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A Hybrid MCDM for the Location of Urban Distribution Centers under Uncertainty: A Case Study of Casablanca, Morocco

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Abstract: In this article, the main subject is the problem of the location of Urban Distribution Centers (UDC) in an environment characterized by uncertainty. Thus, a decision support process based on fuzzy multi-criteria methods (F-MCDM) will be proposed as the solution. The CATWOE method is used for identifying the Stakeholders (PPs) concerned by the localization. Furthermore, direct interviews and the review of the literature help to enhance the decision criteria. The use of the F-SWARA method made it possible to weight the criteria by taking into consideration the opinion of the PPs. The F-ENTROPY method corrected the subjectivity of the weights given by the first method. The hybridization of the two is a first in the literature in this field and allows precise and realistic results. In the end, the different alternatives obtained by the F-VIKOR method are ranked. This approach was applied to the city of Casablanca, which is extremely impacted by the negative externalities of urban freight transport. The results of this study showed that zone four (AIN SBAA) is the best zone to implement the UDC in the city of Casablanca. The sensitivity analysis validated the robustness of the model.

Keywords: fuzzy environment; location; multicriteria decision support method; Urban Distribution Center

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1. Introduction

With the rapid development of the global economy and the demographic concentration in cities (urban dwellers will increase from 54% in 2014 to 66% in 2050 (Dumond, 2018)), the organization of urban distribution has become paramount for the smooth functioning of the city [1]. A distribution system based on mutualization can not only improve traffic flow and mobility, but Urban Distribution Centres (UDCs) are also increasingly finding their place as intermediaries between suppliers and customers [2]. In concrete terms, UDCs are facilities involving the trans-shipment of goods directed to urban areas whose purpose is to manage flows to dense areas [3]. Their main functions are the storage and deconsolidation of goods, warehousing, distribution of these resources in dense areas with less cumbersome and ecological vehicles, and the pooling of infrastructures [4]. UDCs are often set up by a public initiative and can be managed by private or public actors [5]. In Morocco, the downstream of the multi-flow logistics zones (ZLMF) was established in 2014, and the objective of the UDCs is to receive goods from direct and indirect suppliers (companies, ZLMF, etc.), reorganize them according to customer demand, and distribute them with light commercial vehicles (cars, tricycles, etc.).

The choice of location of the UDCs is a strategic problem given that with these long-term repercussions, the economic aspect is not sufficient [6]. Businesses and public authorities are giving more and more importance to compliance with the principle of sustainability, which makes it possible to ensure the viability of the installation in the long term, while gaining on the economic, societal, and environmental side. From the point of view of public authorities, they require companies to respect their social responsibility. Among the decisions that all companies must make, taking these obligations into consideration, is the location of their facilities [7]. By carrying out a territorial analysis, which is based on elements internal to the company, such as the locations of its customers or its need in terms of surface area, or external, such as the state of the ground or the traffic conditions on the roads to take (see all the criteria of the study in Section 4), the company will be able to largely respect the principle of sustainable development for the choice of premises.

The location of UDCs is also a delicate decision given the large number of criteria to be taken into consideration, and also the multitude and divergence of stakeholder interests. In dealing with our problem, a degree of uncertainty and hesitation exists in the data, which verifies the location problem in a fuzzy environment.

After carefully studying the literature, the authors noticed that in-depth research on the establishment of a UDC has not been conducted before in Morocco. To fill this scientific gap in the field, a practical framework containing an F-MCDM tool and contradictory decisive criteria is introduced and applied. More importantly, the framework proposed here can significantly help other research for the establishment and localization of all kinds of logistics platforms in underdeveloped countries.

Taking the problem into account, we chose to deal with this problem with multi-criteria (MCDM) and multi-attribute decision support (MADM) methods in a fuzzy environment. Therefore, we used the F-SWARA and F-VIKOR methods for choosing the ideal location. The remainder of this paper is organized as follows: In the next section, an overview of the localization problems and in particular the problems of localization in a fuzzy environment are presented. In Section 3, the research methodology and the methods used are presented. In Section 4, the decision support process for the case study is explained in detail. Finally, in Section 5, the conclusions and outlines for future studies are clarified.

2. Literature Review

In this section, we will present the existing MCDM methods in the literature that deal with the problem of selecting the location of the distribution centers first in a certain environment. Then, we will introduce fuzzy triangular numbers as well as problem solving methods in a fuzzy environment. The use of MCDMs is justifiable given the multiple quantitative and qualitative criteria to be taken into consideration to select the locations of the distribution centers.

Several MCDM methods can be used to assist decision-makers, such as the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), multi-criteria optimization and trade-off solution (VIKOR), the technique of similarity of control preferences with the ideal solution (TOPSIS), the goal programming method (GP), multi-objective optimization based on ratio analysis (MOORA), the preference ranking method for enrichment evaluations (PROMETHEE), etc. Other MCDM methods complement the function of these methods by weighting the criteria used by these methods, such as the AHP, DELPHI method, Decision-Making Trial and Evaluation Laboratory (DEMATEL), Stepwise Weighted Assessment Ratio Analysis (SWARA), and Tuple Hybrid Ordered Weighted Average (THOWA). When a decision-making challenge incorporates an uncertain decision-making environment, a fuzzy theory is combined with MCDM approaches to develop fuzzy MCDM models that efficiently address problems.

