Evaluation of Pharmacy Warehouse Location Selection Factors under Pandemic Conditions

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Abstract

Determining the most suitable pharmaceutical warehouse locations for drug distribution, which is discussed in this study, is an important problem that needs to be addressed not only in the pandemic period but also in the pre-pandemic periods. The basis of drug distribution is to provide the necessary structure for health systems by providing drugs at the right time and in the right place. Therefore, proper execution of supply chain activities on behalf of this sector is a critical issue. Especially during the pandemic process, a complex structure has emerged for the optimization of the distribution process, with the inclusion of new implementations such as the distribution of COVID-19 drugs and vaccination. At this point, the problem of where the pharmaceutical warehouses should be located in order to ensure that drugs and vaccines can be delivered to the relevant places as soon as possible has gained importance. In this study, we handle the pharmacy warehouse location problem by considering the pandemic conditions and aim to determine the critical factors and their order of importance. For this purpose, after detailed literature research and interviews with experts are conducted, we determine the factors in the selection of the pharmacy warehouse location and determined the weights of these factors using multi-criteria decision-making analysis. Intuitionistic fuzzy sets are used to take into account the uncertainty in the decision process. As a result, the most important and the least important criteria for the location of the pharmacy warehouse during the pandemic process are determined.

Keywords
COVID-19, Intuitionistic Fuzzy Sets, Location Selection, Pharmaceutical Warehouse, SAW

1. Introduction
Pharmaceutical warehouses are important centers that ensure that sufficient quantities of drugs, medical consumables, laboratory products and other support materials are kept in stock, in line with the needs and demands of health and medical supplies, in order not to delay the service in health institutions such as hospitals and pharmacies (Kokilam et al. 2015). Pharmaceutical warehouses serve public institutions and organizations, community pharmacies, other medical device warehouses, private hospitals, private practice, medical device manufacturers, buyers abroad, retail sales centers and different stakeholders of the health sector (Yadav, 2015). Changing demand points can have direct effects on supply chain strategy. The supply network needs to be managed effectively.

The process of supplying pharmaceutical products within the health sector is critical to effectively delivering these products to demand points. The error-free structure of the health sector and the combination of the determined obligations require businesses to make the right decision. A problem that may occur at any stage in the supply process of pharmaceutical products may pose a serious risk that will adversely affect human and public health. In recent years, public and private companies have made great efforts to increase the agility, flexibility and reliability of the pharmaceutical supply chain. It is very important for the selection of a pharmacy warehouse location that will provide suitable warehouse conditions for patient health and safety and a suitable location to meet customer demand.

It is important to consider many factors, including different parameters, together in order to make more accurate decisions when determining a pharmaceutical warehouse location. Problems related to pharmaceutical warehouses have been the subject of many studies due to the importance of the supply chain in terms of human health and its complex structure. Papageorgiou et al. (2001) focused on the pharmaceutical supply chain and developed the novel mixed integer mathematical model for pharmaceutical companies to develop their storage and distribution strategies. Pedroso and Nakano (2009) studied how the information flow should be in the pharmaceutical product supply network, taking into account that consumers make decisions within the knowledge of the doctor while buying drugs. Yu et al. (2010) examined the pharmaceutical products supply chain in China and determined the performance and weakness of the chain. Rossetti et al. (2011) identified key components that change the way biopharmaceutical drugs are purchased, distributed, and sold throughout the supply chain. Masoumi et al. (2012) proposed a generalized oligopoly model for pharmaceutical supply chains using variational inequality theory. Weraikat et al. (2016) proposed an effective coordination model for reverse logistics in the pharmaceutical supply chain. Nematollahi et al. (2017) focused on two-stage pharmaceutical product supply chains to maximize the occupancy rate in the supply chain. Zahiri et al. (2018) developed a stochastic optimization model to handle uncertainty in perishability, substitutability and discounts in bulk purchases of pharmaceutical products. Haial et al. (2020) determined the most appropriate network structure in the pharmaceutical products supply chain, which they dealt with in three stages, with multi-criteria decision-making methods. Ji (2019) dealt with the problem of drug delivery from hospitals and pharmacies to patients and modeled the problem as a vehicle routing problem with time windows. Bahadori-Chinibelagh et al. (2019) considered a drug delivery problem with a large number of pharmaceutical warehouses as a multi-store vehicle routing problem. Yimenu et al. (2021) focused on the management of pharmaceutical warehouse by using an institution-based cross-sectional study method. Abideen and Mohamad (2021) utilized value stream mapping to improve the performance of the Malaysian pharmaceutical warehouse supply chain.

