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How Warehouse Location Decisions Changed in Medical Sector after Pandemic? A Fuzzy Comparative Study

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Abstract

In the decision theory, there are many useful tools for operations in logistics and Supply Chain Management (SCM). One of the vital trivets of logistics operations is warehouse management which is also one of the parts of a supply chain. Deciding on the location of a warehouse has a critical issue especially during an outbreak. In this study, we aimed that to figure out differences between the perceived importance of the considered criteria in the decision process regarding warehouse location in the medical sector in terms of the changing dynamics after the Covid-19 pandemic. Pursuing this goal, the results of a preliminary study which was resulted from the gathered data of a decision-making group including industry professionals before the pandemic outbreak were accepted as an anchor to obtain a comparison with the current state. To construct a proper representation of the post-Covid state, a similar methodology was used, and similar decision-makers data were collected with the preliminary study in the identification of the importance figures and causal relationships between criteria. According to comparative results of pre-and post-Covid studies, it is found that there are significant changes in the perceived role of adjacency to target markets and customs criteria in medical warehouse location decisions. It is obvious that the results will shed light on medical sector professionals' decision process while adapting to the current pandemic conditions.

Keywords: Supply chain management, Logistics, Warehouse, Pythagorean fuzzy sets, Fuzzy DEMATEL, MCDM, Covid-19.

1 | Introduction

The medical sector has been one of the most influenced industries from the Covid-19 (the disease caused by Severe Acute Respiratory Syndrome Coronavirus (SARSCOV-2)) outbreak which was originated in the last month of 2019 and became a pandemic that has influenced the entire global operations.

As for the other sectors such as e-commerce, fast-moving consumer goods, tourism, construction, healthcare, automotive, oil, aviation, etc. had been influenced directly [1]. Besides, the supply chain of healthcare is the most affected one among those. Additionally, the location of the pharmaceutical warehouses, wholesalers, retailers, and hospitals was becoming more important because of the conjectural change after the pandemic outbreak.

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From the customers' perspective, medical firms' supply chain visibility, transparency, and agility became more and more vital due to the changes in the world. Fast delivery of pharmaceutical goods and materials has been a vital issue for citizens during that era [2] and [3].

In this connection, customer demands started to increase its priority which has not been faced before. And the health sector leads the change of this perception for the human being. Those changes have been observed in logistics operations as well. Especially the vital parts of SCM, namely, warehousing and inventory management have started a special period during the pandemic.

As the outbreak spreads, the popularity of electronic commerce and logistics services has increased so much. On the contrary, the industries such as entertainment, manufacturing, and tourism have lost their potential growth.The priority for all goods and services in e-commerce, especially for warehouse management in the medical sector has been raised. Particularly, for the disinfectant materials and medical protective masks, there has been a sudden increase in demand.

In line with the changing dynamics in the medical sector operations after the pandemic outbreak, it is expected that there should be a change in the importance levels of considered criteria in the decision-making process of the medical warehouse location as well. In this paper, the authors are aimed to reveal potential changes in the assessment process and also shifts in the perceived importance of medical warehouse location selection criteria.

Amid 2019, a previous study was performed by the authors before the pandemic outbreak, which includes the evaluations of the criteria that have an influence on the decisions of medical warehouse locations by the professionals of the medical sector [4]. Since Fuzzy Sets (FS) have limitations in handling uncertainty and vagueness, in that research, authors used the Pythagorean Fuzzy (PF) based-Decision MAking Trial and Evaluation Laboratory (DEMATEL) technique [5] and [6] to find out the criteria' importance and the causal relationships between criteria [7] and [8].

This study, it is aimed that to figure out differences between the perceived importance of the considered criteria in the decision process regarding warehouse location selection in the medical sector in terms of the changing sector dynamics after the Covid-19 pandemic. Tuncalı Yaman and Akkartal [4] following the aim, the results of the previous study were accepted as a clear picture of the pre-Covid 19 phase in terms of understanding the decision process of the decision-makers in the medical sector, and a similar design was made to figure out the changing patterns in this process if any. This study, it is aimed that to figure out differences between the perceived importance of the considered criteria in the decision process regarding warehouse location selection in the medical sector in terms of the changing sector dynamics after the Covid-19 pandemic.

Therefore, evaluations were made by the same medical sector professionals against the same criteria which play a role in selecting the location of the medical sector warehouse. Further, the same DEMATEL method was implemented to figure out the current causal relationships and criteria importance to clarify the standing situation. In this manner, previously obtained results were able to be compared with the status quo. By using the aforementioned design of the previous study, the goal of the study which is about understanding the changing perceptions in deciding the location of the medical warehouse has been achieved. The results of this study are expected to pioneer the academicians and researchers about the dynamics of decision regarding the change of the decision process regarding the selection of the location of a medical warehouse after the Covid-19 pandemic.

In the following section, the warehouse location selection problem is emphasized, and the problem statement has been declared for the medical sector. A literature review has been given in the third section. A detailed section regarding the used method has been included in the fourth part. And the fifth section includes the results of the empirical study which compares the pre and post era of the outbreak. In conclusion, comparative results and the possible future studies are discussed.

2 | Warehouse Location Selection Problem

This study aims to investigate the changes in perceived importance and switching patterns between the causal relationships of warehouse location selection criteria determined in the previous study and the current study that was performed after the Covid-19 period. Plus, warehouse location selection criteria, which have a great contribution in ensuring product flow and sustainability in the supply chain, were determined as follows before the Covid-19 period [4].

- *Adjacency to target markets.*
- *Adjacency to terminals, ports, and customs.*
- *Adjacency to the pharmaceutical production facilities.*
- *The warehouse site decision should be made by considering the capacity estimation and location criteria.*
- *Adjacency of qualified employees.*
- *Infrastructure of the site. (Electricity, water, internet sewage, natural gas, etc.).*
- *Climate conditions of the site.*
- *Ground properties of the site (impact of construction on excavation cost).*
- *Leasing cost of the site.*
- *Traffic congestion of the site.*

However, as of the pandemic period, the need for drugs and drug production suddenly increased. As a result, the perceived importance criteria for companies to decide on the choice of warehouse location have also changed. Most of the virus remained in the economy. This change showed itself in the way of transforming it into an agile turn that can respond to very momentary needs. They are expected to be more transparent, flexible, and healthy to the increasing demand. As of this, it is so preferred in warehouse location preferences.