2.1. Location Problems in the Literature

Wu, Yunna, et al. [8] addressed the selection of the optimal location for a wind-PV-seawater pumped storage power plant using a hybrid MCDM approach. Mihajlović, Jelena, et al. [9] worked on the application of some multi-criteria decision-making (MCDM) approaches for the selection of the location of fruit distribution centers in the southern and eastern regions of Serbia. The Analytical Hierarchy Process (AHP) and Weighted

Aggregate Sum Product Assessment (WASPAS) were implemented in this process for site evaluation and selection. Ulutaş, Alptekin, et al. [10] proposed an integrated grey MCDM model including a grey preference selection index (GPSI) and grey proximity indexed value (GPIV) to determine the most suitable warehouse location for a supermarket. Stoilova, Svetla D. et al. [11] proposed a methodology based on the combination of Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis and multi-criteria decision-making (MCDM) methods to select the most suitable location to establish an intermodal terminal. The Analytical Hierarchy Process (AHP) and the Preference Ranking Organization Method for Evaluation Enrichment (PROMETHEE) are the MCDM methods used in the paper. Zhang, Xinfang et al. [12] focused their model on the grey area relational analysis technique for preference ordering by similarity to the ideal solution (GARA-TOPSIS) and in combination with the Analytical Hierarchy Process, entropy method, and game theory. In their study, Badang, Dick Arnie Q et al. [13] combined GIS, AHP, and TOPSIS to obtain the optimal placement of photovoltaic power plants in the region of Cartagena, Spain. Khaengkhan, Martusorn, et al. [14] aimed to select the appropriate warehouse location, which is the objective of commercial organizations that purchase, produce, and store the agricultural products of grass flowers, using the multiple criteria decision-making theory (MCDM). Three methods were used in their studies, namely simple additive weighting (SAW), the Analytic Hierarchy Process (AHP), and the ideal solution similarity ordering preference technique (TOPSIS). A Shannon interval entropy approach was proposed by [15] to find the weights of the interval criteria. Then, a full interval TOPSIS approach was proposed to evaluate potential locations. Finally, using the obtained scores, a mixed-integer linear programming model was developed to meet the constraints and find an optimized set of potential locations for the new branches. Kamangar, Mohammad, et al. [16] suggested a new hybrid MCDM model to select a suitable location for groundwater recharge. The importance of each criterion and its classes was obtained using ANP and AHP methods. The overlay of layers was performed using the TOPSIS method. After removing the limitations, the final zoning map is presented in four classes. Ak, Muhammet Fatih, and A. C. A. R. Derya. [17] weighted the main criteria and sub-criteria with AHP. The ranking of criteria and alternatives was conducted with the TOPSIS method. In this study, the AHP–TOPSIS integrated criteria evaluation is conducted for the HSCW selection problem. Ulutaş, Alptekin et al. [18] developed a new GIS-based integrated MCDM model including fuzzy SWARA, and CoCoSo is introduced in the literature to solve the location selection problem for a logistics center. Al Amin, Md, et al. [19] solved warehouse selection problems using the appropriate MCDM process. Among the different methods, they found that through the AHP and TOPSIS methods, the evaluation criteria references the concerned objective and characteristics for similar criteria. Abdel-Basset, Mohamed, et al. [20] offered a new hybrid methodology for the siting of offshore wind power plants combining the Analytical Hierarchy Process (AHP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)-II in the neutrosophic environment.

2.2. The Problem of Location Literature in a Fuzzy Environment

2.2.1. Triangular Fuzzy Number

Our problem is the location of UCDs with the assumption of data uncertainty, and the subjectivity of the data that gives us the PPs. Therefore, a degree of hesitation blurs the data accuracy. In this situation, fuzzy logic is often the best solution to overcome this problem [21].

In a certain environment, each point represents an x-value. In a fuzzy environment, each element is represented by an interval $\breve{A} = (\tilde{a}1,\tilde{a}2,\tilde{a}3)$. $\tilde{a}1$ and $\tilde{a}3$ are the lower and upper bounds, respectively, and $\tilde{a}2$ is the most probable value of the fuzzy number $\widetilde{A}$. The operational laws of the fuzzy numbers $\widetilde{A} = (\tilde{a}1,\tilde{a}2,\tilde{a}3)$ and $\widetilde{B} = (\tilde{b}1,\tilde{b}2,\tilde{b}3)$ are presented in (1)–(4):

$$\breve{A} \oplus \widetilde{B} = \left(\tilde{a}1 + \tilde{b}1,\ \tilde{a}2 + \tilde{b}2,\ \tilde{a}3 + \tilde{b}3\right) \quad (1)$$

$$\breve{A} \ominus \widetilde{B} = \left(\tilde{a}1 - \widetilde{b}3,\ \tilde{a}2 - \widetilde{b}2,\ \tilde{a}3 - \widetilde{b}1\right) \tag{2}$$

$$\breve{A} \otimes B = \left(\tilde{a}1 \times \widetilde{b}1,\ \widetilde{\tilde{a}2 \times \widetilde{b}2},\ \tilde{a}3 \times \widetilde{b}3\right) \tag{3}$$

$$\breve{A} \oslash \widetilde{B} = \left(\frac{\tilde{a}1}{\widetilde{b}1}, \frac{\tilde{a}2}{\widetilde{b}2}, \frac{\tilde{a}3}{\widetilde{b}3}\right) \tag{4}$$

2.2.2. Location with Fuzzy Logic

To find the best location to build a solar power plant based on both quantitative and qualitative criteria, Wang, Chia-Nan, et al. [22] presents a multi-criterion decision-making model (MCDM) that combines the following three methodologies: the fuzzy analytic hierarchy process (FAHP), data envelopment analysis (DEA), and ideal solution similarity preference ordering technique (TOPSIS). Wang, Ruotong, et al. [23] relied on the fuzzy DEMATEL (Decision-Making Trial and Evaluation Laboratory) approach to establish the criteria weights when working on the location of an electric car battery exchange facility. The FOWA (Fuzzy Order Weighted Averaging) operator is then utilized to aggregate the expert's evaluation values, and the fuzzy MULTIMOORA (Multi-Objective Optimization by Ratio Analysis plus the Full Multiplicative Form) approach is employed to rank the options. Ali, Sajid, et al. [24] worked on the optimal site selection for onshore wind farm development in the territory of South Korea. Karaşan, Ali, İhsan Kaya, and Melike Erdoğan. [25] worked on the location selection of electric vehicle charging stations using the fuzzy MCDM method (DEMATEL, AHP, TOPSIS). Otay, Irem, and Serhat Atik [26] investigated the SF-AHP (Spherical Fuzzy Analytical Hierarchy Process) and SF-WASPAS (Spherical Fuzzy Weighted Aggregated Sum Product Assessment) methodologies. Uyanik, Cihan, et al. [27] introduced an integrated DEMATEL-IF-TOPSIS methodology for the problem of selecting the location of logistics centers. In this approach, an integrated method of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) approach and the intuitionistic fuzzy technique (IF) for ordering preference by similarity to ideal solution (TOPSIS) is used. Zha, Shanshan, et al. [28] considered a hybrid MCDM method using combined weight for the selection of facility layout in the manufacturing system. For this purpose, they proposed a hybrid fuzzy MCDM method with combination weight (CW) based on an integration with Delphi, fuzzy ANP, Entropy and fuzzy PROMETHEE (CW-DFAE-FP) to select the most suitable facility layout alternative in an aircraft assembly shop. Table 1 presents an overview of our literature review.

