

## AN INTEGRATED DEMATEL–IF–TOPSIS METHODOLOGY FOR LOGISTICS CENTERS' LOCATION SELECTION PROBLEM: AN APPLICATION FOR ISTANBUL METROPOLITAN AREA

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**Abstract.** Logistics Centers (LCs) are among the most important facilities for rapid, cost effective, environmental friendly and secure logistics services to the urban logistics problems. Finding proper locations to LCs has an important effect on their success. In this study, LCs' location selection problem for Istanbul Metropolitan area is investigated. Istanbul is a leading city of Turkey in many categories including various industries, import/export amounts, transportation infrastructure and population density. However, industrialization and urbanization have introduced numerous problems to Istanbul. New projects are continuously being announced for the problems of metropolis, however, they may also bring new problems if they are not punctiliously planned and applied. Hence, in this study, it is aimed to propose a systematic Multi-Criteria Decision-Making (MCDM) approach for the LCs' location selection problem of Istanbul. In this approach, an integrated DEcision-MAking Trial and Evaluation Laboratory (DEMATEL) and Intuitionistic Fuzzy (IF) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is utilized. DEMATEL is used to analyse the decision criteria and IF-TOPSIS is used to evaluate candidate locations for LCs. Considering the vagueness inherent to this decision-making problem, IF sets are used for the evaluation process. Results are compared with the results of IF-VIKOR (*VIše Kriterijumska Optimizacija kompromisno Rešenje* – multi-criteria optimization and compromise solution) technique.

**Keywords:** logistics centers, DEMATEL, intuitionistic fuzzy sets, TOPSIS, location selection.

### Notations

#### Abbreviations:

AHP – analytical hierarchy process;  
AHP-GP – analytical hierarchy process and goal programming;  
DEMATEL – decision-making trial and evaluation laboratory;  
DM – decision maker;  
IF – intuitionistic fuzzy;  
IF-TOPSIS – IF technique for order preference by similarity to ideal solution;  
IFS – IF set;  
IF-VIKOR – IF *više kriterijumska optimizacija kompromisno rešenje* (multi-criteria optimization and compromise solution);  
IFWA – IF weighted averaging;  
LC – logistics center;

MCDM – multi-criteria decision-making;  
NRD – network relations diagram;  
NRM – network relationship map;  
TCDD – Turkish State Railway;  
TOPSIS – technique for order preference by similarity to ideal solution.

#### Variables and functions:

A1 – alternative 1 (Halkalı);  
A2 – alternative 2 (Yeşilbayır);  
A3 – alternative 3 (Tuzla);  
A4 – alternative 4 (Çorlu);  
A<sup>+</sup> – IF positive-ideal solution;  
A<sup>–</sup> – IF negative-ideal solution;  
C<sub>i</sub> – closeness coefficient.

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## Introduction

Logistics sector is a rapidly developing sector in parallel with the industrial and commercial improvements. Today, to survive in a competitive environment, having a proper logistics strategy, which responds to the needs of industry and commerce is essential for the companies. Under these circumstances, LCs are considered as one of the most important facilities producing solutions for the urban logistics problems. According to the European Logistics Platforms Association (Europlatforms 2015), which is an association of Transport and LCs all over Europe, LC is a center located in a pre-defined area for performing and organizing the activities such as transportation, logistics and the distribution services, etc. The concept of logistic centers had first appeared in USA together with the industrial development. In Japan, the concept was applied in order to decrease the level of traffic jam, environmental problems, energy and work force costs (Koldemir *et al.* 2009). In 1960s, initial LCs had been established in Europe and since 1980s the number of LCs has increased rapidly (Kapros *et al.* 2005). Today, in the borders of European Union, there are 240 LCs. In Turkey, the first LC has been founded by TCDD and it became active in 2007. Currently, 7 active LCs are active, 6 LCs are at their construction stage and 7 LCs are at their project stage in Turkey.