With the building having the effects of meeting customer requests and needs instantly, the criteria for choosing a warehouse location were redefined in a way to maximize customer satisfaction. These criteria include:

I. Selection of suitable land to increase the storage capacity depending on the increasing demand intensity.
II. Choosing the materials used in the warehouse from materials suitable for recycling to prevent waste.
III. Choosing sites with a wider technological infrastructure so that customers can follow their products to provide a transparent warehouse management approach.
IV. Selection of sites that will enable vehicles to perform loading and unloading more easily to meet the increased instantaneous demand due to pandemic conditions.

Since the main objective of the study was defined as obtaining a comparative result between two phases, criticism of the newly appeared criteria could be a salient aspect of another study.

3 | Literature Review

It is seemed that the factors affecting the selection of the medical warehouse location are not focused on the literature, especially after the pandemic period. However, the importance of the location of the warehouse has increased especially in the drug supply chain. Additionally, there are no new criteria to replace, determined before the pandemic period in the selection of the storage location and this creates gaps in the literature.

Even though academic research papers are not focused on the factors affecting the selection of the medical warehouse location in the literature, especially after the pandemic period, in line with the changing dynamics after the pandemic, the importance of the location of the warehouse has increased especially in the medical supply chain to perform responsive operations. Additionally, customer orientation strategies are getting to be more significant for the medical industry. To avoid these risks, supply chain and warehouse management issues are getting more indispensable. Alike manufacturing firms, medical sector players are obligated for competitive warehousing strategies to select suitable warehouses for the effective supply chain management. Considering increased competitiveness in the market scenario and shifted demand uncertainty after the pandemic, the quantity of the product in the workflow of the warehouse is becoming more crucial occasionally medical firms struggle to find a space for the whole lot in warehouses [9]. At that point, the location of the warehouse, especially in the pharmaceutical industry, also plays an important role to prevent delays and interruptions. In its nature, services provided by medical warehouses have a direct influence on the services offered in medical firms as suppliers and in pharmacies where transportation is offered to customers. Warehousing must be achieved in such a proper way that problems can be avoided, namely, delays in progress regarding the procurement of a drug from the pharmaceutical firm and transportation of it to the patient through pharmacies. That is also an emphasis on how the location of the warehouse plays a key role in distribution activities.

As well as the need for immediate access to medical equipment such as medical masks and disinfectants, which the medical team needs at any time, has increased more during the pandemic period, as well as supplies such as medicines and vaccines. The organization of the warehouse which helps to fulfill the demand of a specific trade region has an important role for successful retailing. Logisticians must take into consideration so many factors such as avoiding the probable discrepancies in the future for a good warehouse quality, suitable political rules and regulations regional functionality regarding relevant consumptions, good traffic conditions possessing effective accessibility, and relatively low rental costs [10].

Considering the studies in the literature focusing on the problem of warehouse location selection, it seemed that Ashrafzadeh et al. [11] have emphasized that the location of a warehouse is generally one of the most important and strategic decisions in the optimization of logistic systems. In another example, Ansari and Smith [12], suggested a clustering method based on the gravity model for warehouses in which there is more than one pick per trip. According to the results, their proposed method improved the performance. Kostikov et al. [13] provided an approach to find the optimal location selection solution based on the model of the Modified Steiner-Weber Problem with restrictive conditions. Their method was found relevant for the central warehouse's optimal location, and it was diminished distribution costs from the central warehouse to sub warehouses/branches located in individual EU countries. Taş [14], studied the evaluation of criteria for the selection of pre-disposal temporary landfill sites for medical products in Turkey. Eight criteria were determined as important in the selection process of these sites. The weights of the criteria were calculated by one of the fuzzy Multi-Criteria Decision-Making (MCDM) methods called the fuzzy Pivot Pairwise Relative Criteria Importance Assessment (PIPRECIA) method. In [15], a pharmaceutical warehouse location implementation was performed.

Further, the need for warehouses as a result of the pandemic process of the regulations brought many questions. Are the warehouse and distribution centers at a level that can meet the needs of the health sector as the economies close? In the health facilities whose capacities are not fulfilled regarding displaying and forecasting the demand, transferring prescription services to pharmacies can help to reduce the quantity of the pharmaceuticals whose expiry dates are approaching [16]. Although many criteria should be considered in the selection of the warehouse location after the Covid process, storage, one of the most important parts of the past before the Covid period, is of vital importance in many sectors, including the medical sector. Parallel to this aspect, in their study, [17] has concluded that it is important to determine the appropriate warehouse location to improve the efficiency of physical distribution and minimize the total cost. For this reason, it is a priority condition that the success factors and methods to be used in the selection of the warehouse location is determined correctly. In addition, all other sectors, including the medical sector, need to design an efficient and efficient warehouse to gain a competitive advantage and to ensure sustainability, especially in terms of efficiency [18] in their study have concluded that, designing of the logistics system, regardless of the industry, is a complicated task. Incorrect decisions in this matter result in the ineffective implementation of transport and storage processes. Thus, it may lead to loss of competitiveness on the market and other serious consequences, including the bankruptcy of an enterprise or group of enterprises. Several health recordings and related files generated by clinical diagnosis equipment are constructed daily. These valuable data are embedded in various medical information. Relevant documents are saved daily generated by many health records and clinical diagnosis equipment. These crucial data are saved in various medical information systems such as HIS, PACS, RIS. Data required to make a better medical decision are hidden in heterogeneous health systems which are not integrated properly. Consequently, it is important for these medical records' integration of one warehouse [19]. Simultaneously, it becomes evident that the warehouses and distribution centers should be distributed daily to pharmacies and health institutions to fulfill the need for thermotics, especially in the supply of medical equipment and medicine. As well, the warehouse managers need to control their inventory to satisfy the market requirements. In his study, the author declared that "The objective is to develop a capacity and warehouse management plan that satisfies the expected market demands with the lowest possible cost" [20]. Besides, Khan et. al. [20] proposed solution measures that help managers to develop action plans for early recovery from COVID-19 disruption for the medical supply chain. Their study identifies the impacts and helps to formulate for mitigating those impacts in various functional levels. Another up-to-date study relating new supply chain processes has been illustrated with the new pattern health care supply chain under Covid-19 in China's Belt and Road Initiative (CBRI) countries. The results of the study represented a novel healthcare supply chain developing process during the pandemic in CBRI [21].