Table 1. Summary table of the literature.

Author	Methods Used	Fuzzy Logic	Year of Appearance
[6]	ENTROPY + TODIM		2019
[7]	AHP + WASPAS		2019
[8]	GPSI + GPIV		2021
[9]	AHP + PROMETHEE		2019
[10]	GARA + TOPSIS		2021
[12]	SAW + AHP + TOPSIS		2019
[14]	TOPSIS		2020
[11,12,17,19]	AHP + TOPSIS		2018, 2021, 2019, 2019
[16]	ANP + AHP + TOPSIS		2019
[18]	CoCOSo + SWARA		2020

Table 1. *Cont.*

Author	Methods Used	Fuzzy Logic	Year of Appearance
[20]	AHP + PROMETHEE		2021
[22]	AHP + DEA + TOPSIS	X	2018
[23]	DEMATEL + FOWA + MULTIMOOORA	X	2020
[24]	AHP	X	2017
[25]	DEMATEL + AHP + TOPSIS	X	2020
[28]	Delphi + ANP + Entropy + DEMATEL	X	2020
Our study	F-SWARA + F-ENTROPY + F-VIKOR	X	2022

3. Methodology

Figure 1 illustrates the recommended methodology. The formulation of the problem was the first step. The problem of selecting the location of UDCs was acknowledged. The authors of this research defined the criteria for selecting UDC locations based on an exhaustive review of the literature and expert comments. The parameters used in our research are territorial criteria. The problem addressed involves many criteria and alternatives in the selection process. MCDMs were developed to help decision-makers deal with such problems. They are frequently used in solving evaluation and sequencing problems involving many conflicting criteria. They are useful for determining the best alternative in a system with several alternatives and several contradictory criteria to take into account. To do this, the weight of the CDU location selection criteria was determined using F-SWARA methods (Fuzzy Stepwise Weighted Assessment Ratio Analysis) and entropy methods. Because we have a multi-attribute, multi-criteria problem involving numerous stakeholders with divergent interests, the F-SWARA technique allows us to weight the criteria without the stakeholders agreeing. All subjectivity from our approach is eliminated by the entropy method. The weights of the hybrid criteria were established by merging these two procedures. The F-SWARA and F-entropy methods were linked because they are both used to obtain objective criterion weights, and when they are combined, a more robust solution is obtained. The importance of the criteria obtained by the hybrid technique was then employed in the F-VIKOR method to obtain the final ranking of the best probable location. The latter is a well-known MCDM method for ranking alternatives that is being applied to fuzzy logic for the first time. The F-VIKOR technique was chosen due to competing and non-measurable criteria, and this method allows the ranking of options despite this limitation. In addition, to the best of the authors' knowledge and that of the literature study, it has never been combined with the weights of the hybrid criterion before, as is the case here. The sensitivity analysis will be used to validate this model by determining the impact of the criteria weights on the selection of UDC locations.

3.1. Fuzzy Stepwise Weighted Assessment Ratio Analysis (F-SWARA) Method

The Stepwise Weighted Assessment Ratio Analysis (SWARA) method is an MCDM method that aims to calculate the weights of criteria and sub-criteria. This method was developed by Keršuliene, Violeta et al. [29] to evaluate conflict resolution methods. Mavi, Reza Kiani, Mark Goh, and Navid Zarbakhshnia [30] added another dimension to the method by incorporating data uncertainty to select the third-party reverse logistics service providers.

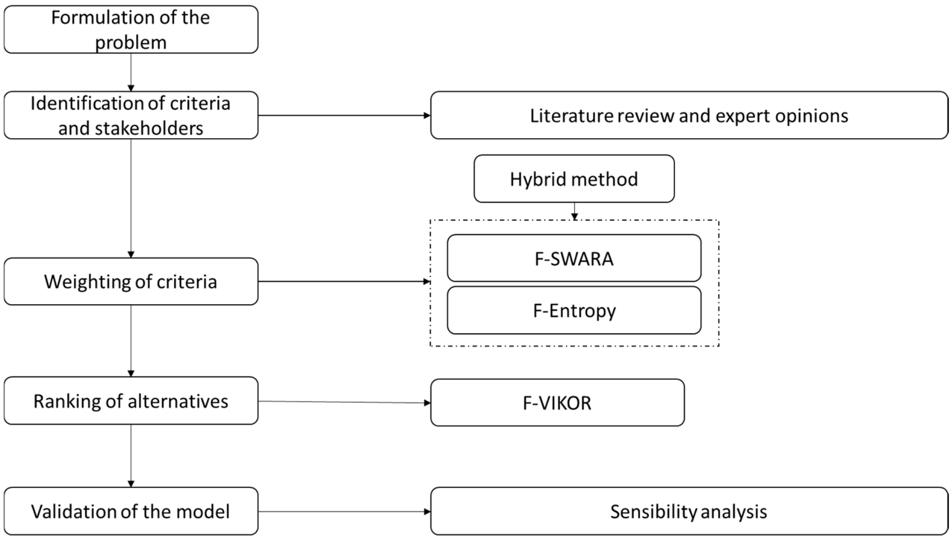

Figure 1. Flow chart of the methodology used for the evaluation and selection of potential UDC sites.

