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LOGISTICS FREIGHT CENTER LOCATIONS DECISION BY USING FUZZY-PROMETHEE

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Abstract. Fuzzy Preference Ranking Organization METHod for Enrichment Evaluation (F-PROMETHEE) was applied for choosing among potential logistics center locations. The method combines the concept of fuzzy sets to represent uncertain information with the PROMETHEE, a subgroup of Multi-Criteria Decision-Making (MCDM) methods. Criteria are identified based on review of scientific and trade literature and inputs received from experts. The suitability of areas have been evaluated on the basis of these criteria. There are substantial uncertainties and subjectivity about site information. Therefore F-PROMETHEE method is preferred. The case study shows that this application provides reasonable results.

Keywords: logistics center; locations selection; MCDM; fuzzy; PROMETHEE.

Introduction

With the increasing development of information technology and modern management theory, logistic centers (freight villages) are becoming more important. In the framework of the on-going economic, political, technical, and technological development within the transport sector, logistic centers are increasingly gaining significance. The locations of logistic centers also have an important impact on logistics activities. Therefore, the location of logistics centers has become an important selection problem. Selecting among reasonable alternatives is defined as a decision making problem. In many decision-making problems, the decision maker likes to pursue more than one goal or consider more than one factor. This desire transforms the decision making problem into a Multi-Objective Decision-Making (MODM) problem or a Multi-Attribute Decision-Making (MADM) problem. These groups of problems all encompass one category defined as Multi-Criteria Decision-Making (MCDM) problems (Nutt 2000; Farahani *et al.* 2010; Brauers, Zavadskas 2008; Rezaeiniya *et al.* 2012; Hashemkhani Zolfani *et al.* 2013a, 2013b; Tamošaitienė *et al.* 2013; Dėjus, Antuchevičienė 2013).

A logistics center is a cluster of quality industrial/intermodal/distribution/logistics buildings located within a secure perimeter, where a range of services are provided by each user (Kayikci 2010). The selection of a logistics center is one of the most important and complex decision-making problems. Selecting the most appropriate location for a logistics center should be considered and evaluated in terms of many influencing factors: this results in a vast amount of information that is mostly uncertain, vague, and imprecise. Many analytical methods for choosing a location for logistics centers combine multi-criteria decision analysis with fuzzy logic. When selecting, it is necessary, first and foremost, to identify the set of influential factors that are relevant to selecting the location of the logistics center. These factors can be both objective and subjective, depending on the basis of the available information. If the available information is numerical or precise, then the factors can be evaluated objectively. If the available information is in a linguistic form, then the factors can be subjective. In order to obtain precise information, a vast amount of studies should be carried out. In this type of problem, the available information is often linguistic; therefore, a fuzzy approach should be used in the selection process of an logistic center location.

Bellman and Zadeh (1970) introduced fuzzy sets into the field of MCDM as an important tool to represent uncertainty and imprecision. Fuzzy-MCDM methods evaluate the alternative ratings and the weight of criteria on imprecision and vagueness expressed by fuzzy numbers (Abbasianjahromi, Rajaie 2012). Wang and Liu (2007) applied fuzzy Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Simi-

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larity to Ideal Solution (TOPSIS); Kayikci (2010) used Fuzzy-AHP and Artificial Neural Network (ANN); Yang *et al.* (2007) used a genetic algorithm in a fuzzy environment; Ghoseiri and Lessan (2008) used Fuzzy-AHP and *ELimination Et Choix Traduisant la REalité* (ELimination and Choice Expressing REality – ELECTRE), and Turskis and Zavadskas (2010) used fuzzy Additive Ratio Assessment (ARAS) method for logistic center location selection. Behzadian *et al.* (2010), Goumas and Lygerou (2000), De Keyser and Peeters (1996), and Zhang *et al.* (2009) stated that Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) is a simple ranking method in conception and application, compared with other methods used for MCDM. Therefore, in this paper, we use the Fuzzy-PROMETHEE method in the selection of a logistic center location.

