a significant impact on cost, timeliness, operational efficiency and the quality of construction, which manifests on the larger and more remote projects. Improper layout can result in a loss of productivity due to excessive travel time for laborers and equipment, or inefficiencies due to safety concerns. An important aim of the layout planning is to ensure continuous flow, which is one of the five principles of lean production. Reduction of bottlenecks, flexibility handling, and production, since in construction sites there are usually a lot of changeovers, and unforeseeable events. In spite of its potential consequences, construction site layout generally receives little advanced planning, and hardly any planning during construction. It is often determined in an ad hoc manner at the time the siting requirement arises. Therefore, an effective construction site layout planning (CSLP) is utmost importance for the success of a construction project. CSLP problems can be broadly divided into static and dynamic ones [2]. Creating layouts that change over time as construction progresses is termed dynamic layout planning. Dynamic layout planning enhances the efficiency of construction operations.

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2. Criteria in construction site layout planning

The first step is to define the criteria, which will be used in the chosen MCMD method. The number and the types of the criteria determine the applicable MCMD methods. From the mathematical point of view there are two main types of criteria: quantitative criteria and qualitative criteria. Quantitative methods consider the actual transportation cost per the amount of materials moved measured by mass each two locations [3]. Qualitative methods, on the other hand, consider a subjective numerical proximity weight to express the desirability of having any two facilities close to each other on the layout, or safety of the layout. Both methods are used in this study. According to [2], [4] these criteria are defined by:

- C1 Safety/OSH/fire protection aspects: Safety of construction operations is usually affected by many factors. A comprehensive literature review and several field studies were conducted in order to explore and identify relevant and important practical considerations that can enhance the safety of construction operations [5]. A fire protection specialist should approve the layouts.
- C2 Operating costs: Operating costs become an important aspect if you have a long term project, in this type of constructions operating costs are more important than set-up costs.
- C3 Installation costs (set-up cost): The investment which is needed to build up the given construction site layout. It includes all the cost. The initial set-up cost will affect the tender price and the long term running cost.
- C4 Traveled distance by human labour: The sum of the distances that the employees should take during the operations.
- C5 Traveled distance by machines: The cost of the predictable displacements of the material handling equipment (mixers, cranes, excavator etc.) during the construction.
- C6 Material handling performance: The flow of raw materials, WIP (work in progress) and finished products between locations in the construction site. Material flow can be measured by cost multiplied by distance (measuring by unit is not applicable because of bulk materials) like „kg*m" or „t*m", or if we have diversified the transportation cost for some material, then we can measure it by transportation cost.
- C7 Possibility of upgrading: Usually during the project there are delays, therefore we need more capacities to keep the deadline, in this situation upgrading possibilities are emphatic.
- C8 Transport connections: The proximity of highways, roads, streets, and overpasses is an important aspect when you choose the optimal layout. Transportation ways and connections can determine the bottlenecks of a system [4].
- C9 Machine/workspace availability: It shows how easily machines can be moved out, or maintained.
- C10 Amount of onsite stockable supply: If there are huge supply distances in the project, storage capacity can become very important.

We defined ten criteria, six quantitative and four qualitative, therefore we need a MCDM method which can manage both types of criteria.

3. Multi-criteria decision making methods

In the following chapter the authors give a brief introduction about the multi-criteria decision making (MCDM) methods especially the ones which are applied in construction industry.

3.1 Analytic Hierarchy Process (AHP). The Analytic Hierarchy Process is a method based on pairwise comparison proposed by [6]. It is frequently applied in group decision making. The method describes the decision making problem as a tree, which levels are formed by sub-criteria, criteria and the goal (Figure 1).

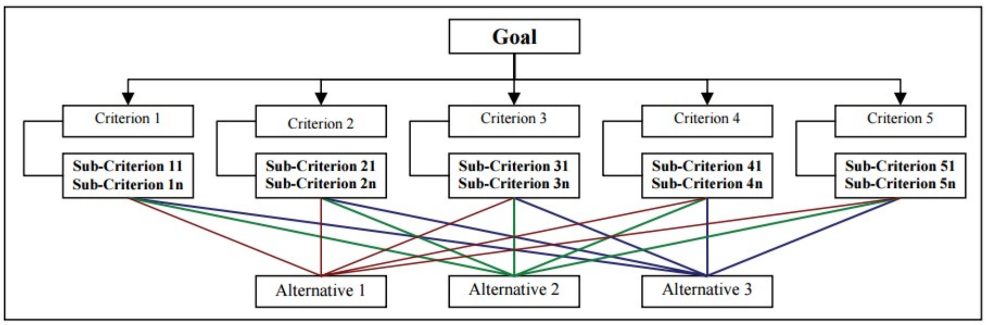


Figure 1. AHP Hierarchy [7]