The most significant criterion is mentioned first and the least important is listed last in this manner. The weights of the criteria are determined in part by the experts (respondents). This method enables professionals to calculate the importance ratio of the criteria while calculating their weight. It is good at gathering and coordinating information from experts. Experts play a critical role in reviewing the estimated weights. Based on their tacit knowledge, information, and experience, each expert determines the importance of each criterion. Then, from the average value acquired from the experts, the weight of each criterion is decided.

The steps for applying the SWARA method are explained below:

Step 1: Sort the evaluation criteria by expected importance in descending $\widetilde{\text{O}}\text{j}$.

Step 2: Determine the relative relevance of criterion j in relation to the previous criterion ($j - 1$), which is more important, and proceed to the final criterion. After all experts had determined their respective importance scores, the geometric mean of the corresponding scores was calculated to aggregate their assessments.

$$\widetilde{\text{K}}\text{j} = \begin{cases} 1 & si\ j = 1 \\ 1 + \widetilde{o}j\ si & j \geq 1 \end{cases} \tag{5}$$

Step 3: Calculate the fuzzy weight $\widetilde{\text{O}}\text{j}$:

$$\widetilde{\text{Q}}\text{j} = \begin{cases} 1 & si \quad j = 1 \\ \frac{\widetilde{q}j-1}{\widetilde{k}j} & si \quad j \geq 1 \end{cases} \tag{6}$$

Step 4: Calculate the relative weights of the evaluation criteria $\widetilde{\text{P}}\text{j}$:

$$\widetilde{\text{P}}\text{j} = \frac{\widetilde{q}j}{\sum_j \widetilde{q}j} \tag{7}$$

Step 5: Steps 2, 3, and 4 are repeated for the sub-criteria independently of the weighting of the criteria, and the weight of each sub-criterion $\widetilde{\text{p}}'\text{j}$ is obtained.

Step 6: The sub-total criteria's weight is determined, this time considering the weight of the criteria $\widetilde{\text{P}}\text{jt}$:

$$\widetilde{\text{P}}\text{jt} = \widetilde{\text{p}}j * \widetilde{p}'j \tag{8}$$

Step 7: Normalize the weights below the criteria to have a sum equal to 1 at each weight parameter, as follows:

$$\widetilde{\mathrm{P}}\mathrm{j} = \frac{\widetilde{P}jt}{\sum_j \widetilde{P}jt} \tag{9}$$

This method was chosen to calculate the weight of the criteria, taking into consideration the opinion of each expert. The strength of this method is that, unlike other methods such as AHP, the analysis is carried out despite the diverging points of view of the PPs.

3.2. Entropy Method

Shannon proposed 'Shannon entropy', also known as information entropy [31]. Shannon entropy is used to measure the uncertainty of data, according to the definition of entropy. The criteria weight values were calculated using the Shannon entropy method.

Step 1: Normalize the matrix:

$$\widetilde{\mathrm{f}}\mathrm{ij} = \frac{\widetilde{m}ij}{\sum_j \widetilde{m}ij} \tag{10}$$

Step 2: Calculate the entropy of indicator j:

$$\widetilde{\mathrm{H}}\mathrm{j} = -\frac{\sum_j \widetilde{f}ij * \ln\left(\widetilde{f}ij\right)}{\ln(m)}\ (\mathrm{Hj} \geq 0;\ \mathrm{i} = 1, 2, \cdots, \mathrm{m};\ \mathrm{j} = 1, 2, \cdots, \mathrm{n}) \tag{11}$$

Step 3: Define the difference coefficient of the indicator:

$$\widetilde{\mathrm{g}}\mathrm{j} = 1 - \widetilde{H}j \tag{12}$$

Step 4: Calculate the weight of indicator j:

$$\widetilde{\mathrm{p}}'\mathrm{j} = \frac{\widetilde{g}j}{\sum_j \widetilde{g}j} \tag{13}$$

This method is used to find the measure of uncertainty associated with the source of information. In addition, the method is used to weight the criteria in an objective way, correcting the uncertainty of the data posed by the experts.

3.3. Hybridization of the F-SWARA and F-ENTROPY Methods

The combined weight can be obtained in Equations (9) and (13) [32]:

$$\widetilde{\omega}\mathrm{j} = \mu\widetilde{\mathrm{P}}\mathrm{j} + (1 - \mu)\widetilde{\mathrm{p}}'\mathrm{j} \tag{14}$$

where μ means the weight coefficient, $0 \leq \mu \leq 1$. The most appropriate value is 0.6, since it gives more robust results, taking into consideration the objective and subjective methods and slightly favouring the objective method.

3.4. Fuzzy Vlse Kriterijumska Optimizacija Kompromisno Resenje (F-VIKOR) Method

The F-VIKOR method (Vlse Kriterijumska Optimizacija Kompromisno Resenje, which means multi-criteria optimization and compromise solution in Serbian) is a method that was introduced by [33], which focuses on the selection and ranking of sets of alternatives according to different criteria. The author of [34] introduced vagueness in his approach to deal with a larger number of problems with this approach.

The steps for applying the F-VIKOR method are explained below:

Step 1: Group the data into a matrix $\widetilde{\mathrm{M}}\mathrm{ij}$.

Step 2: Determine the direction of the criteria (the benefit is to be maximized and the cost to be minimized).

Step 3: Calculate the best and worst solutions ($\widetilde{\text{M}}$i+ and $\widetilde{\text{M}}$i−):

$$\text{For profit functions}: \ \widetilde{\text{M}}\text{i}+ = \max\left(\widetilde{\text{M}}\text{ij}\right) \tag{15}$$

$$\widetilde{\text{M}}\text{i}- = \min\left(\widetilde{\text{M}}\text{ij}\right) \tag{16}$$

$$\text{For } \cos\text{t functions}: \ \widetilde{\text{M}}\text{i}+ = \min\left(\widetilde{\text{M}}\text{ij}\right) \tag{17}$$

$$\widetilde{\text{M}}\text{i}- = \max\left(\widetilde{\text{M}}\text{ij}\right) \tag{18}$$