1. PROMETHEE and Fuzzy-PROMETHEE

The PROMETHEE is a subgroup of the MCDM Methods developed in the early 1980s by Brans *et al.* (1986). They suggested two methodological families: namely, PROMETHEE I for partial ranking and PROMETHEE II for complete ranking. Several years later, other versions of the PROMETHEE methods were developed to tackle more complicated decision-making problems. These versions include PROMETHEE III for ranking based on intervals, PROMETHEE IV for continuous cases, PROMETHEE V for problems with segmentation constraints, PROMETHEE VI for human brain representations, PROMETHEE GDSS for group decision-making, PROMETHEE TRI for sorting problems, and PROMETHEE CLUSTER for nominal classification (Behzadian *et al.* 2010). The success of the PROMETHEE methodology in various applications is attributed to its flexibility and ease of use. The applications of PROMETHEE were categorized into nine areas (Behzadian *et al.* 2010): environmental management, hydrology and water management, business and financial management, chemistry, logistics and transportation, manufacturing and assembly, energy management, social, and other topics (medicine, agriculture, education, design, and sports).

Goumas and Lygerou (2000), and Geldermann *et al.* (2000) extended the PROMETHEE methods to consider fuzzy inputs, fuzzy preferences, and fuzzy weights, in order to rank alternatives. The extended method is defined as F-PROMETHEE. In the F-PROMETHEE method, the performance of each alternative to each criterion is introduced as a fuzzy number. This comes from the fact that, in most cases, the input data cannot be defined within a reasonable degree of accuracy, or it is easy to use linguistic variables for decision makers; in these situations, the usage of fuzzy numbers is considered to be more appropriate. The F-PROMETHEE algorithm given by Geldermann *et al.* (2000) and Zhang *et al.* (2009) has been modified, as given below.

Step 1: Define a suitable preference function $p_k(d_k)$ for each criterion f_k.

Step 2: Define a vector containing the fuzzy weights, each in the form of triangular fuzzy numbers:

$W^T = (w_1, w_2, \dots w_m)$ with $w_k = (m,a,b)_{LR}$

Step 3: The sum of the weights must be equal to one (1). Therefore, the fuzzy weight of each criterion needs to be defuzzified. This is accomplished by ranking the fuzzy numbers:

$$w_{k\_defuzzified} = m + \frac{b-a}{4}. \quad (1)$$

Then, the defuzzified weights are normalized, as given by:

$$w_{k\_normalized} = \frac{w_i}{\sum_{i=1}^{n} w_i}.$$

Step 4: Convert the linguistic expert opinion into fuzzy evaluations for each criteria of alternative a, and then define the average fuzzy $f_k(a)$ evaluation of each criteria to construct an F-PROMETHEE evaluation matrix. This is done using:

$$f_k(j) = \left(average(m_i), \min(a_i), \max(b_i)\right), \quad (3)$$

where: $i = 1, 2, \dots n$(number of decision makers); $k = 1, 2, \dots$ number of criteria; $j = 1, 2, \dots$ number of alternatives.

Then, the F-PROMETHEE evaluation matrix is obtained, as given by:

$$\Pi = \overline{f_k(j)}. \quad (4)$$

Step 5: In order to obtain the preference index, the F-PROMETHEE evaluation matrix is defuzzified. The ranking of fuzzy numbers is carried out by the distance minimization method proposed by Asady and Zendehman (2007) because of its easy application approaches. It is utilized for this operation as given below.

If $u = (m,a,b)$ is a triangular fuzzy number, then the defuzzified $f(u)$ is as follows:

$$f(u) = m + \frac{b-a}{4}. \quad (5)$$

Step 6: The weighted preference degrees that have been calculated for each criterion k are added to define the outranking relation Π:

$$\Pi(a_i, a_j) = \sum_{j=1}^{m} w_k p_k \left(f_k(a_i) - f_j(a_j)\right). \quad (6)$$