The main steps of AHP:

1. Constructing the hierarchical system
2. Pairwise comparison of attributes in order to form reciprocal matrix
3. Estimating relative weights
4. Alternative selection by aggregating weights

It is generally applied for the determination of criterion weights, the main drawbacks are referred (as in case of many other MCDMs) to be rank reversal and non monotonic property.

AHP is still one of the basic components of nowadays complex analyzes of constructions, [8] developed a non-destructive test system for concrete structure, while [9] proposed an AHP selection based methodology to support the design phase of earthquake-proof bridges.

3.2 Analytic Network Process (ANP). This method extended the AHP methodology in [10] by the fact the criteria can depend on each other. To get the weights of criteria first a super matrix is constructed by pairwise comparison. Then transforming its columns to unity a weighted one will be built, from which the weights can be derived by raising it to limiting powers. Where strong interdependencies are present ANP should be applied just like the case underground construction technology selection problem investigated by [11].

3.3 ELimination Et Choix Traduisant la REalité (ELECTRE). The acronym of ELimination and Choice Expressing REality stands for a set of methods from which the first one ELECTRE I was introduced by [12]. These methods are frequently referred as outranking methods and they are based on the calculation of the so called concordance and discordance indices. KIPA is an extension of these methods [13]. While with ELECTRE I one can get promising alternatives and partial rankings, ELECTRE II is capable of the complete ranking. ELECTRE III deals with fuzzy in certain extent and establishes an outranking degree. ELECTRE IV simplifies ELECTRE III (there is no weight in case of criteria hard to measure) [14]. Mostly ELECTRE III model is applied in scenarios dealing with construction problems in recent researches [15] [16].

3.4 Preference Ranking Organization METhod for Enrichment of Evaluations (PROMETHEE). PROMETHEE is a family of outranking methods introduced by [17]. These methods are less frequent applied as a single approach in decision problems concerning constructions [18] likely because dealing with numerous criteria it shows a tendency to dilute the explicitness of the result.

3.5 Technique for Order Preferences by similarity to an Ideal Solution (TOPSIS) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The TOPSIS technique aims to find a compromise solution which is the closest to the ideal solution and farthest from the negative ideal solution measuring these factors by Euclidean distance [19]. Major drawback of the method can be the derivation of normalized scales from narrow gap causing the fact of not reflecting the true dominance of alternatives and not appropriate ranking [20]. VIKOR [21] purpose is the same as TOPSIS but it focuses problems with the presence of conflicting criteria. The significant difference between the two methods is in the aggregation approaches, in VIKOR only distance from the ideal solution is represented in the aggregation function, while in TOPSIS distance from the negative ideal too. These methods applied in recent researches like optimal roofing material selection [22] and evaluation of bidding procedure of construction projects [23].

3.6 Other methods. Naturally one can find other less popular methods in the literature ([24], [25]) and the approaches introduced earlier are still just the bases of a complex decision making system. There are lots of hybrid techniques ([26], [27]) combining the basis methods and their advantages (unfortunately often disadvantages too). The main problem of these methods is their newness, inexperience in their use.

[28] makes a more detailed investigation of MCDM methods in construction and by evaluating the paper production so far makes a forecast also about researches in the near future (Figure 2).

3.7 Summary. The most promising methods TOPSIS, ELECTRE and VIKOR methods are similar in the sense they require to pose of criteria's weights. All the listed method suffers from the absence of dealing with uncertainty [29]. There are several theories concerning this problem for example the Grey System Theory proposed by [30]. This theory distinguishes black (no information), white (complete information) and grey (real world) situations and mostly utilized in decision issues related to construction bidding on the field of construction [31] [32]. However the most widespread of these theories are the fuzzy one, which we introduce in the next chapter and later apply in our method as well.

