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# Extended VIKOR Method based on Interval-Valued Intuitionistic Fuzzy Numbers for Selection of Logistics Centre Location

Lojistik Merkezi Yer Seçimi için Aralık Değerli Sezgisel Bulanık Sayılara Dayalı Genişletilmiş VIKOR Yöntemi

Video Link: https://youtu.be/TfvXgf_Ilu0

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# Lojistik Merkezi Yer Seçimi için Aralık Değerli Sezgisel Bulanık Sayılara Dayalı Genişletilmiş VIKOR Yöntemi


## Öz

Lojistik merkezler (LM) için uygun yerin belirlenmesi, rekabet avantajı elde etmenin, sürdürmenin ve tedarik zinciri faaliyetlerinin verimliliğini artırmanın anahtarıdır. Artan müşteri beklentileri, lojistik maliyetlerinin azaltılmasına yönelik çabalar ve lojistik sektöründe yaşanan rekabet yoğunluğu son yıllarda birçok yeni LM kurulmasına neden olmuştur. Bu merkezler yük taşımacılığında verimliliğin artmasına, lojistik hizmetlerin optimize edilmesine ve bulundukları kentteki trafiğin azaltılmasında önemli ölçüde katkı sağlamaktadır. LM'lerin artan önemi ve konumlarının lojistik faaliyetler üzerindeki önemli etkisi, kurulum yeri seçimini stratejik bir değerlendirme haline getirmiştir. Ancak, LM konum alternatiflerini değerlendirmek, birçok faktörün hesaba katılması gereken karmaşık bir süreçtir. Bu çalışmanın amacı, aralık değerli sezgisel bulanık sayılara (ADSBS) dayalı genişletilmiş bir VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR) yaklaşımı önermek ve uygulanabilirliğini test etmektir. ADSBS'ın uygulanması, insan düşünce ve karar süreçlerindeki belirsizlikle başa çıkmaya katkıda bulunur. Öte yandan VIKOR birbiriyle çelişen ve farklı birimler tarafından temsil edilen kriterleri sıralamayı kolaylaştıran ve uzlaşmacı bir çözüm sunan bir karar verme tekniğidir. Bu çalışmada önerilen ADSBS aracılığıyla genişletilmiş VIKOR yaklaşımının uygulanabilirliği, LM konum alternatiflerinin değerlendirildiği sayısal bir örnekte test edilmiştir. Kriter ağırlıklarının belirlenmesi ve alternatiflerin sıralanması için üç uzman karar vericiye danışılmıştır. Karar vericiler, lojistik ve planlama uzmanı, lojistik operasyon yöneticisi ve tedarik zinciri başmühendisi olarak görev yapmaktadır. Uygulamada alternatifler altı kriter (altyapı, müşteriye yakınlık, tedarikçilere yakınlık, intermodal bağlantı, işgücü arzı ve güvenlik/güvenirlilik) dikkate alınarak değerlendirilmiştir. Sonuç olarak kriterler ağırlıklarına göre intermodal bağlantı (0,255), altyapı (0,194), güvenlik/güvenlik (0,169), müşterilere yakınlık (0,158), tedarikçilere yakınlık (0,131) ve iş gücü arzı (0,093) biçiminde sıralanmıştır. Çalışmada elde edilen bulguların araştırmacılara ve sektör yöneticilerine katkı sağlaması beklenmektedir.


**Anahtar Kelimeler:** Bulanık Küme, Aralık Değerli Sezgisel Bulanık Sayılar, VIKOR, Lojistik Merkez, Yer Seçimi

# Extended VIKOR Method based on Interval-Valued Intuitionistic Fuzzy Numbers for Selection of Logistics Centre Location


## Abstract

Identifying the appropriate location for logistics centres (LC) is key to gaining and maintaining a competitive advantage and increasing the efficiency of supply chain activities. Increasing customer expectations, efforts to reduce logistics costs and the intensity of competition in the logistics sector have led to the establishment of many new LMs in recent years. These centers contribute significantly to increasing efficiency in freight transportation, optimizing logistics services and reducing the traffic. The increasing importance of LCs and the significant impact of their location on logistics activities have made the choice of installation site a strategic consideration. However, evaluating LC location alternatives is a complex process that must take many factors into account. The aim of the present study is to propose an extended VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR) approach based on interval-valued intuitionistic fuzzy numbers (IVIFN) and test its feasibility. Applying IVIFN contributes to coping with uncertainty in human thought and decision processes. On the other hand, VIKOR is a decision-making technique that facilitates ranking criteria that are contradictory and represented by different units, and it offers a compromise solution. The feasibility of the extended VIKOR approach through IVIFN proposed in this study was tested in a numerical example in which LC location alternatives were evaluated. Three experts were consulted to determine the criterion weights and to rank the alternatives. Decision makers serve as logistics and planning specialist, logistics operations manager and supply chain chief engineer. In practice, alternatives were evaluated by considering six criteria. As a result, criteria are listed in the form of intermodal connection (0.255), infrastructure (0.194), security/safety (0.169), proximity to customers (0.158), proximity to suppliers (0.131), and labour supply (0.093), according to their weighted importance. It is expected that the findings obtained in the study will contribute to researchers and sector managers.