Step 7: As a measure for the strength of alternatives a_t, X, A, the fuzzy leaving flow of $a_i \in A$ is calculated as follows:

$$\phi^+(a_i) = \sum_{j=1, j\neq i}^{n} \Pi(a_i, a_j). \quad (7)$$

Step 8: As a measure for the weakness of the alternatives a_t, X, A, the fuzzy entering flow of $a_i \in A$ is calculated as follows:

$$\phi^-(a_i) = \sum_{j=1, j\neq i}^{n} \Pi(a_i, a_j). \quad (8)$$

Step 9: For PROMETHEE II, the differences between entering flow and leaving flow for each alternative are calculated as net flow, as given below:

$$\phi^{net}(a_i) = \phi^+(a_i) - \phi^-(a_i). \quad (9)$$

Criteria Optimization and Preference Function Selection. For each criterion, the preference function translates the difference between the evaluations obtained by two alternatives into a preference degree ranging from zero to one. In order to facilitate the selection of a specific preference function, six types of generalized preference functions have been suggested by Brans *et al.* (1986). The decision makers may also model their preferences using any other specifically shaped preference function. For ranking purposes, the Type III linear preference function (Brans *et al.* 1986) is considered reasonable and is defined by:

$$p_k = \begin{cases} \frac{d_k}{p_k}, & \text{if } 0 \le d_k \le p_k; \\ 1, & \text{if } d_k > p_k, \end{cases} \quad (10)$$

where: $d_k = f_k(a_i) - f_k(a_j)$. The intensity of preference p_k increases linearly with the growth of d_k up to p_k. After the threshold, p_k, has been reached when the intensity is equal to 1. The threshold should be identified by the decision maker and, once determined, the preference becomes strict. For ranking purposes, the parameter p_k can be set as:

$$p_k = f_k(\cdot)\max - f_k(\cdot)\min, \quad (11)$$

where: $f_k(\cdot)$ is the evaluation of all alternatives for criterion k.

2. Case Study

2.1. Alternatives

The Fuzzy-PROMETHEE method was applied to the evaluation of five proposed locations for the construction of a logistic center in Samsun, Turkey. The proposed locations were defined in a report prepared by the Samsun Chamber of Commerce and Industry (TR 83 Bölgesi… 2010). The characteristics of these locations, which are given in Table 1, were tabulated by Elevli and Ak (2011). Four of the locations were in the eastern part of the city center, and the other is located in the south-west part of the city center.

2.2. Criteria

Criteria identification for the PROMETHEE methods requires very clear information that is easily obtained and understood by both decision makers and analysts (Brans, Mareschal 2005). The criteria do not need to be mathematically linked, but they need to be contributing factors in the decision making process. Each criterion should be self-contained and expressed in its own units. This reduces any scaling effects that could affect the outcome. Five criteria have been selected, in order to assess the potential sites for the logistics center. These criteria and metrics were selected based on a literature review and inputs received from experts, which are given below (Theofanis *et al.* 2010; Kayikci 2010):

- *Criterion (A) – Site suitability:* A logistics center is a defined area in which all related activities are carried out. The size and shape should be suitable for the planned capacities and functions of the logistics center. The topography is also important for determining the site preparation cost. The expandability of the area and the existence of buffer zones adjacent to the area also play a role in decision making;
- *Criterion (B) – Background activities/facilities:* Existing activities and facilities that can be incorporated to the logistic center are advantageous for investment purposes;
- *Criterion (C) – Access to transportation/network connections:* The distance to a main access road, railway, seaport, and airport should be in acceptable level;
- *Criterion (D) – Property conditions:* Property price and ownership, the land uses of neighbouring sites, and the attitude of neighbouring sites are also important criteria to be considered;
- *Criterion (E) – Location and interconnected business activities:* This includes the centrality of the site, proximity to major retailers and logistics providers, availability of local trucking, and availability of a suitable workforce. This criterion also covers the importance of freight flow.

Table 1. Characteristics of potential areas for logistics center

Character	Alternatives				
	1	2	3	4	5
Position	12 km to Seaport; 8 km to Airport; 8 km to Railway freight transfer center	12 km to Seaport; 8 km to Airport; 8 km to Railway freight transfer center	25 km to Seaport; 8 km to Airport; 16 km to Railway freight transfer center	9 km to Seaport; 12 km to Airport; 2 km to Railway freight transfer center	17 km to Seaport; 35 km to Airport; 27 km to Railway freight transfer center
Ownership and property conditions	200 acre grassland, remaining private property	850 acre dedicated, remaining public	150 acre public but controversial with private sector	Private property	5.5 acre is dedicated, rest is private property
Property price	25–35 $/m^2$	Public, no defined price	25–35 $/m^2$	100–150 $/m^2$	60–250 $/m^2$
Geographical characteristics	1st grade agricultural land; slope is less than 10%	1st grade agricultural land and flat	1st grade agricultural land and flat; western part is forest	Planned for expansion of housing and industrial area	Slope is between 17–20%