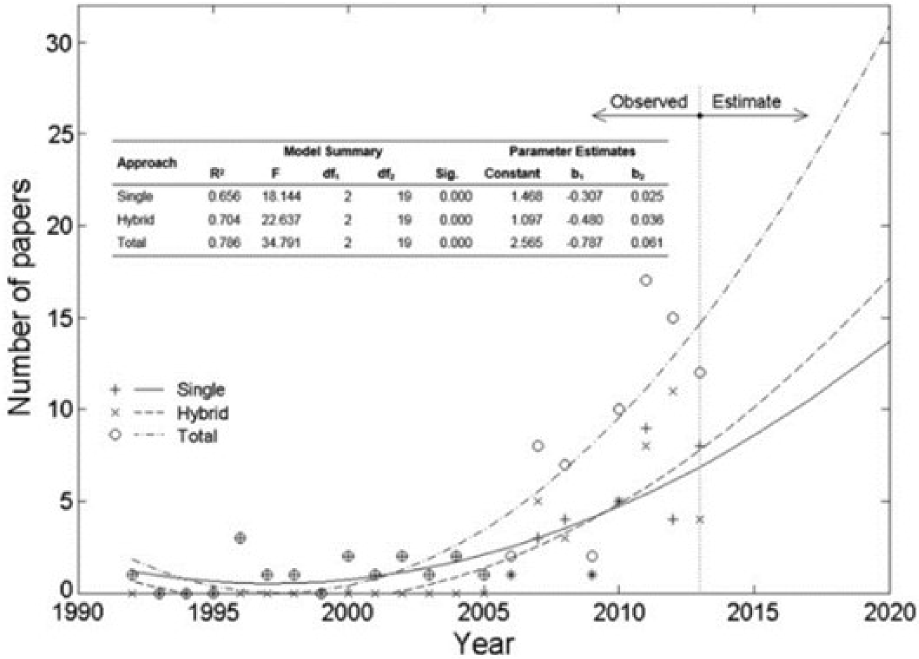


Figure 2. MCDM papers in construction [28]

4. Fuzzy in decision making and support

4.1 The fuzzy concept. Few years after Zadeh created the basics of the fuzzy mathematics in 1965 [33] the first application of the theory in decision making had appeared and [34] it is a highly researched area ever since. Fuzzy logic extends the possible values of binary logic of sets (0,1) to an interval ([0,1]) which expressed by the so called membership function. A set whose elements have degrees of membership is a fuzzy set. A is a fuzzy number in the set of real numbers R, if its membership function is:

$$\mu_A = \begin{cases} 0, & x < a_1, \\ f_A(x), & a_1 \le x \le a_2, \\ 1, & a_2 \le x \le a_3, \\ g_A(x), & a_3 \le x \le a_4, \\ 0, & a_4 < x. \end{cases} \tag{1}$$

where $f_A(x)$ and $g_A(x)$ continuous increasing and decreasing functions called left and right side of the fuzzy number, $a_1, a_2, a_3, a_4 \in R$, $a_1 \le a_2 \le a_3 \le a_4$. [35].

Last we introduce another concept in fuzzy logic which is important for us and for understanding this paper. This is the concept of the linguistic variables. By definition of Zadeh "a variable whose values are not numbers but words or sentences in a natural or artificial language" [36] [37] [38], for example a linguistic variable is the temperature which may have such values as cold, warm, hot. Illustration for the hierarchical structure of linguistic variable age can be seen in Figure 3.

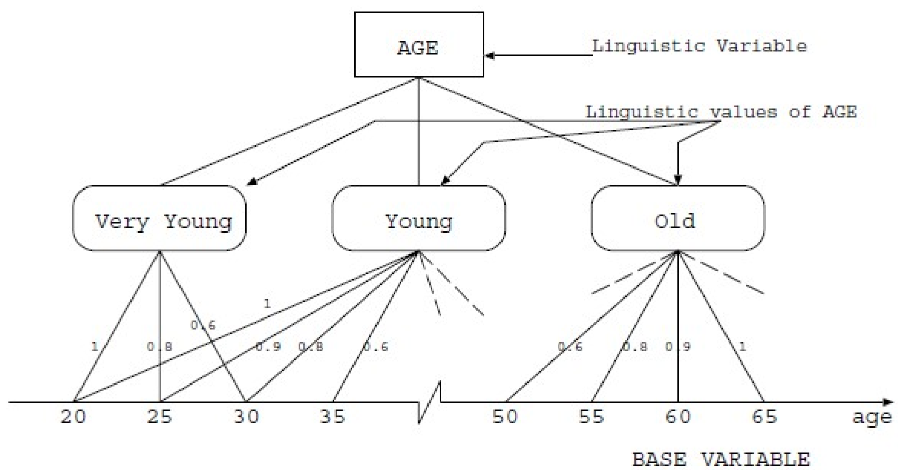


Figure 3. Linguistic variable age [39]