Step 4: Calculate the fuzzy normalized difference

$$\text{For profit functions}: \ \widetilde{\text{d}}\text{jk} = \frac{\widetilde{m}i + -\widetilde{m}ij}{\widetilde{m}i + '3' - \widetilde{m}i - '1'} \tag{19}$$

$$\text{For } \cos\text{t functions}: \ \widetilde{\text{d}}\text{jk} = \frac{\widetilde{M}ij - \widetilde{M}i+}{\widetilde{m}i + '1' - \widetilde{m}i - '3'} \tag{20}$$

Step 5: Calculate the utility measure and the regret measure

$$\text{Measure of regret}: \widetilde{\text{R}}\text{k} = \sum_j \widetilde{p}j * \widetilde{d}jk \tag{21}$$

$$\text{Measure of utility}: \ \widetilde{\text{S}}\text{k} = \max \widetilde{\text{p}}\text{j} * \widetilde{\text{d}}\text{jk} \tag{22}$$

Step 6: Calculate the value of each solution, deduce the ideal solution

$$\widetilde{Q}k = \text{v} * \frac{\widetilde{S}k - \widetilde{S}*}{\widetilde{S}u - \widetilde{S}l} + (1 - \text{v})\frac{\widetilde{R}k - \widetilde{R}*}{\widetilde{R}u - \widetilde{R}l} \tag{23}$$

Step 7: unfuzzy $\widetilde{\text{S}}$k, $\widetilde{\text{R}}$k and $\widetilde{\text{Q}}$k.

$$\text{S}'\text{k} = (\text{SK1} + \text{SK2} + \text{SK3})/3 \tag{24}$$

$$\text{R}'\text{k} = (\text{SK1} + \text{SK2} + \text{SK3})/3 \tag{25}$$

$$\text{Q}'\text{k} = (\text{SK1} + \text{SK2} + \text{SK3})/3 \tag{26}$$

Step 8: Rank the alternatives according to Q'k and deduce the best locations.

This method is used to rank the alternatives according to the index of performance with contradictory and non-measurable criteria, assuming that the compromise is acceptable. Therefore, this method makes it possible to have the compromise solution closest to the ideal, all while moving away from the least good solution. In addition, the F-VIKOR method has been proven in the field of localization by several authors and is the most reliable when compared to other methods such as TOPSIS [35].

4. Decision-Making Process for Evaluating and Selecting UDC Location

The methodology described above was applied to a mass-market product in the city of Casablanca. The main reason for the example was that the city of Casablanca is the economic capital of the Kingdom of Morocco. Therefore, it is the city most affected by the problem of congestion and all its spill-over effects, whether for businesses, householders, or transporters.

4.1. Case Study on the City of Casablanca

4.1.1. Presentation of the Problem

Due to the negative externalities of freight transport in the city, a new UDC is to be set up in the city. The following assumptions are made:

- The existence of a need for a UDC.
- The existence of land that can potentially accommodate a UDC.
- Only territorial criteria influence the choice of location.

The objective of our work is to find the best location for the implementation of a UDC among the m alternatives, based on the n criteria and taking into consideration the opinion of the stakeholders. The set A = {A1, A2, . . . , Am} represents the set of alternatives. The set C = {C1, C2, . . . Cn} is the criteria, whose corresponding weights are noted as $\widetilde{p}$ = {$\widetilde{p}$1, $\widetilde{p}$2, . . . , $\widetilde{p}$j}, and their evaluation directions sw = {sw1, sw2, . . . , swj} with swj = {0, 1}. PP = {PP1, PP2, . . . , PPl} is the set of stakeholders. The weight of the criteria determined by the stakeholders is noted as wjk with j = {1, 2, . . . , N} as the index related to the criteria (N criteria). The data of the alternative sites with respect to the criteria are noted as $\widetilde{M}$ij with I = {1, . . . , M} and j = {1, . . . , N}.

4.1.2. Collection of Information

To demonstrate the feasibility of the method (F-SWARA + F-entropy + F-VIKOR), let us take the example of the city of Casablanca.

Situated in the center-west of Morocco, on the Atlantic coast, Casablanca is considered an economic center, which connects Moroccan cities and also Morocco and other countries of the world. Several tons of goods circulate every day, coming from internal trade, from the industrial zones of the city and other cities of the kingdom, or from international trade, using land transport, such as road and rail, or passing through the port of the city (second largest port of Morocco) and the airport. This enormous flow of goods ranks the city among the most congested cities in Morocco.

The city authorities want to implement a UDC to reduce congestion, and thus, ease traffic flow. The main entrances to the city are presented as A = {A1, A2, A3, A4, A5, A6, A7, A8}. The customers are distributed all over the city and concentrated on the exits of the city (which are at the same time the entrances) and in the commercial areas of the city.

4.2. Application of the Decision-Making Approach for the Location of UDCs

4.2.1. Determination of Stakeholders

To best determine the stakeholders, two methods were applied to identify them (a literature review and the CATWOE method), to be able to compare them and to consider the maximum.

4.2.1.1. Stakeholders in the Literature

Several authors have identified the stakeholders that are directly or indirectly related to the implementation problem. One is [36], who defines them as follows:

Economic Sphere

This category defends its own interest in the private logic of making its resource profitable. It is composed of the following two sub-categories:

- Entrepreneur: The project owner can be private, such as a transport company or a production company whose aim is to pool its resources with other companies, or public, in which case the initiative to set up a UDC can come from a governmental or local decision whose aim is to rationalize urban traffic and minimize the access of heavy goods vehicles to cities.
- Business: this can refer to either customers or suppliers; businesses will desire to minimize their transport costs through their collaboration with the UDC.

Urban Sphere

This category's goal is to maximize collective welfare in the public logic. It is also composed of the following two sub-categories:

- Residents or associations that defend them: they must understand the interest of the implementation of the UDC, knowing the benefits on traffic fluidity, the improvement of mobility in general, etc.
- Institutional: Institutions have a very important role in the implementation of the UDC. The improvement of the quality of life of citizens and the application of standards are the first priority of the institutions and the UDC helps in its application (time restrictions, banning of heavy goods vehicles in cities). The latter can also tighten up regulations to minimize the negative impact of transport in the city, which will also help the project to succeed.