**Keywords:** Fuzzy Set, Interval-Valued Intuitionistic Fuzzy Numbers, VIKOR, Logistics Centre, Location Selection

## Introduction

A logistics centre (LC) is a group of facilities located in a safe environment that provides a range of logistics services (Kayikci, 2010). Due to economic, technical, and technological developments in the transportation sector, the importance of LCs is increasing day by day (Elevli, 2014). In recent years, many new LCs have been established to meet high customer service expectations and reduce logistics costs. These centres play a critical role in optimizing logistics services, increasing efficiency in freight transport, and reducing urban traffic.

Choosing the most suitable location for an LC is a process that involves a great deal of uncertain information and is affected by various factors. Determining the criteria that are essential in this process, calculating the importance levels of the criteria, and choosing the most suitable of the potential locations is a complex decision-making problem. The increasing importance of LCs and the significant impact of their location on logistics activities have made the choice of installation location a strategic consideration. Therefore, many recent studies have aimed to determine appropriate LC locations using multi-criteria decision-making (MCDM) techniques.

VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR), a compromise ranking approach, enables ranking alternatives by considering criteria that contradict each other and are represented in different units (Tan & Chen, 2013). The method offers compromise solutions for problems with conflicting or contradictory criteria. The resulting compromise solution provides maximum group utility and minimum individual regret.

In the method, a multi-criterion ranking index based on the closeness measure is applied to the ideal solution (Li & Jiang, 2011). The technique has been developed for multi-criteria optimization in complex systems and has been accepted in the literature.

In particular, incomplete, contradictory, and subjective information in the solution process of complex decision problems causes imprecision and uncertainty (Deng & Yeh, 2006). To overcome this uncertainty, most MCDM techniques are integrated with fuzzy logic, and fuzzy sets are used. Intuitionistic fuzzy or interval-valued intuitionistic fuzzy concepts have been developed to cope with the shortcomings of fuzzy sets (Büyüközkan et al., 2018). Also, higher order extensions such as interval-valued intuitionistic fuzzy numbers (IVIFN) have been used successfully to address ambiguous human behaviours (Tan & Chen, 2013). The most important advantage of IVIFN over classical fuzzy sets is that it differentiates positive and negative indicators for the inclusion of an element in the set. IVIFN is a suitable approach for modelling and solving complex problems. Today, many researchers have used IVIFN in decision-making problems and expanded it with different approaches.

In the current study, a multi-criteria framework was developed in which the IVIFN-based VIKOR technique was applied to determine the importance of the criteria considered in the LC setup and to rank the alternative locations. Based on a systematic and detailed literature review conducted in the research, the criteria that are effective in choosing LC locations were determined. The proposed integrated method was used to calculate the relative weights of the determined criteria and to rank the alternatives.

## Literature Review

Today, the increasing number and importance of LCs has made the evaluation of LC location alternatives an important decision. Determining the appropriate location is affected by many factors and contains many uncertainties. Recent studies have compared LC location candidates through different MCDM techniques and their extended versions. In this study, it is aimed to evaluate LC alternatives effectively through the proposed integrated decision making approach.

Ugboma et al. (2006) presented an approach using AHP to determine the service features that shippers consider when choosing a port and the importance level of these features. Kayikci (2010) proposed a model using fuzzy AHP and artificial neural network techniques to evaluate the location of intermodal LCs and tested its feasibility. Awasthi et al. (2011) presented an approach including fuzzy TOPSIS application to perform the selection of urban distribution centres and the assessment of uncertain criterion values. Portugal et al. (2011) presented a model based on AHP and graph theory to evaluate potential locations for the establishment of a truck cargo terminal. Long and Grasman (2012) proposed a decision model to analyse the locations of multimodal load centres. Their study aimed to determine the factors that will provide strategic input for decision makers (DM).

Elevli (2014) evaluated LC locations through fuzzy PROMETHEE, taking into account the criteria obtained by utilizing literature and expert opinions. Lirn et al. (2014) developed a model using Delphi and AHP methods to evaluate transit ports for international carriers. Onder and Yıldırım (2014) developed an approach using AHP and VIKOR methods to evaluate logistics villages. The proposed approach has been tested with an application evaluating 11 logistics villages in Turkey. Uysal and Yavuz (2014) conducted a study aiming to select the most appropriate LC location. In their research, a regional commercial review was carried out, and the most suitable plant site was determined through the ELECTRE technique. Żak and Węgliński (2014) performed a macro analysis of LCs in their study and evaluated alternatives in terms of their suitability for LCs using the ELECTRE III/IV technique.

Dyck and Ismael (2015) compared competitiveness levels of logistics ports in West Africa. In their study, competition levels of the ports were examined through AHP, and the ports were ranked. Roso et al. (2015) proposed an approach using AHP to determine the criteria to be considered in determining the preferred regions for installation of an intermodal terminal. Dey et al. (2016) proposed an approach using three methods (TOPSIS, SAW and MOORA) for selecting the most suitable warehouse location. Yang and Chen (2016) analysed the evaluation criteria of international LC ports and compared three international ports. An integrated method, in which AHP and grey relational analysis techniques were used together, was preferred during the application process.