As can be seen in the literature review on pharmaceutical supply chain based studies, there is a limited number of studies on determining criteria weights for pharmaceutical warehouse location selection problems. Therefore we focus on determining and prioritizing criteria for pharmaceutical warehouse location selection problem. In this study, we first review the related literature to define the criteria then interview with the anonymous experts to evaluate criteria prioritiesby applying the intuitionistic fuzzy Simple Additive Weight (IF-SAW). This study is organized as follows: The adopted methodology is explained in Section 2. The real case study is presented in Section 3. Lastly, the conclusions and future recommendations are given in the last section.

2. Adopted Methodology

This section contains general information about IFSs (Atanassov, 1986, Demircioğlu and Ulukan, 2020).

2.1 Preliminaries

Let a set E be fixed and let $A \subset E$ be a fixed set. An IFS, indicated as A^* in E, is a set that has a form as

$$A^* = \{\langle x, \mu_A(x), v_A(x)\rangle : x \in E\}$$

where functions μ_A: E → [0, 1] and v_A: E →[0, 1] presents the degree of membership non-membership of the element x ∈ E accordingly, for every $x \in E$; $0 \leq \mu_A(x) + v_A(x) \leq 1$ and thus, $0 \leq \mu_A(x) \leq 1$ and $0 \leq v_A(x) \leq 1$. Since every ordinary fuzzy set has the structure $\{\langle x: \mu_A(x), 1-\mu_A(x)\rangle : x \in E\}$ and $0 \leq \mu_A(x) + v_A(x) \leq 1$, it is described $\pi_A(x)$ called as "the degree of non-determinacy (uncertainty) of the membership" of element $x \in E$ which is shown by (Atanassov, 1989):

$$\pi_A(x) = 1 - \mu_A(x) - v_A(x) \tag{1}$$

In the case of $\pi_A(x) = 0$, IFS becomes a classical fuzzy set that satisfies $v_A(x) = 1 - \mu_A(x)$. With the help of the above statements, it can also be written a more comprehensive IFS as:

$$A^* = \{\langle x, \mu_A(x), v_A(x)\rangle : x \in E \& 0 \leq \mu_A(x) + v_A(x) \leq 1\} \tag{2}$$

where $\mu_A(x) \to [0,1]$; $v_A(x) \to [0,1]$and $\pi_A(x) \to [0,1]$.

The basic arithmetic operations on IFSs can be conducted as in the following equations (Atanassov, 1986; Kumar De et al. 2000). Let $A = \{\langle x, \mu_A(x), v_A(x)\rangle : x \in E\}$ and $B = \{\langle x, \mu_B(x), v_B(x)\rangle : x \in E\}$ two IFSs, then:

Summation:

$$A + B = \{\langle x, \mu_{A+B}(x), v_{A+B}(x)\rangle : x \in E\} \quad (3)$$

where $\mu_{A+B}(x) = \mu_A(x) + \mu_B(x) - \mu_A(x) \cdot \mu_B(x)$ and $v_{A+B}(x) = v_A(x) \cdot v_B(x)$.

Subtraction:

$$A - B = \{\langle x, \mu_{A-B}(x), v_{A-B}(x)\rangle : x \in E\} \quad (4)$$

where

$$\mu_{A-B}(x) = \begin{cases} \frac{\mu_A(x) - \mu_B(x)}{1 - \mu_B(x)}, & \text{if } \mu_A(x) \geq \mu_B(x) \text{ and } v_A(x) \leq v_B(x) \\ & \text{and } v_B(x) > 0 \\ & \text{and } v_A(x) \cdot \pi_B(x) \leq \pi_A(x) \cdot v_B(x) \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

and

$$v_{A-B}(x) = \begin{cases} \frac{v_A(x)}{v_B(x)}, & \text{if } \mu_A(x) \geq \mu_B(x) \text{ and } v_A(x) \leq v_B(x) \\ & \text{and } v_B(x) > 0 \\ & \text{and } v_A(x) \cdot \pi_B(x) \leq \pi_A(x) \cdot v_B(x) \\ 1, & \text{otherwise} \end{cases} \quad (6)$$

Multiplication:

$$A \times B = \{\langle x, \mu_{A\times B}(x), v_{A\times B}(x)\rangle : x \in E\} \quad (7)$$

where $\mu_{A\times B}(x) = \mu_A(x) \cdot \mu_B(x)$ and $v_{A\times B}(x) = v_A(x) + v_B(x) - v_A(x) \cdot v_B(x)$

