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WAREHOUSE LOCATION SELECTION WITH FUZZY C-MEANS METHOD

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ABSTRACT

Choosing the right warehouse location reduces costs while increasing efficiency and customer satisfaction in logistics processes. However, the choice of warehouse location usually involves a large number of uncertain factors. This study investigates the fuzzy c-means method in the warehouse location selection process. Using the principles of fuzzy logic, it offers a methodology that allows the warehouse location to be evaluated with uncertainty and imprecise data. The flexibility, uncertainty, and successful applicability of fuzzy logic to real-world problems are important in decision-making processes such as warehouse location. The fuzzy C-means method is a clustering algorithm used to identify groups (clusters) in the data set. This approach makes decisions regarding warehouse location selection more accurate and supported by information. The results of the study show that the fuzzy C-means method can be used effectively in warehouse location selection and that this approach adds value to the decision processes in logistics management. This methodology can be used in decision-making processes on logistics planning and strategic selection of warehouse locations, while helping businesses increase their competitive advantage.

Keywords: *Clustering, Fuzzy, FCM, Facility Location Selection, Warehouse Location Selection.*

JEL classification: *C02, C38, M11, R34.*

BULANIK C-ORTALAMALAR YÖNTEMİ İLE DEPO YERİ SEÇİMİ

ÖZET

Depo yerinin doğru seçilmesi, lojistik süreçlerde verimliliği ve müşteri memnuniyetini artırırken maliyetleri düşürmektedir. Fakat depo yeri seçimi genellikle çok sayıda belirsiz faktörler içermektedir. Bu çalışma, depo yerinin seçilmesi sürecinde Bulanık C-ortalamalar yöntemini incelemektedir. Bulanık mantık prensiplerini kullanarak, depo yerinin belirsizlik ve kesin olmayan verilerle değerlendirilmesini sağlayan bir metodoloji sunmaktadır. Bulanık mantığın esnekliği, belirsizliği ve gerçek dünya problemlerinde başarılı uygulanabilirliği, depo yerinin seçimi gibi karar verme süreçlerinde önemlidir.

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Bulanık C-ortalamalar yöntemi, veri setindeki grupları (kümeleri) belirlemek için kullanılan bir kümeleme algoritmasıdır. Bu yaklaşım, depo yerinin seçimiyle ilgili kararları daha doğru ve bilgiyle desteklenmiş hale getirmektedir. Çalışmanın sonuçları, bulanık C-ortalamalar yönteminin depo yerinin seçiminde etkili bir şekilde kullanılabileceğini ve bu yaklaşımın lojistik yönetimindeki karar süreçlerine değer kattığını göstermektedir. Bu metodoloji, lojistik planlama ve depo yerinin stratejik seçimi üzerine karar verme süreçlerinde kullanılabilirken işletmelerin rekabet avantajını artırmalarına yardımcı olabilir.

Keywords: *Kümeleme, Bulanık, BCO, Tesis Yer Seçimi, Depo Yer Seçimi.*

JEL Kodları: *C02, C38, M11, R34.*

1. INTRODUCTION

In today's competitive business world, logistics and supply chain management and costs are of strategic importance. One of the factors affecting logistics costs is facility location selection. At the same time, the location and number of facilities to be opened must ensure customer satisfaction and the company must be able to respond quickly to the demand received. The studies carried out in the selection of the facility location can generally be evaluated as quantitative and qualitative studies in two different ways. Quantitative studies are types of studies that are based on optimization and mathematical programming. Qualitative studies, on the other hand, are the type of studies that examine the main criteria that are important in location selection and the effects of these criteria (Durak and Yıldız, 2015).

Facility layout is generally about reducing costs and being able to reduce the distance between the weighted demand centers and the facility that will serve the demand centers (Ruslim and Ghani, 2006). Determining warehouse locations and distribution points is one of the types of facility location selection problem. Warehouse locations and distribution centers; it is an important factor in supply networks and is where materials are stored (short and long-term) and products are delivered to customers (Langevin and Riopel, 2005).