Sughosh et al. (2017) determined the importance levels of critical factors affecting the site selection of an auto parts manufacturing plant through AHP. In addition, Pareto analysis was performed using the individual preference data collected for each of the factors, and the results were compared. Grine et al. (2018) proposed an AHP-based decision support system to determine the most appropriate LC location. In their study, criteria were determined according to the PESTEL model and accessibility factor category. The developed approach was tested in an application evaluating the location of LCs in Morocco. Essaadi et al. (2019) developed a global approach that pinpoints different types of criteria through fuzzy TOPSIS and evaluated LCs in the African region. Shahparvari et al. (2020) evaluated location alternatives for an LC that will operate as a consolidation centre. In their study, a K-means-based approach was developed, and PROMETHEE and VIKOR techniques were applied. In addition, linear programming was used in the research to cluster the suitable regions. In the current work, studies comparing LC locations using different MCDM techniques were examined. The criteria determined to be used in practice, definitions of the criteria, and the studies in which they were tested are presented in Table 1.

**Table 1.** Criteria for LC location selection

| Criteria | Definition | Reference |
|---|---|---|
| Infrastructure ($C_a$) | Logistics accessibility of the LC and transport efficiency for the distribution of goods | Dyck & Ismael (2015), Lirn et al. (2004), Long & Grasman (2012), Ugboma et al. (2006), Uysal & Yavuz (2014), Żak & Węgliński (2014) |
| Proximity to Customers ($C_b$) | Distance of LC from customer locations | Awasthi et al. (2011), Dey et al. (2016), Lirn et al. (2004), Long & Grasman (2012), Shahparvari et al. (2020), Uysal & Yavuz (2014) |
| Proximity to | Distance of LC from supplier locations | Awasthi et al. (2011), Lirn et al. (2004), Onder & Yıldırım (2014), Roso et al. |

| | | |
|---|---|---|
| Suppliers ($C_c$) | | (2015) |
| Intermodal Connection ($C_d$) | The level of connectivity of the LC with different modes of transport | Awasthi et al. (2011), Elevli (2014), Essaadi et al. (2019), Grine et al. (2018), Kayikci (2010), Lirn et al. (2004), Shahparvari et al. (2020), Uysal & Yavuz (2014) |
| Labour Supply ($C_e$) | Labour supply that can meet the needs of the LC | Long & Grasman (2012), Sughosh et al. (2017), Uysal & Yavuz (2014), Yang & Chen (2016) |
| Security/Safety ($C_f$) | Security of the LC against traffic accidents, theft, robbery and vandalism | Awasthi et al. (2011), Lirn et al. (2004), Portugal et al. (2011), Uysal & Yavuz (2014), Żak & Węgliński (2014) |

The complex nature of MCDM problems and the conflicting criteria have revealed the need to develop a compromise solution approach. The VIKOR method, which was developed as a result of this situation, is an effective method used in solving complex decision making problems (Opricovic & Tzeng, 2002). The effectiveness of the VIKOR technique was compared with methods such as TOPSIS, PROMETHEE and ELECTRE, which are frequently used in the literature, and the results were analysed (Opricovic & Tzeng, 2004; Tzeng & Huang, 2011; Opricovic & Tzeng, 2007). As a result of the studies, it was seen that the method gave effective results.

In order to cope with the complex and uncertain nature of decision making problems today, VIKOR technique has been expanded in many studies in the literature by integrating it with different approaches. In addition to heuristic fuzzy sets, the concept of IVIFN has been proposed and used with different MCDM techniques. In the literature, there are studies in which IVIFN and VIKOR technique are used together in different fields of study (Table 2). IVIFN and VIKOR techniques have been integrated and applied in the solution of decision making problems such as supplier selection for an automobile manufacturer (Li & Jiang, 2011), evaluation of investment alternatives (Tan & Chen, 2013; Rani, Jain & Hooda, 2018); Dammak, Baccour & Alimi, 2020), partner selection of a venture company (Zhao, Tang, Yang & Huang, 2013), industrial robot selection (Narayanamoorthy, Geetha, Rakkiyappan & Joo, 2019), and financing risk assessment of rural tourism projects (Wu, Gao & Wei, 2019).

**Table 2.** Studies integrating IVIFN and VIKOR approaches

| Reference | Application |
|---|---|
| Li & Jiang (2011) | Supplier selection for an automobile manufacturer |
| Tan & Chen (2013) | Evaluation of investment alternatives |
| Zhao, Tang, Yang & Huang (2013) | Partner selection of a venture company |

| | |
|---|---|
| Rani, Jain & Hooda (2018) | Investment choice |
| Narayanamoorthy et al. (2019) | Industrial robot selection |
| Wu, Gao & Wei (2019) | Financing risk assessment of rural tourism projects |
| Dammak, Baccour & Alimi (2020) | Evaluation of investment projects |

## Methodology

VIKOR is a compromise ranking approach that evaluates alternatives by considering conflicting criteria (Tan & Chen, 2013). In this method, in which maximum group utility and minimum individual regret are sought, applicable solutions are offered for many problems. However, incomplete and contradictory information in real-life problems causes uncertainty.