4 | Methodology

DEMATEL is one of the most well-known and effective methods used to determine the causal relationship between the criteria that will form the basis of evaluation for any multi-criteria decision problem [22]. Since an attempt on revealing latent causal relationships is seemed to be a sagacious approach for the interpretation of the decision-making process, in this context, the DEMATEL method was used to determine whether there is a potential relationship among the ten criteria determined as a result of both the review conducted in the current literature in the context of the warehouse location selection problem and feedbacks of sector professionals. In addition, since this study aims to determine the change in the importance levels of the criteria related to the warehouse location selection problem in the same sector before Covid-19, it would be appropriate not to make any changes in the method followed in the reference study [4] and comparable results can be obtained without any bias due to the method changes. Like most MCDM techniques, in literature, fuzzy extensions of DEMATEL are implemented, and it was stated that PF extension of the DEMATEL was found superior compared to traditional approaches when crisp numbers have some extent of limitations in handling vagueness and uncertainty [23]. Prior to detailed and comparative results of PF DEMATEL some preliminaries of the technique along with both fundamental definitions of fuzzy sets and algebraic operations of PF Sets (PFS) are detailed below [7].

4.1 | Pythagorean Fuzzy Sets

Lotfi Zadeh [23] proposed the fuzzy set theory. Since then, fuzzy measurements of vague human behaviors, intentions, evaluations, judgments, are found more realistic and precise. According to Zadeh's definition [23], $X = \{x_1, x_2, \dots, x_n,\}$ is the universal set and form of any FS on X is $F = \left\{< x, \mu_F(x) > | x \epsilon X\right\}$ where $\mu_F: X \rightarrow [0,1]$ for all $x \epsilon X$. The degree of the membership of x in F is denoted by $\mu_F(x)$.

Claiming to confront vagueness and uncertainty better, Atanassov introduced Intuitionistic Fuzzy Sets (IFS) in 1986 [24]. By definition, $X = \{x_1, x_2, \dots, x_n,\}$ is the universal set and form of any IF on X is $I = \left\{< x, \mu_I(x), \nu_I(x) > | x \epsilon X\right\}$ where $\mu_I: X \rightarrow [0,1]$ and $\nu_I: X \rightarrow [0,1]$ for all $x \epsilon X$ under the condition of $0 \leq \mu_I(x) + v_I(x) \leq 1$. The degree of the membership of x in I is denoted by $\mu_I(x)$ and the degree of the non-membership of x in I is denoted by $\nu_I(x)$. Notation of an IF value is is $I = \langle \mu_I, \nu_I \rangle$.

Finally, in 2013, Yager [25] announced a new extension of fuzzy sets called Pythagorean Fuzzy Sets with the following definition [26]: $X = \{x_1, x_2, \dots, x_n,\}$ is the universal set and form of any PFS on X is $P =$

$\{< x, \mu_P(x), \nu_P(x) > | x\epsilon X\}$ where $\mu_P: X \rightarrow [0,1]$ and $\nu_P: X \rightarrow [0,1]$ for all $x\epsilon X$ under the condition of $0 \leq \mu_P(x)^2 + \upsilon_P(x)^2 \leq 1$. The degree of the membership of x in I is denoted by $\mu_P(x)$ and the degree of the non-membership of x in I is denoted by $\nu_P(x)$. The notation of a PF Value (PFV) is $P = \langle \mu_P, \nu_P \rangle$ where P stands for PFV. The degree of indeterminacy of x to P is given by, $\pi_p(x) = \sqrt{1 - \mu_p^2 - \upsilon_p^2}$ where $\mu_P, \nu_P \epsilon[0,1]$ and $\mu_P{}^2 + \upsilon_P{}^2 \leq 1$. Algebraic operations of PFS are detailed below [27].

If $K = (\mu_K, \upsilon_K)$ and $L = (\mu_L, \upsilon_L)$ are two PFVs where $\mu_K, \nu_K \epsilon[0,1]$ and $\mu_L, \nu_L \epsilon[0,1]$, arithmetic operations over two PFVs are,

$$K \cup L = P\left(\max\{\mu_K, \mu_L\}, \min\{v_K, v_L\}\right). \quad (1)$$

$$K \cap L = P\left(\min\{\mu_K, \mu_L\}, \max\{v_K, v_L\}\right). \quad (2)$$

$$K^C = P(v_K, \mu_K). \quad (3)$$

$$K = L \Longleftrightarrow \mu_K = \mu_L, v_K = v_L. \quad (4)$$

$$K \subset L \Longleftrightarrow \mu_K \leq \mu_L, v_K \geq v_L. \quad (5)$$

$$K \oplus L = P\left(\sqrt{\mu_K^2 + \mu_L^2 - \mu_K^2\mu_L^2}, v_K v_L\right). \quad (6)$$

$$K \otimes L = P\left(\mu_K\mu_L, \sqrt{v_K^2 + v_L^2 - v_K^2 v_L^2}\right). \quad (7)$$

$$\lambda K = P\left(\sqrt{1 - \left(1 - \mu_K^2\right)^\lambda}, (v_K)^\lambda\right), \lambda > 0. \quad (8)$$

$$\lambda(K \oplus L) = \lambda K \oplus \lambda L, \lambda > 0. \quad (9)$$

$$K^\lambda = P\left((\mu_K)^\lambda, \sqrt{1 - \left(1 - v_K^2\right)^\lambda}\right), \lambda > 0. \quad (10)$$

Nowadays, there are many theoretical studies on PFSs in the literature, just like the new approaches regarding other fuzzy numbers [28]. For instance, both papers [29] and [30] introduced a modified PF correlation measure. In [31], generalized triparametric correlation coefficient for pythagorean fuzzy sets was discussed in terms of being a useful tool for solving multi criteria decision making problems. The following section is focused on the calculation steps of the Pythagorean Fuzzy DEMATEL method.