4.2.1.2. CATWOE Method

To spot CPs through the CATWOE method, the following elements must be referenced:
The participants.
The owners who can create and modify the system.

➩ The municipality and Private entrepreneur.

Customers who are the direct recipients of the system.

➩ Upstream customer (suppliers) and downstream customer (company or individual).

Actors carrying out the activities of the system.

➩ It is a new activity (no existing competitors).

The people affected.
Groups of stakeholders who are directly needed by the system, e.g., resource providers.

➩ Carrier.

External groups indirectly affected by system activities.

➩ Neighbour.

External groups that indirectly affect the activities of the system.

➩ Everyone is affected by air pollution due to the activity of the system.

The criteria used are a combination of those identified by the first and second methods (see Table 2).

4.2.2. Determination of Criteria

The UDC location problem is a multi-criteria decision support problem (MCDM), i.e., several criteria can influence the choice. From the literature review, a selection of all criteria that can influence the choice of location is obtained. They were classified into the following four categories: economic, social/societal, environmental, and territorial. In this part, the location of UDCs based on territorial criteria is addressed. Five criteria and eleven sub-criteria were selected (Table 2). The choice of territorial criteria was made on the basis that most researchers have focused on economic, social, and environmental criteria, without taking into consideration the territorial characteristics of the location.

Table 2. Stakeholders selected following the interview with the managers.

Methods/PP	Municipalities (PP1)	Private Company (PP6)	Suppliers/Customers (PP2)	Transporters (PP3)	Residents (PP4)	People Affected by Air Pollution (PP7)	States (PP5)
PPi from the literature review	X	X	X	X	X		X
PPi from the CATWOE method	X	X	X	X	X	X	
Final PPs selected after interviews	X		X	X	X		X

To validate the criteria and the stakeholders that could influence the choice of the location of the UDC, interviews with some of the initial stakeholders to make a final decision were held. The following people were interviewed: the head of the municipality, a transport company that could potentially be interested in being the carrier of the UDC project, a supplier (upstream customer), a manager of a mini-market (downstream customer), and the manager of a transport company (carrier). The results of this survey are shown in Tables 3 and 4.

Table 3. Criteria of our model.

Criteria ID		Enumeration		Source
C1	C11	Allocated land	Availability of land	[5,37,38]
	C12		Possibility of extensions	[37,38]
C2	C21	Structure of the city	Existence and position of potential suppliers and customers in the urban air	[27,37–39]
	C22		Infrastructure of the city	[5,27,38]
C3	C31	Soil characteristics	Geographical conditions	[5,40]
	C32		Accessibility of the information system	[37]
C4	C41	Environmental safety	Environmental safety and security	[41,42]
	C42		Natural disaster risk	[5,27]
C5	C51	Government policy	Level of development of the area	[27]
	C52		Attractiveness of the region through investment in logistics	[42]
	C53		Government policy on the development of the area	[5,42,43]

Table 4. Criteria selected following interviews with managers.

Criteria	Validation (Y for Maintain, N for Reject)	Explanation
C11	Y	The existence of land that can accommodate a UDC is crucial to the choice of location
C12	N	A new UDC can be created in the area without sticking to the original
C21	Y	The position of the customers is important
C22	Y	The infrastructure will link the center to the customers, so it is important to consider its condition
C31	Y	The slope and quality of the soil directly influence the price of the land and its construction, and it is important to take this into consideration
C32	N	The information system is almost the same in all big cities
C41	Y	Safety and security are very important for this kind of project
C42	N	Disaster risk is low and equal in all areas
C51	Y	Acceptability of the project to the local population is important for its proper functioning
C52	Y	Are there other projects in the area that may be interested in the UDC? It is important to know the answer to this question, hence its interest.
C53	Y	This criterion is responsible for the long-term viability of the project

It can be observed that the interviewed managers validated the majority of the stakeholders (PP1, PP2, PP3, PP4, and PP5). Their choice was due to the fact that customers and transporters are the most concerned by the project, while local residents also have a role to play in the smooth running of logistics activities after the site is established. The state also plays an important role as it dictates the laws and thus can encourage, deny, or destroy the project (e.g., through laws on time restrictions or the type of vehicles used in the urban area). Our panel also set aside PP6 and PP7: the project must be carried by a public administration and not by a private company to ensure its viability.

4.2.3. Application of the Combined Method

The criteria weights were calculated using the F-SWARA and entropy methods after the criteria and stakeholders were described. To begin, the weights were calculated using each approach separately. Second, the hybrid weights were created by using the equation to combine the findings of both procedures (13). The results of the weights in criteria are given in Tables 5–7.

Table 5. Weight of Wj criteria by F-SWARA method.

Criteria	$\tilde{p}'j$	SUB-CRITERIA	$\tilde{P}j$	$\tilde{P}j=\tilde{p}j*\tilde{p}'j$
C1	(0.33,0.38,0.44)	C11	(0.95,1,1)	(0.31,0.38,0.44)
C2	(0.18,0.23,0.29)	C21	(0,45,0.5,0.55)	(0.081,0.11,0.15)
		C22	(0,45,0.5,0.55)	(0.081,0.11,0.15)
C3	(0.10,0.16,0.21)	C31	(0.95,1,1)	(0.095,0.16,0.21)
C4	(0.07,0.12,0.18)	C41	(0.95,1,1)	(0.065,0.12,0.18)
C5	(0.02,0.08,0.13)	C51	(0.25,0.3,0.35)	(0.005,0.024,0.045)
		C52	(0.25,0.3,0.35)	(0.005,0.024,0.045)
		C53	(0.25,0.3,0.35)	(0.005,0.024,0.045)

Table 6. Sub-criteria weights with the fuzzy entropy method.