In order to overcome the uncertainty encountered in real life problems, the concept of fuzzy set has been frequently used in studies in the literature. As fuzzy set theory developed, many extensions of fuzzy sets emerged. Traditional fuzzy decision making models have been used in different decision models to include these expanded definitions (Atanassov, 2016). The expanded definition presented in the theory of intuitionistic fuzzy sets, which is an extension of fuzzy sets, makes it easier for the decision maker to express his evaluations. Intuitionistic fuzzy sets offer a richer tool for representing uncertainty than traditional fuzzy sets. IVIFN, which is an extension of intuitionistic fuzzy sets, offers a wide area to describe fuzzy information (Opricovic & Tzeng, 2002). Therefore, an extended VIKOR extension based on IVIFN is proposed in the current study. The steps followed in the study are presented below (Büyüközkan et al., 2018).

*Step 1.* DMs evaluate criteria and alternatives in linguistic terms. The linguistic terms are then converted to IVIFN. Tables 2 and 3 are used in this process. In Table 2, linguistic terms used for ranking criterion weights and their IVIFN equivalents are given. In Table 3, linguistic terms used to rank alternatives and their IVIFN equivalents are presented.

*Step 2*. The weights of the criteria are obtained by considering the DM weights $(\lambda^k)$. Equations (1) and (2) are used to calculate criterion weights. The $w_j$ value in Equation (2) represents the final weight of the relevant criterion and $\sum_{j=1}^{n} w_j=1$ equality must be met.

$$\breve{w}_j = 1 - \frac{\sum_{k=1}^{K} \frac{\lambda^k(\mu_{ij}^L+\mu_{ij}^U)}{2}}{\sqrt{\sum_{k=1}^{K} \frac{\lambda^k((\mu_{ij}^L)^2+(\mu_{ij}^U)^2+(v_{ij}^L)^2+(v_{ij}^U)^2)}{2}}} \quad (1)$$

$$w_j = \frac{1-\breve{w}_j}{n-\sum_{j=1}^{n} \breve{w}_j} \quad (2)$$

**Table 2.** Linguistic terms for criteria evaluation (Büyüközkan et al., 2018)

| Linguistic terms | IVIFN ($[\mu^L, \mu^U], [v^L, v^U]$) |
|---|---|
| Highly important | ([0.95, 1], [0, 0]) |
| Very important | ([0.8, 0.85], [0.05, 0.1]) |
| Important | ([0.6, 0.65], [0.1, 0.15]) |
| Less important | ([0.3, 0.35], [0.25, 0.3]) |
| Very unimportant | ([0.2, 0.25], [0.3, 0.35]) |
| Entirely unimportant | ([0, 0.05], [0.45, 0.5]) |

**Table 3.** Linguistic terms for alternative evaluation (Büyüközkan et al., 2018)

| Linguistic terms | IVIFN ($[\mu^L, \mu^U], [v^L, v^U]$) |
|---|---|
| Extremely successful | ([0.99,1], [0,0]) |
| Very very successful | ([0.9,0.95], [0.01,0.04]) |
| Very successful | ([0.8,0.85], [0.05,0.1]) |
| Successful | ([0.7,0.75], [0.15,0.2]) |
| Somewhat successful | ([0.6,0.65], [0.25,0.3]) |
| Neutral | ([0.5,0.55], [0.35,0.4]) |
| Quite unsuccessful | ([0.4,0.45], [0.45,0.5]) |
| Mostly unsuccessful | ([0.3,0.35], [0.55,0.6]) |
| Very unsuccessful | ([0.2,0.25], [0.65,0.7]) |
| Extremely unsuccessful | ([0.1,0.15], [0.75,0.8]) |
| Entirely unsuccessful | ([0,0], [0.99,1]) |

*Step 3.* The decision matrix is obtained as a result of the DMs' evaluation of the alternatives. Then, the transformation is performed by means of Equation (3), and the combined decision matrix is obtained.

$$\check{r}_{ij} = \begin{pmatrix} \begin{bmatrix} 1 - \prod_{j=1}^{n}(1-\mu_{\tilde{A}}^{L})^{\lambda^k}, \\ 1 - \prod_{j=1}^{n}(1-\mu_{\tilde{A}}^{U})^{\lambda^k} \end{bmatrix} \\ \begin{bmatrix} \prod_{j=1}^{n}(v_{\tilde{A}}^{L})^{\lambda^k}, \\ \prod_{j=1}^{n}(v_{\tilde{A}}^{U})^{\lambda^k} \end{bmatrix} \end{pmatrix} \tag{3}$$

*Step 4.* Positive ideal solution (PIS) and negative ideal solution (NIS) values are obtained. Equation (4) is used for benefit-based criteria, while Equation (5) is used for cost-based criteria.

$$\tilde{f}_j^* = ([\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^*), \tilde{\mu}_{\tilde{A}}^{U}(\tilde{x}_j^*)], [\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^*), \tilde{\mu}_{\tilde{A}}^{U}(\tilde{x}_j^*)]) \quad .$$

$$\begin{pmatrix} [\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^*) = \max_i{}^{\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^*)}, \tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^*) = \max_i{}^{\tilde{\mu}_{\tilde{A}}^{U}(\tilde{x}_j^*)}] \\ [\tilde{v}_{\tilde{A}}^{L}(\tilde{x}_j^*) = \min_i{}^{\tilde{v}_{\tilde{A}}^{L}(\tilde{x}_j^*)}, \tilde{v}_{\tilde{A}}^{L}(\tilde{x}_j^*) = \min_i{}^{\tilde{v}_{\tilde{A}}^{U}(\tilde{x}_j^*)}] \end{pmatrix} \tag{4}$$