4.2 | Pythagorean Fuzzy DEMATEL

In DEMATEL methodology, to reveal casual relationships between criteria, pair-wise comparisons are made with the linguistic variable "influence" with the help of a seven-point rating scale which is constructed with seven terms. In practice, experts make their evaluations with correspıning linguistic terms of crisp numbers. PFVs of each linguistic terms are appeared in *Table 1* [5].

Where the decision problem includes n criteria, the initial direct relation matrix $Z = [z_{ij}]_{n \times n}$ which is constituted from pair-wise comparisons of criteria by linguistic terms, is constructed as an $n \times n$ matrix. In practice, the total number of Zs is equal to the total number of experts. Elements of the matrix (z_{ij}) are PFVs, and each indicates the degree to which criterion i, affects the criterion j, where $(i, j = 1,2, \dots, n)$. *Eq. (11)* indicates the initial direct relation matrix of the kth expert.

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$$Z_k = [z_{ij}]_{n\times n} = \begin{matrix} Cr_1 \\ \vdots \\ Cr_n \end{matrix} \begin{bmatrix} Cr_1 & & Cr_n \\ \langle 0,0 \rangle & \cdots & \mu_{k_1 n}, v_{k_1 n} \\ \vdots & \ddots & \vdots \\ \langle \mu_{k_n 1}, v_{k_n 1} \rangle & \cdots & \langle 0,0 \rangle \end{bmatrix}. \quad (11)$$

Table 1. Rating scale of influence factor.

Degree of "Influence"	Rating Scale Crisp Number	PFV
Very low	0	⟨0,0⟩
Low	1	⟨0.1,0.9⟩
Medium low	2	⟨0.2,0.9⟩
Medium	3	⟨0.4,0.6⟩
Medium high	4	⟨0.5,0.7⟩
High	5	⟨0.7,0.2⟩
Very high	6	⟨0.9,0.1⟩

The weighted initial direct relation matrix $W = [w_{ij}]_{n\times n}$ is calculated by *Eq. (8)* which indicates the multiplication of the initial relationship matrix $Z = [z_{ij}]_{n\times n}$ by expert weight λ_k (for expert k, weight is denoted by λ_k). If there are k experts, $\sum_{i=0}^{k} \lambda_i = 1, \lambda_i > 0$ where $(i = 1,2, \dots, k)$. *Eq. (12)* illustrates the weighted initial direct relation matrix of the kth expert.

$$W_k = [w_{ij}]_{n\times n} = \begin{matrix} Cr_1 \\ \vdots \\ Cr_n \end{matrix} \begin{bmatrix} Cr_1 & & Cr_n \\ \lambda_k\langle 0,0 \rangle & \cdots & \lambda_k z_{1j} \\ \vdots & \ddots & \vdots \\ \lambda_k z_{i1} & \cdots & \lambda_k\langle 0,0 \rangle \end{bmatrix}. \quad (12)$$

To aggregate weighted initial direct relation matrices of all experts, the addition operator in *Eq. (6)* is used. The summation of all weighted initial direct relation matrices gives the total aggregated matrix C. For illustration purposes, the notation of an example aggregated matrix of the first two experts is given below.

$$C_{1,2} = W_1 \oplus W_2 = \begin{matrix} Cr_1 \\ \vdots \\ Cr_n \end{matrix} \begin{bmatrix} Cr_1 & & Cr_n \\ \lambda_1\langle 0,0 \rangle \oplus \lambda_2\langle 0,0 \rangle & \cdots & (\lambda_k z_{1j})_1 \oplus (\lambda_k z_{1j})_2 \\ \vdots & \ddots & \vdots \\ (\lambda_k z_{i1})_1 \oplus (\lambda_k z_{i1})_2 & \cdots & \lambda_1\langle 0,0 \rangle \oplus \lambda_2\langle 0,0 \rangle \end{bmatrix}. \quad (13)$$

Defuzzification of the total aggregated matrix creates the crisp valued total average matrix $A = [a_{ij}]_{n\times n}$ where $a_{ij} \in [-1,1]$. As the defuzzification function, the following score function is used.

$$a_{ij} = \mu_{C_{ij}}^2 - v_{C_{ij}}^2. \quad (14)$$

$$A = [a_{ij}]_{n\times n} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}. \quad (15)$$

The normalized total average matrix $N = [n_{ij}]_{n\times n}$ where $0 \le n_{ij} \le 1$ is found by *Eq. (16)* with the use of a normalization factor.

$$N = [n_{ij}]_{n\times n} = s. A, \quad (16)$$

where $s = \frac{1}{max\left(max_{1\le i\le n}\sum_{i=1}^{n} a_{ij}, max_{1\le j\le n}\sum_{j=1}^{n} a_{ij}\right)}$ $\quad i, j = 1,2, \dots, n.$

Based on the normalized total average matrix N, the total relation matrix $T = \left[t_{ij}\right]_{n\times n}$ is obtained by following *Eq. (17)*.

$$T = N(I - N)^{-1}, \tag{17}$$

where I is the identity matrix.