2.3. Determination of Criteria Weight

The weightings assigned to the criteria are at the discretion of the decision makers and generally reflect the relative importance of each criterion in the decision making process. There are various approaches for assessing weights, such as the eigenvector method, AHP method, entropy method, Step-wise Weight Assessment Ratio Analysis (SWARA) method and expert method (Hashemkhani Zolfani *et al.* 2012, 2013a, 2013b; Zavadskas *et al.* 2013a, 2013b; Shannon 1948a, 1948b; Alimardani *et al.* 2013; Maskeliūnaitė, Sivilevičius 2012; Yazdani-Chamzini *et al.* 2012; Hashemkhani Zolfani, Šaparauskas 2013; Palevičius *et al.* 2013; Aghdaie *et al.* 2012). The relevant linguistic terms have been defined, in order to assess the criteria individually, instead of using pair wise comparisons. The fuzzy logic approach has been used on linguistic variables, in order to weight each criterion; these weightings are given in Table 2 (Ertuğrul, Karakaşoğlu 2008; Bilsel *et al.* 2006; Elevli, Ak 2011). Representations of fuzzy numbers are given Fig. 1.

In order to define the importance and weight factor of each criterion, a questionnaire has been prepared. The opinions of experts were tabulated in Table 3. The obtained criteria weights from experts were in the form of linguistic terms. First, they were converted into related fuzzy numbers; then, the fuzzy numbers were defuzzified by using the distance minimization method suggested by Asady andZendehman (2007) as given below.

If a triangular fuzzy number:

$$w = (m, a, b), \text{ then } w_{defuzzified} = m + \frac{b-a}{4}. \quad (12)$$

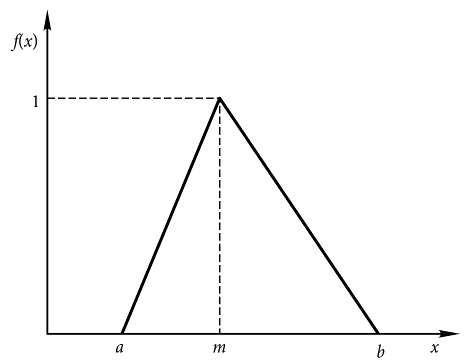

Fig. 1. Graphical presentation of a triangular fuzzy number

Table 2. Linguistic definition for importance weight of criteria

Performance of alternatives	Importance of criteria	Triangular fuzzy numbers (*a*, *m*, *b*)
Very Weak (VW)	Very Low (VL)	(0.00, 0.00, 0.15)
Weak (W)	Low (L)	(0.00, 0.15, 0.30)
Medium Weak (MW)	Medium Low (ML)	(0.15, 0.30, 0.50)
Medium (M)	Medium (M)	(0.30, 0.50, 0.65)
Medium High (MH)	Medium High (MH)	(0.50, 0.65, 0.80)
High (H)	High (H)	(0.65, 0.80, 1.00)
Very High (VH)	Very High (VH)	(0.80, 1.00, 1.00)

Since the sum of the weights should be equal to one (1), the resulting values of each criterion have been normalized; the results are given in Table 4:

$$w_{normalized} = \frac{w_i}{\sum_{i=1}^{n} w_i}. \quad (13)$$

Table 3. The importance of criteria according to experts

Criteria	*DM*1	*DM*2	*DM*3	*DM*4	*DM*5
A	VH	VH	H	MH	H
B	MH	H	M	H	VH
C	H	MH	VH	H	MH
D	M	M	M	ML	M
E	ML	M	ML	ML	M

Table 4. Fuzzy weight and normalized weight

Criteria	Fuzzy Weight			$w_{defuzzified}$	$w_{normalized}$
A	0.68	0.85	0.96	0.920	0.254
B	0.58	0.75	0.89	0.828	0.229
C	0.62	0.78	0.92	0.855	0.236
D	0.27	0.46	0.62	0.548	0.151
E	0.21	0.38	0.56	0.468	0.129
Total				3.618	1.000

2.4. Evaluation of Alternatives Based on Criteria

In order to evaluate the performance of each alternative on the basis of the defined criteria, the expert opinions have been received as linguistic terms. The results obtained are given in Table 5.