$$\tilde{f}_j^- = ([\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^-), \tilde{\mu}_{\tilde{A}}^{U}(\tilde{x}_j^-)], [\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^-), \tilde{\mu}_{\tilde{A}}^{U}(\tilde{x}_j^-)]) \quad .$$

$$\begin{pmatrix} [\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^-) = \min_i{}^{\tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^-)}, \tilde{\mu}_{\tilde{A}}^{L}(\tilde{x}_j^-) = \min_i{}^{\tilde{\mu}_{\tilde{A}}^{U}(\tilde{x}_j^-)}] \\ [\tilde{v}_{\tilde{A}}^{L}(\tilde{x}_j^-) = \max_i{}^{\tilde{v}_{\tilde{A}}^{L}(\tilde{x}_j^-)}, \tilde{v}_{\tilde{A}}^{L}(\tilde{x}_j^-) = \max_i{}^{\tilde{v}_{\tilde{A}}^{U}(\tilde{x}_j^-)}] \end{pmatrix} \tag{5}$$

*Step 5.* Group utility value ($S_{(i)}$) and individual regret value ($R_{(i)}$) are calculated using Equations (6) and (7). The expression $d(\tilde{f}_j^*, \tilde{x}_{ij})$ in the equations represents the distance from the PIS of each alternative and is calculated by Equation (8). Also, $d(\tilde{f}_j^*, \tilde{f}_j^-)$ represents the distance between the PIS and the NIS and is obtained using Equation (9). The expressions $\pi_{\tilde{A}}^{L}$ and $\pi_{\tilde{A}}^{U}$ in Equations (8) and (9) are calculated by means of Equations (10) and (11).

$$S_{(i)} = \sum_{j=1}^{n}[w_j \frac{d(\tilde{f}_j^*, \tilde{x}_{ij})}{d(\tilde{f}_j^*, \tilde{f}_j^-)}] \tag{6}$$

$$R_{(i)} = \max_j [w_j \frac{d(\tilde{f}_j^*, \tilde{x}_{ij})}{d(\tilde{f}_j^*, \tilde{f}_j^-)}] \tag{7}$$

$$d(\tilde{f}_j^*,\tilde{x}_{ij})=\frac{1}{4}\begin{pmatrix} |\tilde{\mu}_{\tilde{A}}^L(\tilde{x}_j^*)-\tilde{\mu}_{\tilde{A}}^L(\tilde{x}_{ij})|+|\tilde{\mu}_{\tilde{A}}^U(\tilde{x}_j^*)-\tilde{\mu}_{\tilde{A}}^U(\tilde{x}_{ij})| \\ +|\tilde{v}_{\tilde{A}}^L(\tilde{x}_j^*)-\tilde{v}_{\tilde{A}}^L(\tilde{x}_{ij})|+|\tilde{v}_{\tilde{A}}^U(\tilde{x}_j^*)-\tilde{v}_{\tilde{A}}^U(\tilde{x}_{ij})| \\ +|\tilde{\pi}_{\tilde{A}}^L(\tilde{x}_j^*)-\tilde{\pi}_{\tilde{A}}^L(\tilde{x}_{ij})|+|\tilde{\pi}_{\tilde{A}}^U(\tilde{x}_j^*)-\tilde{\pi}_{\tilde{A}}^U(\tilde{x}_{ij})| \end{pmatrix} \quad (8)$$

$$d(\tilde{f}_j^*,\tilde{f}_j^-)=\frac{1}{4}\begin{pmatrix} |\tilde{\mu}_{\tilde{A}}^L(\tilde{x}_j^*)-\tilde{\mu}_{\tilde{A}}^L(\tilde{x}_j^-)|+|\tilde{\mu}_{\tilde{A}}^U(\tilde{x}_j^*)-\tilde{\mu}_{\tilde{A}}^U(\tilde{x}_j^-)| \\ +|\tilde{v}_{\tilde{A}}^L(\tilde{x}_j^*)-\tilde{v}_{\tilde{A}}^L(\tilde{x}_j^-)|+|\tilde{v}_{\tilde{A}}^U(\tilde{x}_j^*)-\tilde{v}_{\tilde{A}}^U(\tilde{x}_j^-)| \\ +|\tilde{\pi}_{\tilde{A}}^L(\tilde{x}_j^*)-\tilde{\pi}_{\tilde{A}}^L(\tilde{x}_j^-)|+|\tilde{\pi}_{\tilde{A}}^U(\tilde{x}_j^*)-\tilde{\pi}_{\tilde{A}}^U(\tilde{x}_j^-)| \end{pmatrix} \quad (9)$$

$$\pi_{\tilde{A}}^L = 1- \mu_{\tilde{A}}^U - v_{\tilde{A}}^U \quad (10)$$

$$\pi_{\tilde{A}}^U = 1- \mu_{\tilde{A}}^L - v_{\tilde{A}}^L \quad (11)$$

*Step 6.* The $Q_{(i)}$ value is calculated using Equations (12), (13), and (14). The value of "v" in Equation (12) is a coefficient expressed as "the majority of criteria." Alternatives are ordered by their $Q_{(i)}$ value. The alternative with the lowest $Q_{(i)}$ value is considered the best alternative.