Causal relationships could be identified by sum of rows (c) and sum of columns (r) of the total relation matrix T.

$$c = \sum_{i=1}^{n} t_{ij}. \tag{18}$$

$$r = \sum_{j=1}^{n} t_{ij}. \tag{19}$$

The last step of the process is illustrating the causal relationships of the criteria with casual diagram. Summation and subtraction of c and d are used in plotting the diagram where the horizontal axis indicates $(c + r)$. A positive $(c - r)$ value addresses that the criterion is under the "cause" category. Otherwise, the criterion is evaluated in the "effect" group.

5 | Results

According to the results of the pre-Covid phase study [4] that was conducted in mid-2019, cause and effect groups of criteria were detected by performing previously detailed steps of the PF-DEMATEL algorithm. In line with the objective of this paper which is to uncover the implicit changes in the causal relationship among criteria of warehouse location selection problem in the medical sector, the same methodology was followed with the contemporary evaluations of the same experts after the pandemic, and cause and effect groups of the same criteria were constituted and compared with the results of the previous study that was conducted before the pandemic.

This section covers detailed results of the current study are detailed in steps of PF-DEMATEL and the comparison between two consecutive studies.

To reveal causal relationships among previously defined criteria that influence warehouse location selection for medical sector companies were evaluated by the same six experts who were consulted. Also, appointed weigh scores, based on the experiences of the experts, were kept the same.

Table 2. Expert weights.

Experts	λ_k
E1	0.23
E2	0.23
E3	0.22
E4	0.12
E5	0.10
E6	0.10

Computer administered telephone interviews were realized with the experts and as judgments, linguistic terms-based pair-wise comparisons of criteria were collected. For each expert, pair-wise comparisons in the linguistic terms of influences between criteria were transformed into 10×10 personal initial direct relation matrices. For six experts, six different initial direct relation matrices were created by *Eq. (11)*. *Table 3* presents the initial direct relation matrix $Z_{k1} = \left[z_{ij}\right]_{10\times10}$ of Expert #1. The z_{ij} values which are the elements of the initial direct relation matrix imply the degree to which the criterion i affects the criterion j.

Table 3. Initial direct relation matrix of expert #1.

Criteria		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	μ	0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	v	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
C2	μ	0.7	0	0.4	0.5	0.5	0.5	0.7	0.5	0.5	0.7
	v	0.2	0	0.6	0.7	0.7	0.7	0.2	0.7	0.7	0.2
C3	μ	0.5	0.5	0	0.9	0.5	0.4	0.7	0.7	0.5	0.7
	v	0.7	0.7	0	0.1	0.7	0.6	0.2	0.2	0.7	0.2
C4	μ	0.5	0.5	0.5	0	0.9	0.5	0.7	0.5	0.9	0.5
	v	0.7	0.7	0.7	0	0.1	0.7	0.2	0.7	0.1	0.7
C5	μ	0.5	0.7	0.5	0.5	0	0.7	0.7	0.5	0.9	0.5
	v	0.7	0.2	0.7	0.7	0	0.2	0.2	0.7	0.1	0.7
C6	μ	0.5	0.7	0.5	0.4	0.7	0	0.1	0.5	0.4	0.5
	v	0.7	0.2	0.7	0.6	0.2	0	0.9	0.7	0.6	0.7
C7	μ	0.9	0.5	0.9	0.5	0.7	0.5	0	0.4	0.7	0.7
	v	0.1	0.7	0.1	0.7	0.2	0.7	0	0.6	0.2	0.2
C8	μ	0.4	0.5	0.5	0.5	0.4	0.7	0.7	0	0.5	0.5
	v	0.6	0.7	0.7	0.7	0.6	0.2	0.2	0	0.7	0.7
C9	μ	0.1	0.7	0.7	0.5	0.5	0.7	0.7	0.5	0	0.7
	v	0.9	0.2	0.2	0.7	0.7	0.2	0.2	0.7	0	0.2
C10	μ	0.5	0.5	0.7	0.7	0.5	0.5	0.7	0.7	0.7	0
	v	0.7	0.7	0.2	0.2	0.7	0.7	0.2	0.2	0.2	0

Elements of W_k for each expert were provided by *Eq. (12)*, getting the product of expert weights (λ_k) (see *Table 2*) by the elements of related initial direct relation matrix (W_k). *Table 4* illustrates the weighted initial direct relation matrix $W_{k1} = \left[w_{ij}\right]_{10\times10}$ of Expert #1. For all provided matrices, the numbers are rounded to 2 decimals.

Table 4. Weighted initial direct relation matrix of expert #1.

Criteria		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	μ	0.00	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	v	0.00	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
C2	μ	0.38	0.00	0.20	0.25	0.25	0.25	0.38	0.25	0.25	0.38
	v	0.69	0.00	0.89	0.92	0.92	0.92	0.69	0.92	0.92	0.69
C3	μ	0.25	0.25	0.00	0.57	0.25	0.20	0.38	0.38	0.25	0.38
	v	0.92	0.92	0.00	0.59	0.92	0.89	0.69	0.69	0.92	0.69
C4	μ	0.25	0.25	0.25	0.00	0.57	0.25	0.38	0.25	0.57	0.25
	v	0.92	0.92	0.92	0.00	0.59	0.92	0.69	0.92	0.59	0.92
C5	μ	0.25	0.38	0.25	0.25	0.00	0.38	0.38	0.25	0.57	0.25
	v	0.92	0.69	0.92	0.92	0.00	0.69	0.69	0.92	0.59	0.92
C6	μ	0.25	0.38	0.25	0.20	0.38	0.00	0.05	0.25	0.20	0.25
	v	0.92	0.69	0.92	0.89	0.69	0.00	0.98	0.92	0.89	0.92
C7	μ	0.57	0.25	0.57	0.25	0.38	0.25	0.00	0.20	0.38	0.38
	v	0.59	0.92	0.59	0.92	0.69	0.92	0.00	0.89	0.69	0.69
C8	μ	0.20	0.25	0.25	0.25	0.20	0.38	0.38	0.00	0.25	0.25
	v	0.89	0.92	0.92	0.92	0.89	0.69	0.69	0.00	0.92	0.92
C9	μ	0.05	0.38	0.38	0.25	0.25	0.38	0.38	0.25	0.00	0.38
	v	0.98	0.69	0.69	0.92	0.92	0.69	0.69	0.92	0.00	0.69
C10	μ	0.25	0.25	0.38	0.38	0.25	0.25	0.38	0.38	0.38	0.00
	v	0.92	0.92	0.69	0.69	0.92	0.92	0.69	0.69	0.69	0.00

The total aggregated matrix (C), which originally provides the summation of all weighted initial direct relation matrices of experts, was created by the addition operator in *Eq. (6)*. In *Table 5*, the total aggregated matrix is given below.