In the literature, as a reflection of the emerging number of application projects, an increasing number of studies have been prepared for the problems related to the LCs. According to the Uyanik *et al.* (2018), literature for LCs location selection problem can be classified into three categories: MCDM techniques, mathematical programming based studies and integrated approaches of MCDM techniques and mathematical models. Naturally, location selection problems require the consideration of multiple criteria and MCDM techniques are the most widely used techniques for this research area. In most of the MCDM studies for this problem, initial step is the determination of decision criteria for the evaluation of alternatives. It is a well-known fact that determination of evaluation criteria and their weights is very important for decision-making processes since it directly effects the final ranking. For this purpose, researchers applied different approaches to obtain more accurate criteria and their weights and tried to generate hybrid models via integrating different MCDM methodologies (Bamyacı, Tanyaş 2008; Kayıkci 2010; Elgün, Elitaş 2011; Görgülü 2012; Elevli 2014; Chen *et al.* 2014; Demiroğlu, Eleren 2014; Peker *et al.* 2016). Literature review also revealed that some of the studies use two or more MCDM methodologies for the same problem and then compare the results to find the most appropriate methodology for the focused problem and decide the ranking (Can 2012; Yildirim, Önder 2014; Önden *et al.* 2018; Özceylan *et al.* 2016). AHP is the mostly used technique in the literature. Additionally, in most of the recent studies, fuzzy sets based approaches are implemented to reflect the vagueness inherent to the real life problems (Chen, Qu 2006; Wang, Liu 2007; Yu *et al.* 2009; Erkay-

man *et al.* 2011; Li *et al.* 2011; Zalluhoğlu *et al.* 2014; Önden *et al.* 2018)

Mathematical programming based approaches are also used for logistics centers' location selection problem. In 1999, Taniguchi *et al.* (1999) proposed a vehicle routing and scheduling model and the dynamic traffic simulation model to find optimal size and location for public logistics terminals. Genetic algorithms are applied to find road network of the central area in Kobe City, Japan. Klapita and Švecová (2006) focused on uncertain costs and compared different solution methodologies for LCs location problem. Yang and Moodie (2011) generated a mathematical model to find location and size of logistics terminals and shopping centers in China with the objective function of total retail supply chain cost minimization. They also considered personal shopping trips. Aksoy and Özyörük (2015) proposed a linear programming and 0–1 integer-programming model to evaluate 12 LCs locations, which are determined by TCDD. Bayraktutan and Özbilgin (2014) compared a classical model and a fuzzy model for an application from Turkey. The foreign trade volume, highway, seaway and airway freight traffic, transportation types of cities in Turkey were determined by using both the classical and the fuzzy logic method. Objective function of the model tries to minimize the total costs including LC establishment costs, operation management costs and transportation costs.

In some of the studies, MCDM techniques and mathematical models are integrated for LCs' location selection problem. Tomić *et al.* (2014) investigated convenient LC locations in the capital cities of the Balkan Peninsula by incorporating Greedy heuristic algorithm and AHP. Regmi and Hanaoka (2013) compared the results of AHP and combined AHP-GP methods for alternative location evaluations. The models were developed based on location models and public and private sector stakeholders evaluated them.

In this study, LCs' location selection problem is investigated by using an integrated MCDM approach. Different from the literature, Istanbul Metropolitan area is selected for the case study since it can be considered as a leading city of Turkey in many categories including various industries, import–export amounts, transportation infrastructure and population density. However, industrialization and urbanization have introduced numerous problems to Istanbul. New projects are continuously being announced for the problems of metropolis, however, they may also bring new problems if they are not punctiliously planned and applied. From this point of view, selecting a proper LC location is very important to reduce the amount of transport vehicles in Istanbul. Moreover, location of the LC may have an effect on the traffic, noise and environmental pollution levels. In addition, it is a well-known fact that selecting the proper location is as important as the other functions of LCs. In the current situation, there are two logistic centers in Istanbul, which controlled by TCDD: the first one located in Halkalı and is currently ac-