	C11	C21	C22	C31	C41	C51	C52	C53
A1	(0.15,0.21,0.26)	(0.06,0.10,0.16)	(0.05,0.09,0.13)	(0.09,0.13,0.19)	(0.09,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
A2	(0.06,0.10,0.16)	(0.06,0.10,0.16)	(0.06,0.10,0.16)	(0.06,0.10,0.16)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
A3	(0.15,0.21,0.26)	(0.04,0.08,0.13)	(0.04,0.08,0.13)	(0.06,0.10,0.16)	(0.09,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
A4	(0.04,0.08,0.13)	(0.06,0.10,0.16)	(0.15,0.21,0.26)	(0.06,0.10,0.16)	(0.04,0.08,0.13)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
A5	(0.15,0.21,0.26)	(0.04,0.08,0.13)	(0.04,0.08,0.13)	(0.08,0.13,0.19)	(0.09,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
A6	(0.02,0.05,0.10)	(0.15,0.21,0.26)	(0.15,0.21,0.26)	(0.08,0.13,0.19)	(0.15,0.21,0.26)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
A7	(0.02,0.05,0.10)	(0.06,0.10,0.16)	(0.06,0.10,0.16)	(0.09,0.13,0.19)	(0.06,0.10,0.16)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
A8	(0.06,0.10,0.16)	(0.13,0.18,0.25)	(0.06,0.10,0.16)	(0.09,0.13,0.19)	(0.06,0.10,0.16)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)
Wej	(0.04,0.08,0.13)	(0.06,0.10,0.16)	(0.15,0.21,0.26)	(0.06,0.10,0.16)	(0.04,0.08,0.13)	(0.08,0.13,0.19)	(0.08,0.13,0.19)	(0.08,0.13,0.19)

Table 7. Weights according to the hybrid method.

Criteria	Weight with F-SWARA	Weight with F-Entropy	Final Weight
C11	(0.31,0.38,0.44)	(0.09,0.13,0.19)	(0.17,0.23,0.29)
C21	(0.081,0.11,0.15)	(0.08,0.13,0.19)	(0.08,0.12,0.17)
C22	(0.081,0.11,0.15)	(0.09,0.13,0.19)	(0.08,0.12,0.17)
C31	(0.095,0.16,0.21)	(0.04,0.08,0.13)	(0.06,0.11,0.16)
C41	(0.065,0.12,0.18)	(0.09,0.13,0.19)	(0.08,0.12,0.18)
C51	(0.005,0.024,0.045)	(0.15,0.21,0.26)	(0.09,0.13,0.17)
C52	(0.005,0.024,0.045)	(0.06,0.10,0.16)	(0.03,0.06,0.11)
C53	(0.005,0.024,0.045)	(0.06,0.10,0.16)	(0.03,0.06,0.11)

The results of the hybrid F-SWARA/F-Entropy method are as follows:

$\widetilde{P}j$ = {(0.31,0.38,0.44); (0.081,0.11,0.15); (0.081,0.11,0.15); (0.095,0.16,0.21); (0.065,0.12,0.18); (0.005,0.024,0.045); (0.005,0.024,0.045); (0.005,0.024,0.045)} represents the respective weights of the sub-criteria for all stakeholders. These weights will be used to feed the F-VIKOR method to choose the best location for the implementation of the UDC.

Applying the F-VIKOR method shows the performance indexes of each alternative Pj. The scores and ranking are given in Table 8.

Table 8. Performance index of alternatives.

	F-SWARA		F-ENTROPY		Hybridation	
	Pi	**Rank**	**Pi**	**Rank**	**Pi**	**Rank**
A1	0	8	0	8	0	8
A2	1.0244145	6	0.99512365	5	0.64068348	5
A3	0.6547895	7	0.55365478	6	0.368209814	7
A4	2.0324895	1	1.54948762	1	1.728088018	1
A5	1.5236547	4	0.25321456	7	0.53358569	6
A6	1.3652489	5	1.52365789	2	1.417528352	3
A7	1.8563214	2	1.42146972	3	1.55667757	2
A8	1.6245879	3	1.12365478	4	0.753944441	4

Result of the F-VIKOR Method

According to the results of our research, the entrance to the city of Casablanca where the regional road linking the coastal cities to the Atlantic passes (A4) is the best alternative for establishing a UDC in Casablanca, followed by A7 and so on: A4 > A7 > A6 > A8 > A2 > A5 > A3 > A1.

4.2.4. Interpretation of Results

The weights obtained via fuzzy F-SWARA are utilized as input for the fuzzy F-VIKOR approach in this part. The steps of the combined method are performed as shown in Tables [4,8].

- The ranking of the alternatives is different when considering the hybrid method and the weighting methods each separately, which shows that the use of the hybridization method makes it possible to obtain a result that combines the two methods and approaches more than reality.
- Alternative 4 was selected as the best option, as it is a regional road connecting the city with several internal and external industrial centers. Very close to potential customers and logistics platforms, a UDC in this location can be a major asset for the city. The only drawback is the low availability of land in the desired area.
- The next most effective UDCs are alternatives 7 and 6, where the most effective criteria were the proximity to internal customers and security, since this alternative is in the city center. The main weakness of these alternatives is the state of the road, which is very congested by the various road users and the permanent road works.
- Alternatives 1 and 3 were voted as the worst UDC locations. The distance and the low demand from nearby customers tipped the analysis towards this result. On the positive side, the availability of land and the safety of the area should not be ruled out.
- The other UDC alternatives were positioned between the high- and low-ranking alternatives mentioned.
- Various criteria can be utilized in MCDM models. In this case, 11 criteria in five dimensions in this study were looked for. Other factors, such as economic, societal, and environmental consequences, were not considered in this study.
- Criteria are always confronted with uncertainty in studies in the field of selection procedures, such as this one. However, fuzzy logic was used in this study to deal with and overcome uncertainty. Other strategies for overcoming uncertainty (such as stochastic data and grey numbers) were also accessible but they do not matter

for the study. Finally, the model may be solved using all three methods, and the results compared.

To be able to validate this model, let us observe a sensitivity analysis.

4.3. Sensitivity Analysis

To measure the influence of the weights of the criteria on the selection of the optimal location, let us carry on to a sensitivity analysis. The objective of this analysis is to verify the stability and robustness of the model by varying the weights of the criteria. Five experiments are required. In each experiment, one criterion is emphasized over the others. Tables 9 and 10 present the details of these experiments.