4.2 Fuzzy extensions. The most general applications of fuzzy in decision support are the expert systems. Most of fuzzy based expert systems inputs are linguistic values formulated by experts and after some evaluation of "fuzzy if then rules" and defuzzification the output will be a crisp value [40].

Beside that numerous utilization of fuzzy mathematics are present in the decision making literature. One can find a detailed description about the state of the art fuzzy concepts in [41]. The most significant ones are based the earlier extensions of fuzzy sets:

- intuitionistic fuzzy sets (IFS): considers nonmembership of the elements beside membership degree [42],
- type-2 fuzzy sets (T2FS): uncertainty is present in the definition of membership function due to possibility distribution [43],
- interval-valued fuzzy sets (IVFS): membership degree is given by a closed subinterval [44],
- hesitant fuzzy sets (HFS): there are some possible values which indicates hesitation [45].

There exists research papers which aims to develop new methods based on fuzzy concept instead of extending that, e.g. Fuzzy Decision Maps (FDM) [46] which method allows using fuzzy linguistic values in cognitive maps in order to express relative importance. Over and above there are methodologies that merge one of the methods of

Chapter 2 and the fuzzy paradigm so combining their advantages. For example the fuzzy TOPSIS [47] or fuzzy AHP [48] methods, and our method is similar as well.

4.3 Fuzzy in layout planning. Fuzzy mathematics is just as widespread in specific decision problems for instance layout planning as it is in general cases. There were many successful attempts to apply the concept in different layout planning problems. [49] utilize fuzzy constraint theory for planning the layout of operating theatres in hospitals. The advantages of the method are capability of considering the opinion of more than one decision maker, it is mathematic method for evaluation which also provide analysing possibility too. However drawbacks are also present, because subjectivity still cannot be totally avoided and it requires more tests. In [49] a two stage procedure is proposed for manufacturing facility layout planning. The first stage (facility selection routine) is a kind of fuzzy based expert system mentioned before and in a second stage (facility placement routine) an optimization runs for minimizing the material handling cost (Figure 4).

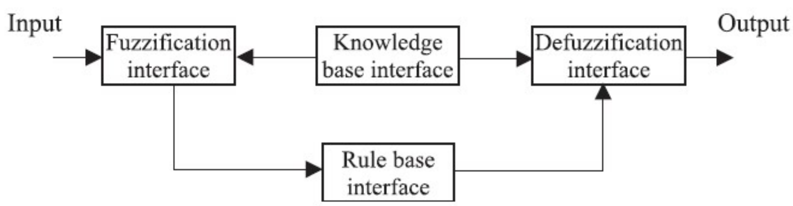


Figure 4. Fuzzy decision support system [50]

Naturally, construction site layout planning is concerned by fuzzy decision support. A non-structural fuzzy decision support system is tested in [51] and the test result showed that it is applicable in initial phase of design for the major site facilities, but it is sensitive to the evaluation factors.

5. Proposed method

Our Multi-criteria Decision-Making Method combines the well-established KIPA method with trapezoidal valued hesitant fuzzy sets, so it integrates their benefits, we call it HFS-KIPA. While KIPA method is a mature and complete technique for multi-criteria evaluation which can include criteria weight calculation too, with the help of hesitant fuzzy sets one can consider multiple decision makers' opinion and if they are trapezoidal valued it can be done in the most generic way. In [52] the author proposed a method which is based on some element of fuzzy theory and KIPA method, however our method completely different from it. The main differences are:

– Our method uses the Guilford method for determining the weight numbers of evaluation criteria instead of fuzzy AHP. Guilford method is proved to be efficient with KIPA insomuch their joint use is frequently referred as "extended KIPA".
– HFS-KIPA aggregates multiple decision makers' evaluation instead of considering just one.