Table 5. Total aggregated matrix.

Criteria		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	μ	0.00	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
	v	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
C2	μ	0.28	0.00	0.23	0.24	0.22	0.20	0.27	0.18	0.29	0.34
	v	0.40	0.00	0.43	0.39	0.51	0.64	0.00	0.73	0.37	0.34
C3	μ	0.22	0.30	0.00	0.30	0.24	0.29	0.32	0.23	0.33	0.21
	v	0.53	0.58	0.00	0.25	0.40	0.31	0.00	0.39	0.27	0.52
C4	μ	0.20	0.20	0.23	0.00	0.29	0.21	0.24	0.29	0.32	0.20
	v	0.51	0.58	0.48	0.00	0.33	0.52	0.00	0.40	0.34	0.61
C5	μ	0.25	0.21	0.17	0.22	0.00	0.30	0.28	0.23	0.33	0.25
	v	0.41	0.55	0.67	0.55	0.00	0.32	0.00	0.47	0.23	0.39
C6	μ	0.19	0.23	0.22	0.20	0.22	0.00	0.26	0.32	0.29	0.22
	v	0.00	0.00	0.52	0.50	0.52	0.00	0.62	0.00	0.37	0.52
C7	μ	0.31	0.23	0.30	0.19	0.24	0.24	0.00	0.17	0.24	0.28
	v	0.44	0.53	0.46	0.00	0.33	0.50	0.00	0.69	0.41	0.39
C8	μ	0.22	0.21	0.29	0.25	0.29	0.32	0.24	0.00	0.33	0.16
	v	0.51	0.52	0.47	0.00	0.42	0.00	0.00	0.00	0.44	0.64
C9	μ	0.28	0.25	0.24	0.29	0.19	0.25	0.31	0.19	0.00	0.21
	v	0.42	0.29	0.40	0.36	0.00	0.40	0.00	0.00	0.00	0.54
C10	μ	0.23	0.18	0.25	0.27	0.20	0.24	0.31	0.23	0.24	0.00
	v	0.62	0.70	0.39	0.00	0.62	0.48	0.32	0.46	0.34	0.00

following step, defuzzification of the total aggregated matrix was realized by the score function (see *Eq. (14)*). The final total average matrix (A) with crisp values whose notation is given in *Eq. (15)*, is presented in *Table 6*.

Table 6. Total average matrix.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.00	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
C2	-0.08	0.00	-0.13	-0.10	-0.21	-0.37	0.08	-0.50	-0.05	0.00
C3	-0.24	-0.25	0.00	0.03	-0.10	-0.01	0.10	-0.10	0.04	-0.23
C4	-0.22	-0.30	-0.17	0.00	-0.02	-0.23	0.06	-0.07	-0.01	-0.34
C5	-0.10	-0.26	-0.41	-0.26	0.00	-0.01	0.08	-0.17	0.06	-0.09
C6	0.04	0.05	-0.22	-0.21	-0.22	0.00	-0.31	0.10	-0.05	-0.23
C7	-0.10	-0.23	-0.12	0.03	-0.05	-0.19	0.00	-0.44	-0.11	-0.07
C8	-0.21	-0.23	-0.13	0.06	-0.09	0.10	0.06	0.00	-0.09	-0.39
C9	-0.10	-0.02	-0.10	-0.05	0.04	-0.10	0.10	0.04	0.00	-0.25
C10	-0.34	-0.46	-0.09	0.07	-0.35	-0.17	0.00	-0.16	-0.06	0.00

For normalization purposes, the normalization facor (s) was used and, the normalized total average matrix $N = [n_{ij}]_{10\times10}$ was calculated by *Eq. (16)*. The final elements of N are provided in *Table 7*.

Table 7. Normalized total average matrix.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.00	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
C2	-0.24	0.00	-0.40	-0.30	-0.64	-1.12	0.23	-1.52	-0.16	0.01
C3	-0.72	-0.76	0.00	0.09	-0.31	-0.03	0.30	-0.29	0.12	-0.70
C4	-0.66	-0.91	-0.53	0.00	-0.07	-0.70	0.18	-0.22	-0.03	-1.03
C5	-0.31	-0.79	-1.26	-0.78	0.00	-0.03	0.24	-0.51	0.18	-0.28
C6	0.11	0.16	-0.66	-0.63	-0.68	0.00	-0.94	0.30	-0.16	-0.69
C7	-0.29	-0.70	-0.37	0.11	-0.15	-0.58	0.00	-1.34	-0.33	-0.23
C8	-0.64	-0.69	-0.40	0.19	-0.28	0.31	0.18	0.00	-0.26	-1.18
C9	-0.29	-0.06	-0.31	-0.15	0.11	-0.31	0.29	0.11	0.00	-0.75
C10	-1.02	-1.39	-0.27	0.22	-1.06	-0.52	-0.01	-0.49	-0.18	0.00

The total relation matrix $T = \left[t_{ij}\right]_{n \times n}$, whose column and row sums are used in the provision of c and r figures, was calculated by *Eq. (17)*. In *Table 8*, along with elements of T, c and r values are detailed. In the calculation of c and d, *Eq. (18)* and *Eq. (19)* were used respectively.