Multiplication by a number: Let n a real number where $n \geq 0$

$$n.A = \{\langle x, \mu_{n\cdot A}(x), v_{n.A}(x)\rangle : x \in E\} \quad (8)$$

where $\mu_{nA}(x) = 1 - [1 - \mu_A(x)]^n$ and $v_{nA}(x) = [v_A(x)]^n$.

n is a positive integer or $n = 1/k$ with k a positive integer. Former is used for multiplication of IF number by a positive integer, while latter is used for a division of IF number by a positive integer.

Division:

$$A : B = \{\langle x, \mu_{A:B}(x), v_{A:B}(x)\rangle : x \in E\} \quad (9)$$

where

$$\mu_{A:B}(x) = \begin{cases} \frac{\mu_A(x)}{\mu_B(x)}, & \text{if } \mu_A(x) \geq \mu_B(x) \text{ and } v_A(x) \leq v_B(x) \\ & \text{and } v_B(x) > 0 \\ & \text{and } v_A(x) \cdot \pi_B(x) \leq \pi_A(x) \cdot v_B(x) \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

and

$$v_{A:B}(x) = \begin{cases} \frac{v_A(x) - v_A(x)}{1 - v_B(x)}, & \text{if } \mu_A(x) \geq \mu_B(x) \text{ and } v_A(x) \leq v_B(x) \\ & \text{and } v_B(x) > 0 \\ & \text{and } v_A(x) \cdot \pi_B(x) \leq \pi_A(x). v_B(x) \\ 1, & \text{otherwise} \end{cases} \quad (11)$$

Power by a number: Let n a real number

$$A^n = \{\langle x, \mu_{A^n}(x), v_{A^n}(x)\rangle : x \in E\} \quad (12)$$

where $\mu_{A^n}(x) = [\mu_A(x)]^n$ and $v_{nA}(x) = 1 - [1 - v_A(x)]^n$

Score function:

A score function $S(A)$ of an *IF* number can be represented as follows (Kaur and Kumar, 2012)

$$S(A) = \mu - v, \quad S(A) \in [-1,1] \quad (13)$$

Table 1 Linguistic variables and corresponding IF numbers

Linguistic Terms	**μ**	**v**	**π**
Very Important (VI)	0.90	0.05	0.05
Important (I)	0.75	0.20	0.05
Somewhat Important (SI)	0.60	0.30	0.10
Medium Important (MI)	0.50	0.40	0.10
Somewhat Unimportant (SU)	0.30	0.60	0.10
Unimportant (U)	0.25	0.60	0.15
Very Unimportant (VU)	0.10	0.80	0.10

2.2. IF-SAW

The Simple Additive Weight (SAW) is one of the most used MCDM approaches developed by Hwang and Yoon (1981). It is used to rate the performance of the weighted sum of each alternative on all attributes (Ramadiani et al. 2019). Let $C_1, C_2, C_3 ..., C_m$ be the attributes in the decision-making problem. The weights of decision-makers are represented by a weighting vector $W=\{W_1, W_2, W_3 ..., W_n\}$. $m \times n$ matrix is constructed where m presents the nufmber of criteria and n presents the number of decision-makers. The steps of the IF-SAW methodology is shown as follows:

Step 1. Get the evaluations of the factors created by using the linguistic expressions in Table 1 from the decision-makers by means of a questionnaire. The $\boldsymbol{\mu}, \boldsymbol{\pi}$ *and* $\boldsymbol{v}$ in Table 1 show the degree of membership, non-membership and non-determinacy (uncertainty) values for each linguistic term, respectively.

Step 2. Convert the linguistic evaluations of decision-makers to IF numbers and construct an intuitionistic fuzzy decision matrix: $\tilde{R} = (\tilde{\boldsymbol{r}}_{ij})_{mxn}$ such that:

$$\tilde{R} = \begin{pmatrix} \tilde{r}_{11} & \cdots & \tilde{r}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{r}_{m1} & \cdots & \tilde{r}_{mn} \end{pmatrix}$$

where $\tilde{r_{ij}} = (\mu_{ij}, v_{ij}, \pi_{ij})(i = 1,2, ..., m; j = 1,2, ..., n)$ which are contained in an intuitionistic fuzzy decision matrix.