– With the definition of fuzzy numbers trapezoidal valued ones have the functions: $f_A(x) = \frac{x-a_1}{a_2-a_1}$, $g_A(x) = \frac{x-a_4}{a_3-a_4}$, triangular valued ones are just the specific case of it with $a_2 = a_3$.

The steps of HFS-KIPA:

1. Guilford method in order to calculate the weight numbers of evaluation criteria
2. Converting the decision makers' opinion formulated by linguistic terms to linguistic values of trapezoidal fuzzy numbers
3. Composing the hesitant fuzzy decision matrix

$$\tilde{H} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{h}_{11} & \tilde{h}_{12} & \cdots & \tilde{h}_{1n} \\ \tilde{h}_{21} & \tilde{h}_{22} & \cdots & \tilde{h}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{h}_{m1} & \tilde{h}_{m2} & \cdots & \tilde{h}_{mn} \end{bmatrix} \end{array}, \quad (2)$$

where $\{A_1, A_2, \ldots, A_m\}$ set of alternatives, $\{C_1, C_2, \ldots, C_n\}$ set of criteria and $\tilde{h}_{ij}$ is a trapezoidal hesitant fuzzy element.

4. Computing the matrix of expected values

$$E = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} E_{11} & E_{12} & \cdots & E_{1n} \\ E_{21} & E_{22} & \cdots & E_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ E_{m1} & E_{m2} & \cdots & E_{mn} \end{bmatrix} \end{array}, \quad (3)$$

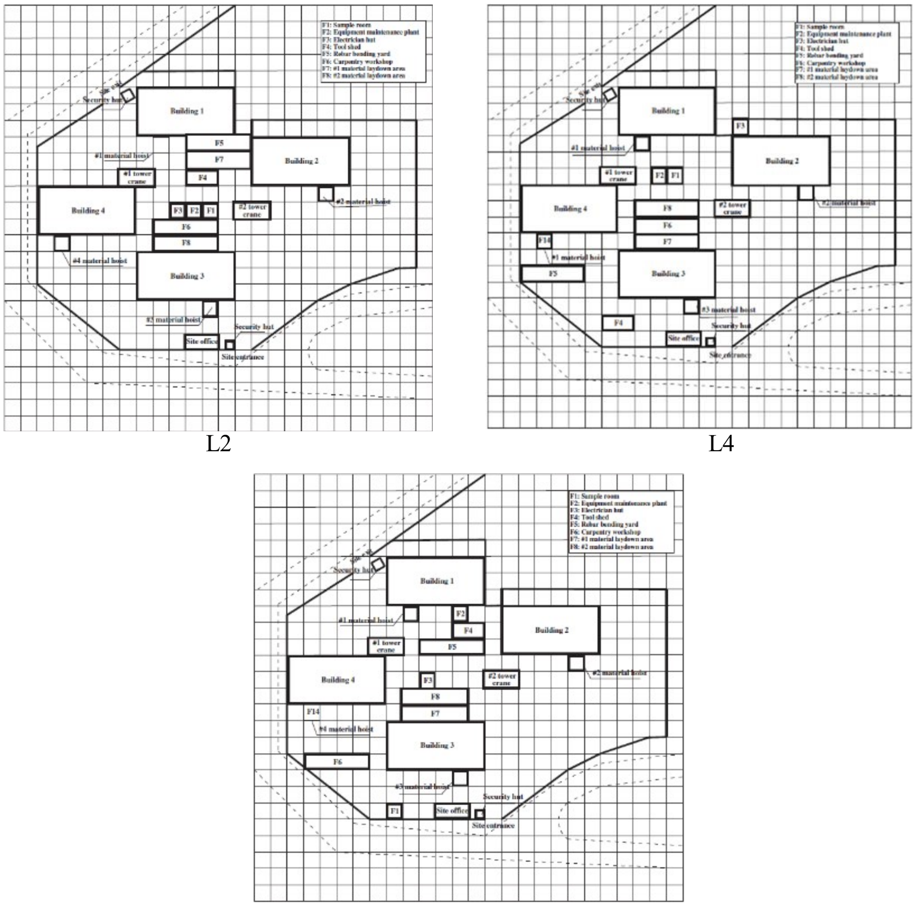
where: $E_{ij} = \left(\frac{1}{4\#\tilde{h}_{ij}}\right) \sum_{\tilde{a}_{ij} \in \tilde{h}_{ij}} \left(a_1^{ij} + a_2^{ij} + a_3^{ij} + a_4^{ij}\right)$ [53]