Table 8. Total relation matrix.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	c
C1	-0.19	-0.11	-0.39	0.09	0.38	0.10	0.38	-0.02	0.30	0.14	0.69
C2	-0.57	-1.42	0.29	0.39	-0.03	-0.78	0.32	-0.76	-0.09	0.54	-2.11
C3	-0.07	-0.01	-0.02	-0.25	0.13	0.09	0.17	-0.29	0.19	-0.41	-0.47
C4	0.17	-0.21	-0.99	-0.41	0.67	-0.10	0.14	0.08	0.09	-0.14	-0.69
C5	0.13	0.13	-0.65	-0.51	-0.51	0.34	-0.35	0.27	-0.02	0.45	-0.72
C6	0.03	0.63	0.53	0.03	-0.64	-0.59	-0.27	-0.27	-0.03	-0.07	-0.66
C7	0.02	-0.56	-0.24	0.08	0.15	0.08	-0.29	-0.18	-0.13	0.15	-0.93
C8	0.16	0.41	-0.29	-0.09	0.04	0.10	0.06	-0.34	-0.15	-0.38	-0.48
C9	-0.02	-0.22	-0.53	-0.24	0.45	-0.33	0.39	-0.30	0.02	0.22	-0.58
C10	-0.21	0.03	0.17	0.18	-0.52	0.38	-0.45	0.76	-0.29	-1.10	-1.06
d	-0.55	-1.32	-2.12	-0.74	0.11	-0.71	0.11	-1.05	-0.12	-0.61	

To identify causal relationships between criteria, $(c + r)$ and $(c - r)$ values of each criterion were gathered. For interpretation, one should consider that if a $(c - r)$ is positive, then the belonging criteria will be in the cause category. Otherwise, then the criterion should be evaluated in the effect category. According to the results of the Pre-Covid phase study [4], there were five criteria in the cause group, namely "Proximity to the ports and customs.", "Proximity to the pharmaceutical production centers.", "Proximity of qualified workforce.", "Location decision of a warehouse must be submitted together with capacity and demand estimation." and "Ground properties of the location (impact of construction on excavation cost)". One can expect that criteria under the cause category have an influence on the criteria in the effect group. The rest of the criteria were classified in the effect group ("Proximity to target markets. (Hospitals, pharmacies)", "Infrastructure of the area (electricity, water, sewage, transportation, natural gas, etc.)", "Climate of the location.", "Leasing cost of the location.", and "Traffic density of location").

When we observed the results of the current study, the criterion "Proximity to target markets. (Hospitals, pharmacies)" has moved to the effect group with a higher importance value whereas "Proximity to the ports and customs" has moved to the effect group. Due to comparative purposes, results of both studies, including $(c + r)$ and $(c - r)$ values, are given in *Table 9*.

Table 9. (c + r) and (c − r) values by criterion.

Criteria	Pre-Covid (c + r)	Pre-Covid (c − r)		Post-Covid (c + r)	Post-Covid (c − r)
C1	Proximity to target markets.	-0.84	-0.14	0.14	1.24
C2	Proximity to the ports and customs.	-2.91	0.18	-3.43	-0.79
C3	Proximity to the pharm. production centers.	-1.94	1.22	-2.59	1.66
C4	Proximity of qualified workforce.	-2.46	0.09	-1.44	0.05
C5	Infrastructure of the area.	-1.51	-0.40	-0.61	-0.83
C6	Capacity and demand estimation.	-1.61	0.13	-1.37	0.05
C7	Climate of the location.	-1.22	-0.75	-0.82	-1.04
C8	Ground properties of the location.	-2.49	0.73	-1.53	0.57
C9	Leasing cost of the location.	-1.05	-0.50	-0.70	-0.46
C10	Traffic density of location.	-1.10	-0.58	-1.67	-0.45