The linguistic terms have been translated into fuzzy numbers for each expert, and then the single fuzzy numbers for each alternative are estimated by using the fuzzy operations below:

$$w_i = (a_i, m_i, b_i) \rightarrow \tilde{w}_i = \left(\min(a_i), \frac{\sum_{i=1}^{n} m_i}{m}, \max(b_i) \right). \quad (14)$$

The obtained F-PROMETHEE criteria evaluation matrix is given in Table 6, and the fuzzy representation of alternatives for criterion *A* is given in Fig. 2.

As seen in Table 6, the results are in the form of fuzzy numbers. The main problem arises in comparing the ranking of two fuzzy numbers. Several approaches have been proposed for ranking fuzzy numbers (Cheng 1998; Wang *et al.* 2006; Detyniecki, Yager 2001; Tran, Duckstein 2002; Asady, Zendehman 2007; Nasseri *et al.* 2012). In this study, the distance minimization method proposed by Asady and Zendehman (2007) was used because of its easy application. Then, a defuzzified PROMETHEE criteria evaluation matrix was obtained, as given in Table 7.

The preferences for each criteria over the others were then evaluated, added together, and weighted to obtain the preference indices for each site. These values

Table 5. The opinion of decision makers for each alternative on the basis of criterion

Criteria	Alternatives	Decision Makers				
		*DM*1	*DM*2	*DM*3	*DM*4	*DM*5
A	*A*1	M	M	M	MH	H
	*A*2	MH	MH	MH	H	M
	*A*3	MH	M	H	MH	H
	*A*4	W	MW	MW	M	MW
	*A*5	MH	M	M	MH	MW
B	*A*1	VW	W	MW	VW	MW
	*A*2	VW	W	MW	M	M
	*A*3	VW	VW	W	M	W
	*A*4	M	W	MW	MW	W
	*A*5	H	H	H	MW	H
C	*A*1	H	M	MH	MH	H
	*A*2	M	M	M	MH	MH
	*A*3	MH	H	H	H	VH
	*A*4	H	H	H	M	MH
	*A*5	M	M	MH	M	MH
D	*A*1	M	M	MH	MH	M
	*A*2	H	MH	H	VH	H
	*A*3	MW	MW	M	M	M
	*A*4	MW	W	MW	M	VW
	*A*5	W	W	W	MW	MW
E	*A*1	M	M	MH	MH	M
	*A*2	M	M	M	MW	MH
	*A*3	MH	M	MH	MH	H
	*A*4	H	H	MH	M	H
	*A*5	H	VH	H	VH	H

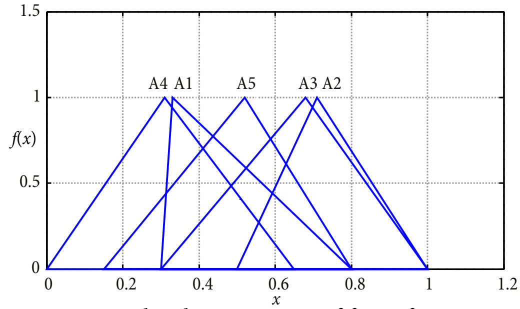

Fig. 2. Graphical presentation of fuzzy functions of alternatives for criterion *A*

were then placed in a preference index table indicating the preference of one site over the others (Table 8). For example, *A*1 is preferred over *A*2 by 0.074, whereas *A*2 is preferred over *A*1 by 0.035. This means *A*1 is better than *A*2. The total leaving Φ^- and entering Φ^+ flows provide a measure of outranking. The entering flow provides the total prefer ability of one alternative over the other alternatives. The leaving flow provides the total preferability of other alternatives over the one alternative. For example, the total preferability of *A*1 is 0.141, whereas the preferability of other alternatives over *A*1 is 0.260. The net flow Q^{net} provides the overall outranking characteristic of the alternative and is the resulting difference of Φ^+ and Φ^-. The greater the entering flow and the lesser the leaving flow, the greater the net flow, and hence, the higher the overall preference for the alternative.