tive, and the second one is located in Yeşilbayır and in the project stage. In this study, Halkalı, Yeşilbayır, Tuzla and Çorlu locations are evaluated for their convenience as LCs locations using the integrated DEMATEL and IF–TOPSIS methodology. During the criteria determination phase, a detailed literature review is conducted and also expert opinions are taken into consideration. Collected criteria are analysed and eliminated by applying DEMATEL. Criteria evaluation phase is conducted by experts from logistics sector, academy, civil society and governmental sector. As discussed previously, determination of the evaluation criteria is a vital step for decision-making problems. In this study, DEMATEL is used to determine final criteria list for analysis. The underlying reason of selecting DEMATEL is that it provides a great advantage on evaluating relationship among evaluation criteria; hence, it also provides insights for their elimination procedure. In addition, DEMATEL method enables to designate cause and affect group considering multiple criteria to analyse relationship among criteria and generate NRM (Tzeng, Huang 2011). Another critical point, which has a direct impact on the final ranking, is the selection of the proper method for criteria and alternatives evaluation process. In this study, IF–TOPSIS procedure is selected for the analysis since in the weight determination step; linguistic terms can be used to collect expert opinions. In many complex decision-making problems, the information provided by the DMs is insufficient and uncertain. For this reason, in the analysis of uncertainty inherent to the decision-making problems, fuzzy logic becomes one of the most preferred methods. IF sets can be considered as an extended version of the fuzzy set theory, which better models imperfect knowledge (Atanassov 1986) and become a useful solution tool to describe uncertain decision-making data fairly well. Criteria weights and alternative locations' ratings on the basis of criteria were calculated by using linguistic terms and IF numbers in IF–TOPSIS method. Results of the methodology is compared with the results of the IF–VIKOR approach. In the next section of this study, solution methodologies and the proposed approach are explained and in the second section, case study and its results are presented.

## 1. Methodology

In this study, an integrated DEMATEL and IF–TOPSIS methodology is used for LC location selection problem. This methodology starts with definition of the problem and the alternatives. Then, evaluation criteria are listed via conducting a comprehensive literature review and gathering expert opinions. DEMATEL methodology is used to determine final evaluation criteria based on the analysis of the relationship among criteria. Weight of each criteria is calculated by using linguistic terms based on the opinions of representing groups. As a final step, alternatives are ranked by applying IF–TOPSIS methodology.

### 1.1. DEMATEL procedure

DEMATEL method was developed by the Battelle Memorial Institute of Geneva Research Center in 1972. DEMATEL enable to designate cause and effect groups among multiple criteria to indicate relationship among criteria and generate NRM (Tzeng, Huang 2011). Steps of DEMATEL method are explained in Figure 1 (Tzeng, Huang 2011; Hori, Shimizu 1999; Tsai, Chou 2009).

### 1.2. IF–TOPSIS procedure

Fuzzy set theory definition was firstly proposed by Zadeh (1965) and defined a “membership function” with a value between zero and one.  $A$  is a fuzzy set in  $X$ :

$$A = \{x, \mu_A(x) \mid x \in X\}, \quad (1)$$

where:  $\mu_A : X \rightarrow [0, 1]$  is a membership function of fuzzy set  $A$ ;  $\mu_A(x)$  is degree of membership of  $x$  in  $A$  (Xu 2007; Szmidt, Kacprzyk 2000).

Almost fifteen years later then the fuzzy sets are firstly introduced by Zadeh (1965), Atanassov (1986) introduced IFS as an extension of fuzzy sets. In addition to the membership degree, non-membership degree is defined to offer a solution to the problem of vagueness.  $A$  is an IFS in  $X$ :

$$A = \{x, \mu_A(x), \nu_A(x) \mid x \in X\}, \quad (2)$$

where:

$$\begin{aligned} \mu_A : X \rightarrow [0, 1] \text{ and } \nu_A : X \rightarrow [0, 1]; \\ 0 \leq \mu_A(x) + \nu_A(x) \leq 1 \\ \text{for all } x \in X. \end{aligned} \quad (3)$$

Degree of membership and non-membership functions of IFS  $A$  are indicated by  $\mu_A(x)$ ,  $\nu_A(x)$ . IFSs also have another value,  $\pi_A(x)$  to define a degree of indeterminacy of  $x$  to  $A$  (Atanassov 1986) and it is called as intuitionistic index (Szmidt, Kacprzyk 2000) or hesitancy degree.  $\pi_A(x)$  value indicates certainty of  $x$ ,  $x$  is considered more certain if  $\pi_A$  has a small value. If  $\pi_A$  has a big value,  $x$  is considered as more uncertain (Shu *et al.* 2006).

$$\begin{aligned} \pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \\ \text{and } 0 \leq \pi_A(x) \leq 1 \\ \text{for all } x \in X. \end{aligned} \quad (4)$$

Let  $A = \{A_1, A_2, \dots, A_m\}$  be a set of  $m$  alternatives and  $C = \{C_1, C_2, \dots, C_n\}$  be a set of  $n$  criteria. Steps of IF–TOPSIS are given in Figure 2 (Boran *et al.* 2009; Joshi, Kumar 2014).