$$Q_{(i)} = v\left(\frac{S_{(i)}-S^*}{S^- - S^*}\right) + (1-v)\left(\frac{R_{(j)}-R^*}{R^- - R^*}\right) \quad (12)$$

$$S^* = \min_i S_{(i)},\ S^- = \max_i S_{(i)} \quad (13)$$

$$R^* = \min_i R_{(i)},\ R^- = \max_i R_{(i)} \quad (14)$$

*Step 7.* At this stage, the compliance of two conditions is checked. In Condition 1, it is confirmed whether the most suitable alternative has an acceptable advantage. For this condition to be fulfilled, the $Q^{[2]} - Q^{[1]} \geq$ DQ condition must be met. Here, $Q^{[1]}$ denotes the first ranked alternative, and $Q^{[2]}$ denotes the second ranked alternative. The DQ value is calculated in the format DQ = 1 / $(A_z - 1)$. However, if the number of alternatives is four or less, it is considered DQ = 0.25.

Condition 2 checks whether the most suitable alternative is constant, that is, whether it has acceptable stability. If the most suitable alternative according to the $Q_i$ value is the most suitable alternative according to the $S_i$ and $R_i$ values, Condition 2 is met.

## Application

In the current study, an expert committee consisting of three people was formed to rank the importance of the criteria and the suitability of the alternatives. DMs follow careers as logistics and planning specialist ($DM_1$), logistics operations manager ($DM_2$) and procurement and supply chain lead engineer ($DM_3$). These DMs evaluated six criteria and four locations, and the steps followed in practice are given below.

*Step 1.* The DMs evaluate the importance of the criteria and the level of alternatives meeting the criteria in linguistic terms. Linguistic terms are converted to IVIFN via Tables 2 and 3. Their transformations into IVIFN of linguistic assessments according to the criteria are given in Table 4.

**Table 4.** IVIFN version of criteria assessments

| Criteria | $DM_1$ | $DM_2$ | $DM_3$ |
|---|---|---|---|
| $C_a$ | ([0.3, 0.35], [0.25, 0.3]) | ([0.2, 0.25], [0.3, 0.35]) | ([0.6, 0.65], [0.1, 0.15]) |
| $C_b$ | ([0.3, 0.35], [0.25, 0.3]) | ([0.2, 0.25], [0.3, 0.35]) | ([0.2, 0.25], [0.3, 0.35]) |
| $C_c$ | ([0, 0.05], [0.45, 0.5]) | ([0.3, 0.35], [0.25, 0.3]) | ([0.2, 0.25], [0.3, 0.35]) |
| $C_d$ | ([0.8, 0.85], [0.05, 0.1]) | ([0.95, 1], [0, 0]) | ([0.8, 0.85], [0.05, 0.1]) |
| $C_e$ | ([0.3, 0.35], [0.25, 0.3]) | ([0, 0.05], [0.45, 0.5]) | ([0.2, 0.25], [0.3, 0.35]) |
| $C_f$ | ([0.2, 0.25], [0.3, 0.35]) | ([0.3, 0.35], [0.25, 0.3]) | ([0.2, 0.25], [0.3, 0.35]) |

*Step 2.* The criterion weights are obtained using Equations (1) and (2). At this stage, the weights of the DMs are listed as 0.25, 0.45, and 0.30. Calculating the criterion weight of $C_a$ is shown below.

$$\breve{w}_{c_a} = 1 - \frac{0.25*(0.3+0.35)+0.45*(0.2+0.25)+0.3*(0.6+0.65)}{\sqrt{\begin{array}{c}(0.25*(0.3)^2+(0.35)^2+(0.25)^2+(0.3)^2)+\\(0.45*(0.2)^2+(0.25)^2+(0.3)^2+(0.35)^2)+\\(0.3*(0.6)^2+(0.65)^2+(0.1)^2+(0.15)^2)\end{array}}} = 0.243 \quad .$$

$$w_{c_a} = \frac{1-0.243}{6-2.102} = 0.194 \quad .$$

The weights of the criteria are listed as 0.194, 0.158, 0.131, 0.255, 0.093 and 0.169, respectively.

*Step 3.* The transformed versions of the linguistic assessments of the DMs regarding alternatives to IVIFN are presented in Table 5. These evaluations are combined using Equation (3). The aggregated fuzzy decision matrix obtained is given in Table 6.

**Table 5.** IVIFN version of alternative assessments

| $DM_i$ | $C_j$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|---|
| $DM_1$ | $C_a$ | [0.7, 0.75], [0.15, 0.2] | [0.6, 0.65], [0.25, 0.3] | [0.6, 0.65], [0.25, 0.3] | [0.5, 0.55], [0.35, 0.4] |
| | $C_b$ | [0.5, 0.55], [0.35, 0.4] | [0.3, 0.35], [0.55, 0.6] | [0.6, 0.65], [0.25, 0.3] | [0.4, 0.45], [0.45, 0.5] |
| | $C_c$ | [0.5, 0.55], [0.35, 0.4] | [0.3, 0.35], [0.55, 0.6] | [0.4, 0.45], [0.45, 0.5] | [0.2, 0.25], [0.65, 0.7] |