Step 3. Determine the weight of decision-makers based on their experience, knowledge and level of expertise on the subject as $W=\{W_1, W_2, W_3 ..., W_n\}$.

Step 4. Calculate the weighted IF decision matrix by using Equation (8) in the IF environment by multiplying the weights of decision-makers with criteria evaluations.

Step 5. Aggregate the weighted evaluations by using Equation (3) where the IF numbers are recursively summed.

Step 6. Determine the score function for each criteria $S(C_1), S(C_2), ..., S(C_m)$ with using Equation (13).

Step 7. Normalize the score function values of each criterion and rank the criteria according to their normalized score function. The largest value of $S(C_m)$ shows the most important criteria.

3. Real Case Study

In this paper, the factors to be considered in the selection of pharmaceutical warehouse location under pandemic conditions are determined and the importance weights of these factors are calculated. First of all, detailed literature research is carried out and which factors are considered in the selection of the pharmacy warehouse location before the pandemic period is defined; it is investigated which factors are taken into account in the selection of health institutions along with the pandemic process. Then, the experts/decision-makers whose evaluations will be taken in this decision problem are determined and interviews are made with each expert and their evaluations about the criteria are obtained through a questionnaire. Six criteria are determined for the decision-making process such as C_1: Proximity to target locations (Hospital, pharmacy,…), C_2: Infrastructure of the area, C_3: Accessibility, C_4: Cost, C_5: Climate conditions and C_6: Pandemic conditions. Table 2 shows the evaluations of decision-makers (DMs) for each criterion with linguistic evaluators shown in Table 1. For example, decision maker-1 evaluates the C1 criteria as Somewhat Important (SI) as shown in Table 2. Table 3 shows the corresponding IF numbers of evaluations in Table 2.

Table 2. DM's evaluations in linguistic form

	DM-1	***DM-2***	***DM-3***	***DM-4***
C1	SI	MI	VI	I
C2	I	U	SI	SI
C3	MI	SI	I	VI
C4	VI	I	MI	SU
C5	U	SI	SU	MI
C6	SI	MI	I	I

Table 3. Corresponding IF numbers of evaluations

	DM-1		**DM-2**		**DM-3**		**DM-4**	
	μ	**v**	**μ**	**v**	**μ**	**v**	**μ**	**v**
C1	0.6	0.3	0.5	0.4	0.9	0.05	0.75	0.2
C2	0.75	0.2	0.25	0.6	0.6	0.3	0.6	0.3
C3	0.5	0.4	0.6	0.3	0.75	0.2	0.9	0.05
C4	0.9	0.05	0.75	0.2	0.5	0.4	0.3	0.6
C5	0.25	0.6	0.6	0.3	0.3	0.6	0.5	0.4
C6	0.6	0.3	0.5	0.4	0.75	0.2	0.75	0.2

While taking evaluations for the criteria, specifications about decision-makers are also taken into account. Our decision-makers consist of four researchers as decision-makers who have previously sought solutions to location selection of health institution problems. Different weights are determined for each of these researchers, taking into account their working years, the number of studies and area of study. Accordingly, the weight of the first decision-maker is specified as 0.15, the weight of the second decision-maker is specified as 0.25, the weight of the third decision-maker is specified as 0.20 and the weight of the fourth decision-maker is specified as 0.40. Table 4 shows the weighted decision matrix which is obtained through multiplying evaluations with weights of decision-makers. As an example of the calculations, to find the values in the first and second column of the C1 criteria in Table 4, the weight of the first decision maker's, 0.15, is multiplied with the quantitative corresponding of the evaluation score (SI) shown in Table 3 with using Equation (8).

Table 4. Weighted decision matrix

	DM-1		**DM-2**		**DM-3**		**DM-4**	
	μ	**v**	**μ**	**v**	**μ**	**v**	**μ**	**v**
C1	0.128417	0.834773	0.159104	0.795271	0.369043	0.54928	0.425651	0.525306
C2	0.187748	0.785515	0.069395	0.880112	0.167447	0.786003	0.306855	0.617801
C3	0.098750	0.871583	0.204729	0.740083	0.242142	0.72478	0.601893	0.301709
C4	0.292054	0.638036	0.292893	0.668740	0.129449	0.832553	0.132960	0.815193
C5	0.042234	0.926238	0.204729	0.740083	0.068850	0.90288	0.242142	0.693145
C6	0.128417	0.834773	0.159104	0.795271	0.242142	0.72478	0.425651	0.525306

After the weighted matrix is computed, the weighted evaluations are aggregated via summation operation. The score function is calculated for each criterion and then these values are normalized. The aggregated weighted decision matrix is shown in Table 5. For example, to obtain the aggregation values for the C1 criteria, the weighted values in the first row of Table 4 are summed up using Equation (3). Then, the score function value for C1 criteria is calculated using Equation (13) and finally, all the score function values are normalized as in the fifth column of Table 5, and rankings of the alternatives are obtained.