## 2. Case study

Istanbul Metropolitan area is selected for the case study since it can be considered as a leading city of Turkey in many categories including various industries, import–export amounts, transportation infrastructure and population density. In the current situation, there are two LCs ( $A_1$  – Halkalı and  $A_2$  – Yeşilbayır) in Istanbul controlled by TCDD.

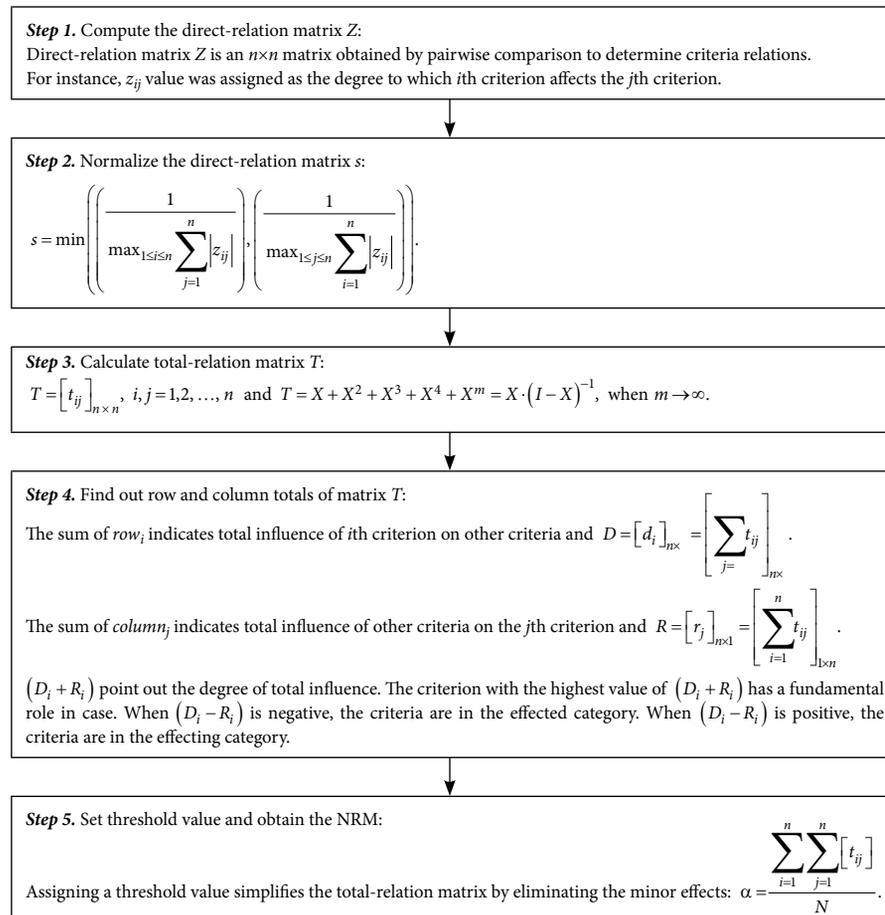


Figure 1. Steps of DEMATEL

While Halkalı is an active LC, Yeşilbayır is in its project stage. In this study, in addition to the A1 and A2 alternatives, considering the expert opinions, A3 and A4 (Tuzla and Çorlu) are also evaluated as candidate LC locations via the procedure given in Figure 3.