| | | | | | |
|---|---|---|---|---|---|
| | $C_d$ | [0.7, 0.75], [0.15, 0.2] | [0.3, 0.35], [0.55, 0.6] | [0.9, 0.95], [0.01, 0.04] | [0.5, 0.55], [0.35, 0.4] |
| | $C_e$ | [0.6, 0.65], [0.25, 0.3] | [0.7, 0.75], [0.15, 0.2] | [0.7, 0.75], [0.15, 0.2] | [0.5, 0.55], [0.35, 0.4] |
| | $C_f$ | [0.8, 0.85], [0.05, 0.1] | [0.4, 0.45], [0.45, 0.5] | [0.5, 0.55], [0.35, 0.4] | [0.8, 0.85], [0.05, 0.1] |
| $DM_2$ | $C_a$ | [0.9, 0.95], [0.01, 0.04] | [0.7, 0.75], [0.15, 0.2] | [0.7, 0.75], [0.15, 0.2] | [0.6, 0.65], [0.25, 0.3] |
| | $C_b$ | [0.4, 0.45], [0.45, 0.5] | [0.5, 0.55], [0.35, 0.4] | [0.6, 0.65], [0.25, 0.3] | [0.4, 0.45], [0.45, 0.5] |
| | $C_c$ | [0.3, 0.35], [0.55, 0.6] | [0.3, 0.35], [0.55, 0.6] | [0.5, 0.55], [0.35, 0.4] | [0.3, 0.35], [0.55, 0.6] |
| | $C_d$ | [0.7, 0.75], [0.15, 0.2] | [0.3, 0.35], [0.55, 0.6] | [0.7, 0.75], [0.15, 0.2] | [0.5, 0.55], [0.35, 0.4] |
| | $C_e$ | [0.7, 0.75], [0.15, 0.2] | [0.5, 0.55], [0.35, 0.4] | [0.7, 0.75], [0.15, 0.2] | [0.4, 0.45], [0.45, 0.5] |
| | $C_f$ | [0.8, 0.85], [0.05, 0.1] | [0.3, 0.35], [0.55, 0.6] | [0.4, 0.45], [0.45, 0.5] | [0.6, 0.65], [0.25, 0.3] |
| $DM_3$ | $C_a$ | [0.8, 0.85], [0.05, 0.1] | [0.5, 0.55], [0.35, 0.4] | [0.5, 0.55], [0.35, 0.4] | [0.6, 0.65], [0.25, 0.3] |
| | $C_b$ | [0.4, 0.45], [0.45, 0.5] | [0.5, 0.55], [0.35, 0.4] | [0.7, 0.75], [0.15, 0.2] | [0.5, 0.55], [0.35, 0.4] |
| | $C_c$ | [0.4, 0.45], [0.45, 0.5] | [0.4, 0.45], [0.45, 0.5] | [0.5, 0.55], [0.35, 0.4] | [0.4, 0.45], [0.45, 0.5] |
| | $C_d$ | [0.8, 0.85], [0.05, 0.1] | [0.4, 0.45], [0.45, 0.5] | [0.7, 0.75], [0.15, 0.2] | [0.4, 0.45], [0.45, 0.5] |
| | $C_e$ | [0.7, 0.75], [0.15, 0.2] | [0.6, 0.65], [0.25, 0.3] | [0.6, 0.65], [0.25, 0.3] | [0.4, 0.45], [0.45, 0.5] |
| | $C_f$ | [0.7, 0.75], [0.15, 0.2] | [0.3, 0.35], [0.55, 0.6] | [0.5, 0.55], [0.35, 0.4] | [0.5, 0.55], [0.35, 0.4] |

**Table 6.** Aggregated fuzzy decision matrix

| $C_j$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| $C_a$ | [0.838, 0.896], [0.032, 0.079] | [0.624, 0.676], [0.24, 0.29] | [0.624, 0.676], [0.24, 0.29] | [0.577, 0.627], [0.276, 0.326] |
| $C_b$ | [0.427, 0.477], [0.423, 0.473] | [0.456, 0.507], [0.407, 0.458] | [0.633, 0.684], [0.221, 0.271] | [0.432, 0.482], [0.422, 0.472] |
| $C_c$ | [0.386, 0.436], [0.463, 0.513] | [0.332, 0.382], [0.522, 0.572] | [0.477, 0.527], [0.377, 0.427] | [0.309, 0.359], [0.551, 0.602] |
| $C_d$ | [0.734, 0.786], [0.108, 0.162] | [0.332, 0.382], [0.522, 0.572] | [0.772, 0.833], [0.117, 0.163] | [0.472, 0.522], [0.382, 0.432] |
| $C_e$ | [0.678, 0.728], [0.17, 0.221] | [0.588, 0.64], [0.274, 0.325] | [0.673, 0.723], [0.181, 0.231] | [0.427, 0.477], [0.427, 0.477] |
| $C_f$ | [0.774, 0.825], [0.07, 0.123] | [0.326, 0.377], [0.527, 0.577] | [0.457, 0.507], [0.397, 0.447] | [0.64, 0.695], [0.238, 0.288] |

*Step 4.* In this step, PIS and NIS values are calculated and Equation (4) is used since all criteria are utility-based. The PIS and NIS of the criteria are presented in Table 7.