Table 9. Experiments proposed for the sensitivity analysis.

Experience	C1	C2	C3	C4	C5
EXP1	(0.8,0.9,1)	(0,0.1,0.2)	(0,0.1,0.2)	(0,0.1,0.2)	(0,0.1,0.2)
EXP2	(0,0.1,0.2)	(0.8,0.9,1)	(0,0.1,0.2)	(0,0.1,0.2)	(0,0.1,0.2)
EXP3	(0,0.1,0.2)	(0,0.1,0.2)	(0.8,0.9,1)	(0,0.1,0.2)	(0,0.1,0.2)
EXP4	(0,0.1,0.2)	(0,0.1,0.2)	(0,0.1,0.2)	(0.8,0.9,1)	(0,0.1,0.2)
EXP5	(0,0.1,0.2)	(0,0.1,0.2)	(0,0.1,0.2)	(0,0.1,0.2)	(0.8,0.9,1)

Table 10. Result of the sensitivity analysis.

Alternative/ Experience	Initial Solution	EXP1	EXP2	EXP3	EXP4	EXP5
A1	8	8	6	8	6	8
A2	5	6	4	7	5	6
A3	7	7	8	6	7	7
A4	3	4	5	2	8	5
A5	6	1	7	1	1	1
A6	1	2	1	3	2	2
A7	2	3	2	4	3	3
A8	4	5	3	5	4	4

As can be seen in Figure 2, all five experiments favor the choice of A4 and A5. Thus, even giving the priority to one criterion over the others, i.e., putting one of the criteria at 80% importance and the others at 5%, and recalculating the weights of the sub-criteria simultaneously, the choice of location remains unchanged.

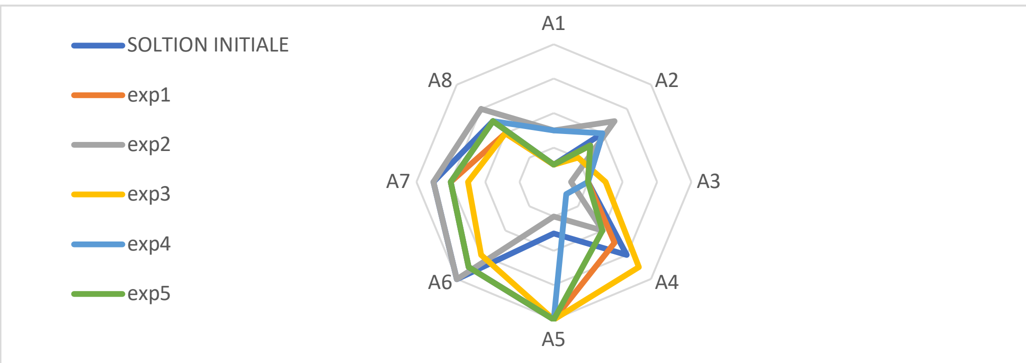

Figure 2. The direction of the experiments in the sensitivity analysis.

The sensitivity analysis then shows that the choice of the location of the UDC in the city of Casablanca remains insensitive to the weights of the criteria; it also shows the robustness of the model.

5. Conclusions and Perspectives

This study's purpose is proposing a decision support process for the evaluation and selection of the location of UDCs with fuzzy logic. The primary goal of the suggested methodology was to make a theoretical contribution to the subject of logistics hub location that would aid managers and scientists in considering several approaches to evaluating and selecting the location of their LFPs.

The best choices were ranked using a combination of three methods. The F-SWARA approach was used to determine the weights of the criterion by considering the opinions of the stakeholders. The F-Entropy approach was used to eliminate subjectivity from the data. To generate a ranking of viable alternatives, the F-VIKOR approach was combined with the F-SWARA and F-Entropy methods. The final ranking results were unchanged in each case, whether separate (F-entropy-F-VIKOR; F-SWARA-F-VIKOR) or coupled (hybrid-F-VIKOR). The goal of combining the first two procedures was to obtain objective criteria weights, which should result in more reliable outcomes. A sensitivity analysis was performed to test the stability of the proposed hybrid F-VIKOR approach. When five trials of adjusting the criteria weights were undertaken, the results of the study revealed that there was no change in the ranking alternatives. The compound approach to the LFP locating process yielded the following ranking order in our case study: A4 > A6 > A8 > A2 > A5 > A3 > A1. The AIN SBAA area was determined as the best possible alternative using this method. The entry connected to the A7 highway, on the other hand, was the lowest-ranked option. As a result, it is strongly advised to choose the AIN SBAA area, as it was determined to be the best option using the technique.

The major contributions of this article are as follows: (i) A novel combination of methodologies for locating urban distribution locations was introduced. (ii) A hybrid method combining the F-SWARA and F-Entropy methods was utilized to prioritize the factors impacting location selection; by combining two objective methodologies into one hybrid method, subjectivity was minimized and a more robust answer was created. (iii) To rate probable UDC sites, a novel hybrid-FVIKOR approach was created. (iv) The approach was explained in a straightforward and simple manner, and it should be useful in the field of LFP siting.

The limitations of this research may point to places where it could be expanded. The following limitations were identified: (1) the methodology was applied based on stakeholder scores; (2) the criteria influencing the decision-making process were filtered not only through the literature review, but also through expert opinions—indeed, the filtering was primarily conducted through discussions with experts in the field; (3) the problem has been treated with triangular fuzzy numbers, but the data can be much more complex, so the next study will be directed towards quasirung fuzzy sets [44] and q-rung fuzzy numbers [45].

The methodology, however, is generic and can be used with any other parameters that influence the evaluation and selection of LFP locations. The main goal of the paper was to demonstrate that the approach could be used to answer the above-mentioned research questions. (4) Further limitations include: only territorial criteria were evaluated. It is also feasible to incorporate any other factors that should be considered during the decision-making process, such as economic, social, and environmental considerations; (5) the authors did not investigate how this procedure may be included into the broader LFP management strategy in the research area, particularly for the current multi-flow logistics zones (MFLZs) for Morocco as an upstream client.

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