Table 5. The order of importance of the criteria

Criteria	**Aggregation**		**Score Function Values**	**Normalized Weights**	**Ranking**
	μ	***v***			
C_1	0.734400	0.191553	0.542847	0.245864	2
C_2	0.563793	0.335711	0.228083	0.103302	5
C_3	0.783754	0.141053	0.642700	0.291089	1
C_4	0.622151	0.289585	0.332566	0.150624	4
C_5	0.462496	0.42900	0.033496	0.015171	6
C_6	0.680982	0.252756	0.428226	0.193950	3

As a result of the fuzzy multi-criteria decision-making analysis, it is determined that the most important factor in the selection of warehouse location during the pandemic period is "Accessibility". Besides, it has been determined that the least important factor is "Climate conditions". Pandemic conditions have been identified as the third most important factor, which can be said to have a more significant impact than many of the criteria previously addressed in location selection problems.

If the weights of considered factors are analyzed, "Accessibility" and "Proximity to target locations" are the most important factors with the highest importance rate of 29.11% and 24.59%, respectively. In today's competitive world, customer satisfaction is prioritized and it is desired to create a continuous purchasing habit, not a one-time purchase. Continuous purchasing will only be possible if what the customer wants and desires is in the goods and services. Businesses can be considered successful as long as they have their goods and services in the place, time and amount desired by the customer. This is even more important in the healthcare supply chains. Every second waiting for an important drug ordered from a pharmacy can have an irreparable consequence. In such cases, the timing and delivery of the order to the patient's relatives at the desired time is of vital importance. It can be said that more accessible pharmaceutical warehouses are required to make more robust healthcare supply chains. Because, transportation times can be reduced by increasing the accessibility of stakeholders and it improves the resilience of supply chains, especially healthcare supply chains. Factors such as proximity to pharmacies, drugstores and density of them are important in the health sector. It is very important to choose the alternative with the shortest distance to medical substance and drug manufacturers. There is always demand in the health sector and warehouses are critical points in order to meet the demand in this process. A business that is close to the raw material reduces the transportation cost. In regions with high population density, the need for medical substances and drugs naturally increases day by day. Therefore, it can be claimed that the results obtained are significant.

After the criterion weights have been successfully determined, the next dimension of this decision problem, which is the site selection stage, can be started among the alternative regions for future studies.

4. Conclusion

The procurement process of pharmaceutical products in the healthcare industry is critical in delivering these products to demand points efficiently. Problems that may occur at any stage of the supply process of the specified products may cause serious risks that will put human life at risk. Companies in the public and private sectors have recently made great efforts to increase agility, flexibility and reliability in the pharmaceutical supply chain. The selection of a pharmacy warehouse location is crucial for choosing a suitable location that will provide appropriate warehouse conditions in terms of patient health and safety and meet customer demand.

In this study, we aimed to determine the importance levels of the factors related to pharmaceutical warehouse location under pandemic conditions. For this purpose, firstly literature research is performed to determine the factors that affect the pharmaceutical warehouse location. Six different factors, Proximity to target locations (Hospital, pharmacy,…), Infrastructure of the area, Accessibility, Cost, Climate conditions and Pandemic conditions, are specified which can be used to identify the best locations. Then experts are consulted to evaluate these factors. Four different experts evaluate the factors using linguistic expressions. Intuitionistic fuzzy numbers are utilized to convert expert opinions into mathematical expressions from linguistic expressions. SAW methodology is utilized to determine the importance level of each factor under an intuitionistic fuzzy environment. Accessibility is determined as the most important factor to determine pharmaceutical warehouse location according to four different anonymous experts. It is very important for public health that pharmaceutical warehouses are accessible during periods when social isolation is necessary, such as a pandemic, and when time is more valuable.

As future directions, the number of criteria can be increased or the main criteria can be detailed with sub-criteria sets. Different multi-criteria decision-making methodologies can be adopted and results can be compared. Besides, candidate locations can be compared and the best location can be selected via this proposed methodology.

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Biography

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