**Table 7.** PIS and NIS

| $C_j$ | PIS | NIS |
|---|---|---|
| $C_a$ | [0.838, 0.896], [0.032, 0.079] | [0.577, 0.627], [0.276, 0.326] |
| $C_b$ | [0.633, 0.684], [0.221, 0.271] | [0.427, 0.477], [0.423, 0.473] |
| $C_c$ | [0.477, 0.527], [0.377, 0.427] | [0.309, 0.359], [0.551, 0.602] |
| $C_d$ | [0.772, 0.833], [0.108, 0.162] | [0.332, 0.382], [0.522, 0.572] |
| $C_e$ | [0.678, 0.728], [0.17, 0.221] | [0.427, 0.477], [0.427, 0.477] |
| $C_f$ | [0.774, 0.825], [0.07, 0.123] | [0.326, 0.377], [0.527, 0.577] |

*Step 5.* The distance $(d(\tilde{f}_j^*, \tilde{x}_{ij})$ from the PIS to each alternative and the distance $(d(\tilde{f}_j^*, \tilde{f}_j^-)$ between the PIS and NIS are obtained (Table 8). Making use of these obtained values, $S_{(i)}$ and $R_{(i)}$ values are obtained using Equations (6) and (7) (Table 9).

**Table 8.** $d(\tilde{f}_j^*, \tilde{x}_{ij})$ and $d(\tilde{f}_j^*, \tilde{f}_j^-)$ values

| $C_j$ | $d(\tilde{f}_j^*, \tilde{x}_{ij})$ | | | | $d(\tilde{f}_j^*, \tilde{f}_j^-)$ |
|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | |
| $C_a$ | 0.009 | 0.219 | 0.219 | 0.255 | 0.265 |
| $C_b$ | 0.204 | 0.189 | 0.003 | 0.203 | 0.211 |
| $C_c$ | 0.089 | 0.148 | 0.003 | 0.177 | 0.177 |
| $C_d$ | 0.021 | 0.433 | 0.342 | 0.293 | 0.452 |
| $C_e$ | 0 | 0.104 | 0.011 | 0.256 | 0.261 |
| $C_f$ | 0 | 0.455 | 0.326 | 0.167 | 0.469 |

*Step 6.* Using Equation (12), the $Q_{(i)}$ values of the alternatives are reached (Table 9). At this stage, the majority of criteria value ($v$) was accepted as 0.5. The $Q_{(i)}$ values are listed as 0, 1, 0.094, and 0.632. According to these results, the most successful alternative is $A_1$. Alternatives are ranked according to their success as $A_1 > A_3 > A_4 > A_2$.

**Table 9.** $S_{(i)}$, $R_{(i)}$ and $Q_{(i)}$ values

| - | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|
| $S_{(i)}$ | 0.237 | 0.857 | 0.479 | 0.786 |
| $R_{(i)}$ | 0.153 | 0.244 | 0.193 | 0.187 |
| $Q_{(i)}$ | 0 | 1 | 0.415 | 0.629 |

*Step 7.* The compliance of Conditions 1 and 2 is verified. The difference between the $Q_i$ values of the second most suitable ($A_3$) alternative and the most suitable alternative ($A_1$) is 0.415 and is more than DQ = 0.25. In addition, $A_1$ which is the most suitable alternative, is also the best alternative in terms of $S_i$ and $R_i$ values. Therefore, Conditions 1 and 2 are accepted.

## Conclusion

The most strategic decision that can be made during the establishment of an LC is determining the location of the facility. In this study, a multi-criteria framework was developed for LC location considerations. The target of the research is to present an integrated method in which the IVIFN-based VIKOR technique is applied to determine the weights of the criteria used to evaluate LC locations and the alternatives and to select the best option.

The criteria for evaluating alternatives for LC selection were determined through a comprehensive and systematic literature review. As a result, criteria are listed in the form of intermodal connection (0.255), infrastructure (0.194), security/safety (0.169), proximity to customers (0.158), proximity to suppliers (0.131), and labour supply (0.093), according to their weighted importance. The results of the study provide useful findings for strategic DMs and LC users in the increasingly competitive logistics market. DMs should pay attention to the level of connection of the region with different transportation modes, especially when choosing an LC location. In addition, the logistics accessibility and infrastructure of the centre are other important factors.

VIKOR is an MCDM technique focused on evaluating alternatives in processes with conflicting criteria. The method has been accepted in the literature and has been used to solve many varied decision problems. However, in today's increasingly complex decision-making processes, traditional decision-making techniques cannot properly handle real-life problems. To overcome uncertainty in the decision-making process, making evaluations with IVIFN will provide effective results. Therefore, in the current study, a VIKOR extension has been proposed in which criteria and alternatives are expressed with IVIFN values to maintain the decision-making process effectively.

It has been tested on a real case to verify the feasibility of the proposed method and demonstrate its effectiveness. Four potential LC locations in Turkey were evaluated in line with the opinions of the three DMs, taking into account six criteria. With the developed approach, it has been seen that DMs can benefit from their preferences effectively and the method can be applied in a practical way.

Utilizing the findings obtained in the study, information that can give a competitive advantage to the selected LC location is readily accessible to the DMs. In addition, the IVIFN extended VIKOR method proposed in the study is an approach that can produce effective results in decision problems having incomplete and uncertain information. However, some aspects could be improved in future research. For example, sensitivity analysis might be used to analyse how results change with changes in criterion weights or alternative judgments. In addition, integrating a different technique that can be used in the determination of criterion weights in the proposed approach is a subject of study that can contribute to the literature.

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