5. Executing the "narrow KIPA method" on the matrix of expected values

6. Example on the proposed method

The HFS-KIPA method is illustrated on an example taken from [54] in order to be comparable with other methods in the literature. We choose three significantly different layout (and such that are not adjacent in the authors' preference order) respectively L2, L4 and L6 (Figure 5) to construct an example. In this scenario three alternatives and three decision makers and our previously introduced ten criteria are considered.

In the first step Guilford method is used to produce the preference order of the criteria and their weights too. Table I. shows the aggregated preference table and preference values (Z) of each criteria in 0-100 interval scale.



L2 L4

L6

Figure 5. Layout versions in HFS-KIPA example [54]

Table I.

Aggregated preference table

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	Z
C_1	x	3	3	3	3	3	3	3	3	3	100
C_2	0	x	2	3	3	3	3	3	3	3	76
C_3	0	1	x	3	3	3	3	3	3	3	71
C_4	0	0	0	x	1	0	0	0	0	0	0
C_5	0	0	0	2	x	0	1	0	0	0	11
C_6	0	0	0	3	3	x	1	2	0	1	36
C_7	0	0	0	3	2	2	x	2	2	1	41
C_8	0	0	0	3	3	1	1	x	1	1	36
C_9	0	0	0	3	3	3	1	2	x	2	47
C_{10}	0	0	0	3	3	2	2	2	1	x	44

A linear transformation $f(Z) = a \cdot Z + b$ was executed on the scale in order to get unit weight sum.

Table II.

Linguistic values for linguistic terms

Very Low	(0,0,0,0)
Low	(0,0.1,0.2,0.3)
Fairly Low	(0.2,0.3,0.4,0.5)
Fair	(0.4,0.5,0.6,0.7)
Fairly High	(0.6,0.7,0.8,0.9)
High	(0.8,0.9,1,1)
Very High	(1,1,1,1)

The transpose matrix of trapezoidal hesitant fuzzy decision matrix had the form:

{(0.6,0.7,0.8,0.9)}	{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}
{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}
{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}	{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}
{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.2,0.3,0.40.5),(0.4,0.5,0.6,0.7)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}
{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}
{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}
{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.4,0.5,0.6,0.7),(0.8,0.9,1,1)}	{(0,0.1,0.2,0.3),(0.2,0.3,0.4,0.5)}
{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}	{(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}
{(0,0.1,0.2,0.3),(0.4,0.5,0.6,0.7),(0.8,0.9,1,1)}	{(0.2,0.3,0.40.5),(0.4,0.5,0.6,0.7),(0.6,0.7,0.8,0.9)}	{(0,0.1,0.2,0.3),(0.6,0.7,0.8,0.9))}
{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}	{(0.6,0.7,0.8,0.9),(0.8,0.9,1,1)}

This yield the matrix of expected values, which transpose matrix is:

E'=

0.75	0.8375	0.8375
0.8375	0.8375	0.8375
0.8375	0.65	0.8375
0.8375	0.45	0.65
0.8375	0.65	0.65
0.7417	0.65	0.65
0.8375	0.7375	0.35
0.8375	0.65	0.65
0.5417	0.55	0.45
0.8375	0.8375	0.8375

Finally KIPA matrix was constructed which gave us the following preference order result: L2>L4>L6.

7. Conclusion

The layout design problem is a strategic issue and has significant impacts on the efficiency of the manufacturing and the logistic system. The first aim was to collect the main criteria in a construction layout planning. Ten general criteria were collected which are usually important in a layout planning, also in a project there can be other specific criteria. Our Multi-criteria Decision-Making Method combines the well-established KIPA method with trapezoidal valued hesitant fuzzy sets, it integrates the advantages of the two methods, and it aggregates multiple decision makers' evaluation instead of considering just one. Also the evaluation criteria are weighted with the Guilford method. Finally, the method was successfully applied to a practical case, so that the method proposed was proved to be viable and efficient. To develop the method validation is needed, such as applying it in practical cases more times.

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