A literature review study on LCs' location selection problem has been carried out by Uyanik *et al.* (2018) to determine the evaluation criteria. Uyanik *et al.* (2018) listed the main and sub-criteria by reviewing publications and then prepared a criteria list. Then, 453 criteria are evaluated and classified into cost, cargo capacity/economic reflections, environment, location and social factor categories. At the final step, criteria, which are used less than 6 times was omitted and following this elimination process, 19 criteria are selected (Uyanik *et al.* 2018). In this study, among these 19 criteria, three of them are eliminated, namely: "proximity to an airport", "state subsidies", "safety and security". "Proximity to an airport" is eliminated, because, for this case, air transportation volume is at an ignorable level, while the criteria of "state subsidies" and "safety and security" are eliminated, because, alternative locations have similar characteristics for these aspects, hence, they are not distinctive. Final list of the selected criteria are given below:

- cost (C1);
- natural resources (C2);

- proximity to railroad system (C3);
- proximity to highway system (C4);
- proximity to city center (C5);
- proximity to harbour (C6);
- size (C7);
- suitability to enlargement (land) (C8);
- proximity to industrial zone (C9);
- macro-economic benefits/performance (C10);
- environmental impacts (C11);
- freight transport (C12);
- suitability to construction (topography, geography, ground structure) (C13);
- cost of construction process (C14);
- accessibility to labour pool (C15);
- transportation and logistics attractiveness (C16).

The action and reaction relations among the criteria are found by using DEMATEL technique. The question – "How  $i$ th criterion affects  $j$ th criterion?" – is asked to the DMs and the responses are used to form direct-relation matrix  $Z$ . Following the steps of DEMATEL methodology, row and column totals of total-relation matrix are found as mentioned in Step 4 of the DEMATEL methodology (Figure 1) and shown in Table 1.

The threshold value is obtained as 0.06 by using the formula given in the Step 5 of the DEMATEL methodology (Figure 1) and NRD is found as shown in Figure 4.