In logistics management, the correct selection of the warehouse location is of critical importance for supply chain efficiency and effectiveness. Failure to properly select the warehouse location can lead to an increase in shipping costs, delays in delivery times, and customer dissatisfaction. The proper selection of warehouse location is vital to optimizing material flow, reducing transportation costs, and increasing customer satisfaction. For these reasons, the selection of a warehouse location represents a strategic decision process for logistics managers and companies. This decision process regarding the selection of the warehouse location involves a number of complex and interconnected factors. Factors such as geographical location, demand patterns, supplier locations, logistics infrastructure, land costs, basic needs (energy, electricity, and water), security, and legal procedures are important elements to consider when selecting the right warehouse location (Sule, 2001). These factors are often expressed in imprecise and ambiguous data, which makes decisions about the selection of warehouse location more complicated.

Fuzzy logic is a powerful tool for dealing with uncertainty and imprecise data. The flexible nature of fuzzy logic offers a viable solution for modeling and evaluating uncertain and imprecise data. This study aims to deal with uncertainty by using the fuzzy c-means method in the warehouse location selection process. This method can offer a valuable decision support tool to logistics managers and companies by making the warehouse location selection process more sensitive and supported by information.

The scope of this study is to examine how fuzzy logic can be integrated with warehouse location selection and to reveal the potential of this method in logistics management. For this purpose, the effects of the fuzzy C-means method on warehouse location selection were evaluated. The results of this study aim to demonstrate the value and impact of this innovative approach in the field of logistics management.

In the subsequent section, a preliminary exposition is provided, succeeded by an exploration of the study's contextualization within the extant academic literature. The third section elucidates the research methodology, delineating the procedural framework employed. Subsequently, the fourth section expounds on the analysis undertaken and the consequent findings derived from the study. The concluding section encapsulates the study's outcomes and presents the final results for comprehensive understanding.

2. LITERATURE REVIEW

The selection of the warehouse location has become a complex and multidimensional problem that needs to be optimized under certain conditions. This process involves various uncertainties. Examples of this process include demand fluctuations, changes in transportation costs, and the uncertainty of geographical factors. Strategic selection of warehouse locations can increase the competitive advantage of enterprises because fast delivery, low costs, and effective inventory management make it possible to provide customers with quality products at competitive prices. In addition, selecting the right warehouse location can strengthen the ability to ensure business continuity in the face of unexpected situations, such as natural disasters. Therefore, it is vital for enterprises to select a warehouse location by carefully analyzing it and taking into account the needs for future growth and change for their long-term success.

Mrad et al. (2023) addressed an integrated warehouse location, allocation, and routing problem. In this context, two collaborative scenarios were proposed and solved using genetic algorithms. Peker and Görener (2022) determined the importance weights of the criteria in facility location selection using the Fuzzy FUCOM method. Birgün and Ulu (2021) studied the location selection of a training center focused on Industry 4.0 and digitalization using DEMATEL and COPRAS.

Wang et al. (2021) studied warehouse location selection and optimization of resource allocation for emergency rescue under uncertainty. They propose a mixed integer programming model based on time cost under uncertainty to solve the emergency warehouse location and distribution problem. Kabadayı and Esen (2021) used the gray relational-based TOPSIS method, one of the multi-criteria decision-making methods, for warehouse location selection.

Fu et al. (2020) studied facility location and capacity planning considering uncertain demand. It proposes a simulation-based optimization approach for site selection. The first one aims to find a set of feasible decisions using fuzzy and stochastic simulation, while the second one is used to obtain the best decision from the feasible decisions obtained by hybridizing stochastic simulation with optimal computational budget allocation and mathematical programming. Sağnak (2020) aimed to select the most suitable warehouse location by integrating fuzzy AHP and fuzzy TODIM methods, which are multi-criteria decision-making methods for warehouse location selection in the retail sector.

Küçükdeniz et al. (2019) the first proposed algorithm is a comprehensive version of the single-iteration fuzzy c-means (SIFCM) algorithm. The second algorithm used a Gustafson-Kessel (GK) fuzzy clustering algorithm in the same framework instead of fuzzy c-means. Numerical results are reported using the MWP problem on a medium-sized data class (106 bytes). A new approach is to use clustering algorithms to find and allocate new facilities while maintaining existing facilities. When applied to large problems, the speed of the proposed algorithms allowed for finding a solution. Güzelgöz et al. (2019) in this paper, a hybrid method is proposed to solve planar multi-plant location problems without capacity. This paper is a pioneering work on the hybrid use of revised weighted fuzzy c-means and augmented Weiszfeld algorithms.