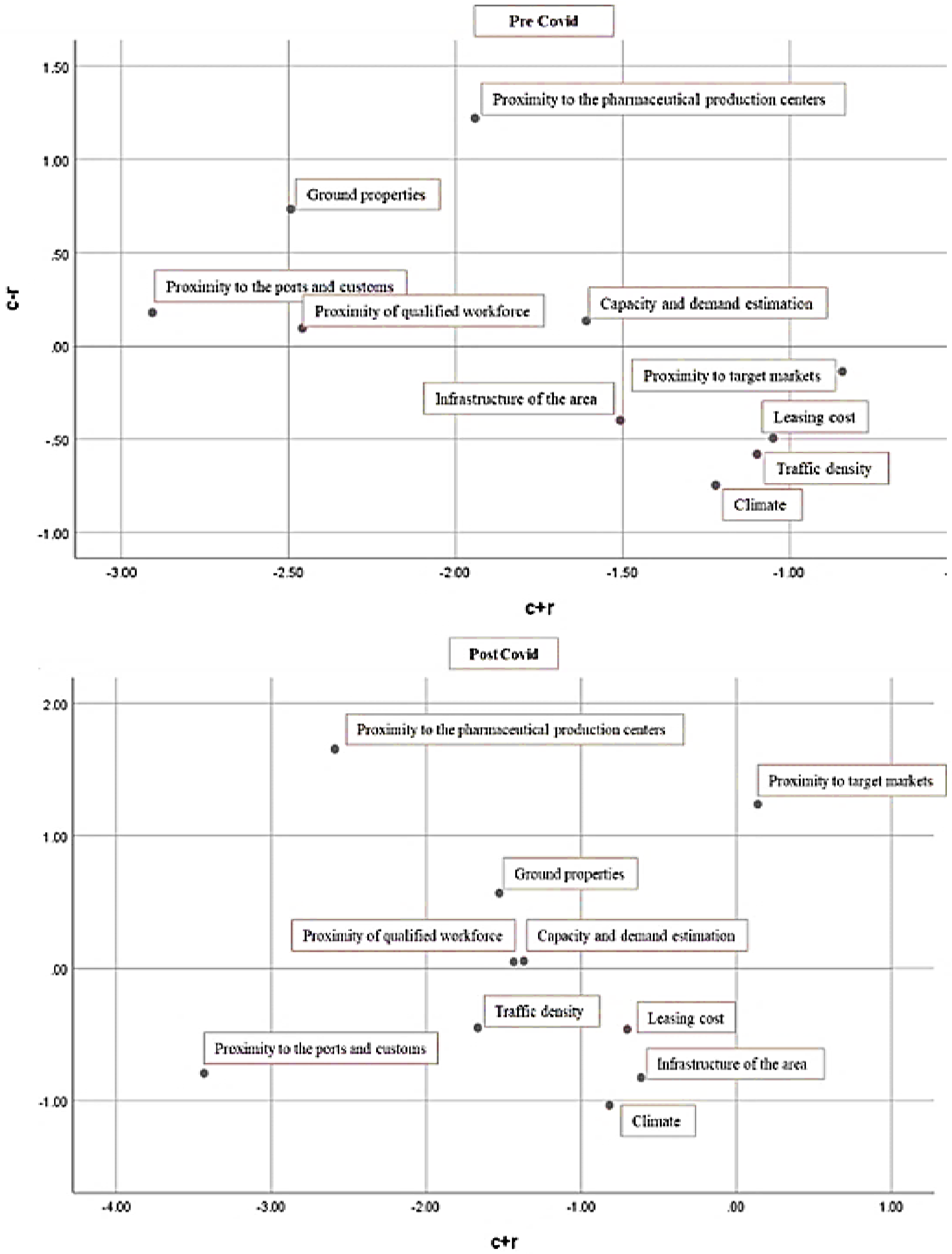

Fig. 1. Causal diagrams.

By plotting related $(c - r)$ and $(c + r)$ values of each criterion where the horizontal axis values are $(c + r)$s, a causal diagram was also obtained. By pursuing a comparative assessment, causal diagrams of both studies are illustrated in *Fig. 1*. The aforementioned changes in the characteristics of the criteria between the two phases could be easily observed via the causal diagrams. For the interpretation of the diagram, one could note that the criterion "Proximity to target markets. (Hospitals, pharmacies)" was on the negative quadrant in the pre-Covid phase diagram and moved to the positive one in the post-Covid phase plot.

6 | Conclusion and Discussion

Since the beginning of the Covid-19 pandemic, studies continue to be carried out to observe the effects in many different areas [1]. In this study, the authors carried out a similar study with [4], which was realized at the end of 2019, to determine the factors that affect the selection of warehouse location in the medical sector through the PF-DEMATEL method. The main purpose of this subsequent study, which was realized at the end of 2020, is to determine how the warehouse location decisions the medical sector was affected by the changing situations after Covid-19. As discussed in the introduction, along with e-commerce, consumer products, and logistics, the medical sector can be counted as one of the most affected sectors after the pandemic. The fact that the medical industry is in a direct and natural relationship with human health, the unexpected differentiation of customer behaviors and the incredible shift in both customers' and stakeholders' expectations under pandemic conditions, finally the pursuit of both responsiveness and profitability under these circumstances are undoubtedly reflected in the perceptions of industry professionals. Considering that the warehouse location of any medical firm directly affects the effectiveness of logistics operations and the responsiveness level of the organization, we investigated that how the changing dynamics of the Covid-19 pandemic are altered the medical sector professionals' judgments and potential actions.

In this study, we aimed to create a comparative inference between pre-Covid and post-Covid eras in terms of the perceptions of decision-makers towards important criteria in the medical warehouse location decisions. With the help of the proposed study design and the PF-DEMATEL method-based approach, causal relationships between criteria were identified by analyzing decision-makers' evaluations on predefined criteria set. Data collection of this study is realized after pandemic outbreak then these results are accepted as the indicators of the post-Covid phase. There were the results of the previous study, which covers causal relationships between the same criteria, were held at the beginning of 2019 already at hand, thus the results of that research were considered as the benchmark that reflects the pre-Covid phase's perceptions. According to the results of the Pre-Covid phase study [4], there were five criteria in the cause group, namely "Proximity to the ports and customs.", "Proximity to the pharmaceutical production centers.", "Proximity of qualified workforce.", "Location decision of a warehouse must be submitted together with capacity and demand estimation." and "Ground properties of the location (impact of construction on excavation cost)". The rest of the evaluated criteria were classified in the effect group ("Proximity to target markets. (Hospitals, pharmacies)", "Infrastructure of the area (electricity, water, sewage, transportation, natural gas, etc.)", "Climate of the location.", "Leasing cost of the location.", and "Traffic density of location").

When we observed the results of the current post-Covid phase study, the criterion "Proximity to target markets. (Hospitals, pharmacies)" has moved to the effect group with a higher importance value whereas "Proximity to the ports and customs" has moved to the effect group. In the light of the obtained comparative results gathered by sector experts' evaluation of the important criteria in the selection of medical warehouse location via the proposed methodology, it was noted that the criterion is related to the proximity of the warehouse location to the target markets is gained higher importance and clustered in the cause group in contradistinction to the pre-Covid phase study. Plus, the criterion that is related to proximity to the ports and customs has moved to the effect group. In this case, the priority of the decision-makers in the medical sector became to provide faster service by being close to the target market compared to the market conditions before the pandemic. However, their perception regarding being close to the customs by considering the operations related to exports and imports has been changed and the criterion is accepted as an affected one by the causal criteria. It is clear that the results should be evaluated as an effort for sector professionals to adapt to the pandemic conditions and also can be accepted as the essential offering of the article.

It is recommended that the aforementioned changes in the perspectives of the medical industry, which plays the most crucial role in the organization of medical supply and vaccines especially after the pandemic, should be considered in future studies. It is recommended that approaches providing comparative results for future studies should be used to assess the impact of the pandemic more objectively in different sectors and/or different decision problems. By considering that there is no similar study performed in the tackled problem here, different MCDM methods can be applied to assess the superiority of the different approaches.

Conflicts of Interest

All co-authors have seen and agreed with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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