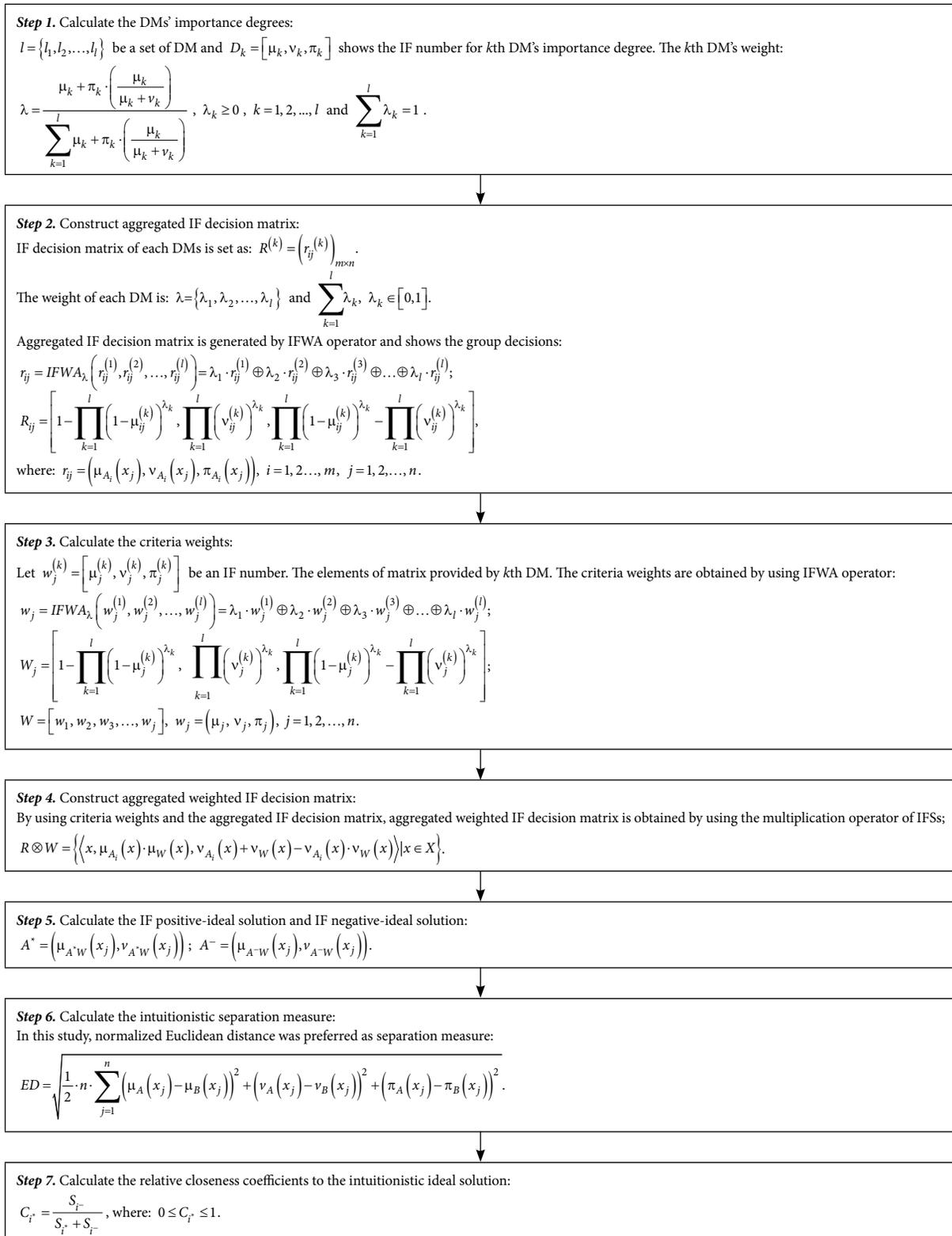


Figure 2. Steps of IF-TOPSIS

The criteria C1, C2, C3, C4, C5, C6, C7, C8, C9 and C13, which have the positive  $D_i - R_i$  values, are located in the category of the affecting criteria. On the other side, C10, C11, C12, C14, C15, C16, C17 criteria, which have negative  $D_i - R_i$  values, are located in the category of the affected criteria. C10 and C14 with the lowest  $D_i - R_i$  val-

ues are eliminated and the remaining 14 criteria are used in IF-TOPSIS method.

IF-TOPSIS method is used to evaluate four alternative locations for LCs in Istanbul. The DMs are chosen as representative of logistics sector, civil society organization, academy and government/public groups and have

different importance weights. As can be seen from Table 2, there is a slight difference between DMs' weights in terms of linguistic terms. It is found convenient to weight opinions of experts from logistics sector and academics slightly more than other DMs considering their studies on logistics and specifically on LCs. Their weights (Table 2) are found by the formula given in the Step 1 of IF-TOPSIS procedure (Figure 2) with respect to the linguistic terms given in Table 3.