Table 6. F-PROMETHEE criteria evaluation matrix

Criteria	Obj.	Alternative sites					*w*
		*A*1	*A*2	*A*3	*A*4	*A*5	
A (Site suitability)	Max	0.30, 0.33, 0.8	0.50, 0.71, 1.00	0.30, 0.68, 1.00	0.00, 0.31, 0.65	0.15, 0.52, 0.80	0.254
B Background activities/Facilities	Max	0.00, 0.15, 0.50	0.00, 0.29, 0.65	0.00, 0.16, 0.65	0.00, 0.34, 1.00	0.15, 0.70, 1.00	0.229
C Access to transportation/ Networks connections	Max	0.30, 0.68, 1.00	0.3, 0.56, 0.80	0.50, 0.81, 1.00	0.3., 0.71, 1.00	0.30, 0.50, 0.80	0.236
D Property conditions	Max	0.30, 0.56, 0.80	0.50, 0.81, 1.00	0.15, 0.42, 0.65	0.00, 0.31, 0.65	0.00, 0.20, 1.00	0.151
E Location and interconnected business activities	Max	0.30, 0.56, 0.80	0.15, 0.49, 0.80	0.30, 0.65, 1.00	0.30, 0.71, 1.00	0.65, 0.80, 1.00	0.129

Table 7. Defuzzified PROMETHEE criteria evaluation matrix

Criteria	Obj.	Alternative sites					p_k	*w*
		*A*1	*A*2	*A*3	*A*4	*A*5		
A Site suitability	Max	0.455	0.835	0.855	0.473	0.683	0.400	0.254
B Background activities/Facilities	Max	0.275	0.453	0.323	0.590	0.913	0.638	0.229
C Access to transportation/Networks connections	Max	0.855	0.685	0.935	0.885	0.685	0.250	0.236
D Property conditions	Max	0.685	0.935	0.545	0.473	0.335	0.600	0.151
E Location and interconnected business activities	Max	0.685	0.653	0.825	0.885	0.968	0.315	0.129

Table 8. The preference index

	*A*1	*A*2	*A*3	*A*4	*A*5	**Φ⁺**	Φ*net*	Ranking
*A*1		0.074	0.007	0.011	0.050	**0.141**	–0.119	5
*A*2	0.035		0.073	0.069	0.050	**0.226**	–0.037	4
*A*3	0.081	0.064		0.062	0.080	**0.286**	0.129	1
*A*4	0.047	0.067	0.024		0.045	**0.183**	–0.016	3
*A*5	0.098	0.059	0.054	0.057		**0.267**	0.043	2
Φ⁺	**0.260**	**0.263**	**0.158**	**0.199**	**0.224**			

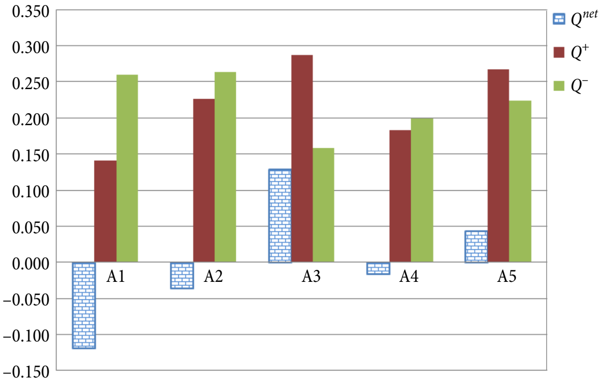

Fig. 3. Comparative representation of flows (Q^{net}, Φ^+, Φ^-)

The final ranking is then achieved by a numerical sort from highest to lowest net flow. The comparative graphical representation of flows is provided in Fig. 3. As can be seen in Fig. 3, the ranking order of the alternatives was *A*3 > *A*5 > *A*4 > *A*2 > *A*1.

Conclusions

The purpose of this study was to develop a scientific framework for evaluating and selecting logistic center locations, which is a multidimensional and multilevel decision making problem.

This research utilized the PROMETHEE method, even though the input data were in the form of linguistic terms.

The linguistic term were transferred into fuzzy numbers – then, these numbers were converted into single values, in order to use the PROMETHEE and so called F-PROMETHEE methods.

The results indicate that the PROMETHEE method can also be used when substantial uncertainties and subjectivity exist in the site information.

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