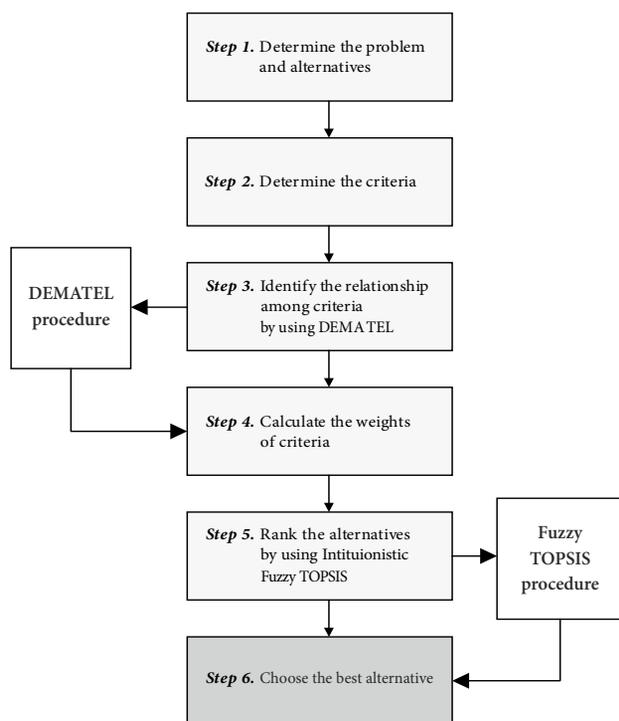


Figure 3. Steps of the proposed methodology

Table 1. Impacts on criteria

	$D_i$	$R_i$	$D_i + R_i$	$D_i - R_i$	Status
C1	1.930	1.806	3.736	0.124	cause
C2	1.040	0.814	1.854	0.226	cause
C3	0.954	0.457	1.411	0.497	cause
C4	0.870	0.519	1.389	0.351	cause
C5	1.456	0.503	1.959	0.953	cause
C6	1.200	0.435	1.635	0.765	cause
C7	1.073	0.861	1.934	0.212	cause
C8	0.958	0.928	1.886	0.030	cause
C9	0.986	0.367	1.353	0.619	cause
C10	0.497	1.700	2.197	-1.203	effect
C11	0.760	1.373	2.133	-0.613	effect
C12	1.164	1.520	2.684	-0.356	effect
C13	0.837	0.732	1.569	0.105	cause
C14	0.419	1.169	1.588	-0.750	effect
C15	0.634	0.895	1.529	-0.261	effect
C16	0.686	1.382	2.068	-0.696	effect

DMs are requested to evaluate the alternative locations with respect to their performance on the determined criteria set by using linguistic terms given in Table 4. Aggregated IF decision matrix (Step 2 of IF-TOPSIS procedure given in Figure 2) is formed by using DMs' evaluations on each criterion.

DMs evaluate the criteria by using the linguistic terms given in Table 4 and the formula given in the Step 3 of IF-TOPSIS procedure is used (Figure 2) to find the weights. By using criteria weights and the aggregated IF decision matrix, aggregated weighted IF decision matrix is obtained by using the multiplication operator of IFSs as shown in Step 4 of the IF-TOPSIS procedure. In Step 5, IF positive-ideal solution and IF negative-ideal solution values are calculated. In this study, normalized Euclidean distance was preferred as separation measure and  $S_i^+$  and  $S_i^-$  are obtained in Step 6. As a final stage, Step 7 is implemented to find relative closeness coefficients to the intuitionistic ideal solution. Final scores are presented in Table 5.

Finally, ranking of the alternatives is obtained as A4 (Corlu) > A3 (Tuzla) > A1 (Halkalı) > A2 (Hadımköy). Evaluation result of Çorlu is very close to its nearest alternative, Tuzla. In addition, evaluation results of last two (Halkalı and Hadımköy) alternatives are very close to each other.

To compare the results of IF-TOPSIS approach, IF-VIKOR methodology is also applied for the same problem. For the comparison, IF-VIKOR is selected, because, it has a similar structure with IF-TOPSIS. VIKOR methodology is based on an aggregation function presenting closeness to the ideal solution as in TOPSIS. However, they are different in some aspects. In TOPSIS, chosen alternative is the alternative with the highest relative closeness coefficient, which is calculated based on distances from negative-ideal and positive-ideal solutions. In VIKOR, the best alternative is the closest one to the ideal solution and it is generally the highest ranked alternative. Opricovic and Tzeng (2004) stated in their study that the main difference between mentioned methodologies is their aggregation approaches. Results of the IF-TOPSIS and IF-VIKOR methods are presented in Table 6.

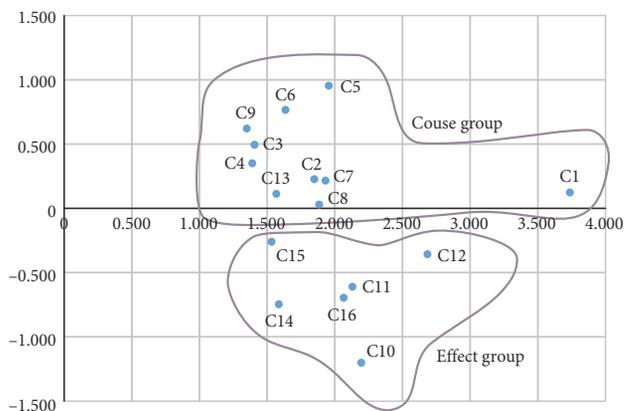


Figure 4. NRD

Table 2. Importance of DMs

ID	Representing group	Linguistic term	Weight
DM1	logistics sector	very important (VI)	0.2725
DM2	civil society organization	important (I)	0.2275
DM3	academy	very important (VI)	0.2725
DM4	government / public	important (I)	0.2275

Table 3. Linguistic terms for criteria and the DMs weight evaluation (Boran et al. 2009)

Linguistic terms	IFNs
Very important (VI)	(0.90, 0.10)
Important (I)	(0.75, 0.20)
Medium (M)	(0.50, 0.45)
Unimportant (U)	(0.35, 0.60)
Very Unimportant (VU)	(0.10, 0.90)

Table 4. Linguistic terms for alternative evaluation (Boran et al. 2009)

Linguistic terms	IFNs
Extremely good (EG)	[1.00, 0.00]
Very very good (VVG)	[0.90, 0.10]
Very good (VG)	[0.80, 0.10]
Good (G)	[0.70, 0.20]
Medium good (MG)	[0.60, 0.30]
Fair (F)	[0.50, 0.40]
Medium bad (MB)	[0.40, 0.50]
Bad (B)	[0.25, 0.60]
Very bad (VB)	[0.10, 0.75]

Table 5. Final scores for candidate locations

	$S^+$	$S^-$	$C_i^*$
A1	0.0157	0.1035	0.86861
A2	0.0147	0.0796	0.84412
A3	0.0116	0.1762	0.93845
A4	0.0112	0.1942	0.94549

Table 6. Comparison of final scores for candidate locations

	IF-TOPSIS	IF-VIKOR
		Q
A1	0.86861	0.7895
A2	0.84412	0.5145
A3	0.93845	0.5000
A4	0.94549	0.1411

In the VIKOR methodology, smaller VIKOR index Q is better, thus, final ranking is obtained as A4 (Çorlu) > A3 (Tuzla) > A2 (Hadımköy) > A1 (Halkalı). This result does not show a significant difference with the result of IF-TOPSIS. Only, the ranking of last two alternatives – Halkalı and Hadımköy – switched in IF-VIKOR approach.

In addition, these two alternatives’ evaluation values are found very close in the IF-TOPSIS methodology. This slight difference is an expected situation due to the applied approaches’ dissimilarities explained previously.

As a conclusion, Çorlu is found as the best alternative in the proposed approach and the IF-VIKOR methodology. It is advantageous over other alternatives in many ways. A LC to be established in Çorlu would have lower fixed costs, larger size, and more flexibility of land expansion, closer to industrial zones and areas of consumption and more suitable to construction.

### Conclusions

It is important that an established LC does not remain idle and public resources are not wasted. It depends mostly on the location of the LCs, hence, in this study, a two-stage methodology is proposed to evaluate and determine their locations. The first stage is the determination of the evaluation criteria and alternative locations. In this study, after a literature review is performed, lists of criteria are determined, and then, this list is evaluated, eliminated and weighted. During the criteria evaluation process, they are divided in two groups – effect and cause group – by using DEMATEL and a NRD is created. At the final step of DEMATEL method, *macro-economic benefit/performance* and *cost of construction process* criteria are eliminated since they are highly affected by the other criteria.

In the second step of the study, alternative locations for a LC is determined. The most recent projects for Istanbul have been restricted to the province’s boundaries. Because of the difficulty in deciding suitable locations for large industrial projects for Istanbul, neighbouring provinces like as Kocaeli and Tekirdağ have begun to attract more industry. These areas, even they are not located within Istanbul’s provincial boundaries, share in a common economic space with Istanbul. For that reason, this study focused on this metropolitan area and Çorlu, Halkalı, Tuzla and Hadımköy is considered as the alternatives for LCs.

In deploying IF-TOPSIS, opinions of four expert groups from the logistic sector, civil society, the civil service and academia are taken. Weights of the criteria and possible locations’ ratings for each evaluation criteria were determined by using linguistic term scale and their IF numbers. After the IF-TOPSIS procedure implemented, based on found final ranking, Çorlu is selected as the best location among considered alternatives. To compare the results of the proposed methodology, IF-VIKOR method is applied and same alternative location is found proper. Çorlu’s position in comparison with other alternatives proves the importance of lower costs.

In this study, Istanbul Metropolitan area is examined and a logistic center location for this area is determined. However, it is planned to use this proposed model for the evaluation of different locations in Turkey in the future studies. In the evaluation of different locations, new criteria can be added to the model considering the characteristics and the requirements of the region and then

DEMATEL method should be repeated to achieve the final criteria list. Additionally, different multi-criteria decision-making approaches can be applied to the same problem and results of the proposed model can be compared.

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