Bastı and Sevkli (2015), the artificial bee colony algorithm is one of the latest meta-heuristic techniques used to solve combinatorial optimization problems. In this paper, an artificial bee colony algorithm model is used to solve the p-median problem, which is an important type of facility location problem and belongs to the class of NP-hard problems. Esnaf et al. (2014) in this study, a new algorithm is proposed to solve unpredictable facility siting problems. The algorithm is a special version of the original fuzzy c-means (FCM) algorithm.

Esnaf and Küçükdeniz (2013) in this study, a revised weighted fuzzy c-means algorithm is proposed for uncorrected planar multi-facility layout problems. The results show that the proposed method based on the revised weighted fuzzy c-means algorithm is superior in terms of cost minimization and CPU time. Fo and Silva Mota (2012) in their study on the location selection problem of healthcare institutions in Brazil, used four different facility location selection models to optimize the location of healthcare institutions. They analyzed p-center, p-median, maximum coverage, and cluster coverage models by comparing their results.

Kim and Soh (2012) used the p-median method model with the aim of arranging the bus line carrying students studying at Wonkwang University and dispersed in the region and reducing the travel time. The researchers modeled the resulting data in an Excel environment to ensure usability and presented the model to the authorities as a preliminary study for initial testing and future use. Ndiaye et al. (2012) created a model for assigning the distance between school and home to the most appropriate school using the p-median method, taking into account the number of students moving from middle school to high school. The model presented a solution alternative with the help of the CPLEX solver.

Özçakar and Bastı (2012) studied the particle swarm algorithm approach in p-median establishment location selection. They applied this algorithm to two commonly used test problems and compared the results with the results obtained from different solution algorithms previously used with similar test problems. The results showed that the algorithm outperformed the other algorithms, except for one of the studies with the same test problems. Esnaf and Küçükdeniz (2009) in this study, a hybrid method based on fuzzy clustering is presented for the multi-facility location problem.

3. RESEARCH METHODOLOGY

Fuzzy Clustering Analysis is an analytical technique developed based on fuzzy logic theory. The fuzzy clustering method is employed to compute membership functions that determine the degree to which objects belong to clusters and to identify overlapping clusters within a dataset (De Oliveira and Pedrycz, 2007). This method becomes appropriate when clusters are not distinctly separated or when there is instability in the membership of certain units. Fuzzy clusters are functions that determine the membership of each unit in the cluster, defined between 0 and 1. Units with similar characteristics are placed in the same cluster based on a high membership degree (Şahinli, 1999). Therefore, the fuzzy clustering method calculates coefficients for the potential membership of units in one or more clusters. The sum of membership coefficients always equals 1, ensuring that a unit is assigned to the cluster with the highest membership coefficient. Similar to other clustering methods, fuzzy clustering relies on distance measurements, with the choice of distance metric depending on the cluster structure and algorithm used (Naes and Mevik, 1999). One advantage of fuzzy clustering over classical clustering methods is its ability to provide more detailed information about the data. However, it also has its drawbacks. In cases involving a large number of individuals and clusters, there may be an abundance of outputs, making summarization and categorization challenging. Additionally, fuzzy clustering algorithms tend to be complex in structure and are often employed when there is a higher degree of uncertainty (Zorlutuna and Erilli, 2018).

The Fuzzy C-means clustering algorithm, one of the most widely used clustering methods, was first proposed by Dunn (1974) and developed by Bezdek (1981). The membership matrix, which is the most important feature of the fuzzy c-means algorithm, has positive effects on clustering. This matrix facilitates the identification of uncertain situations (Azem, 2013). Since the degree of membership is low, the impact of unusual data is low. It also has a flexible structure. Its ability to find overlapping clusters is greater than that of other splitting algorithms.

The fuzzy clustering method is used to calculate membership functions that determine the degree to which objects belong to clusters and to detect overlapping clusters in the data set (De Oliveira and Pedrycz, 2007). In this study, the clustering process of data sets with common features was performed using the Fuzzy C-Means method, which is one of the most widely used methods in the literature.

In this approach, if the separation of clusters from each other does not occur completely and clearly, or if there is an unstable structure related to which cluster membership records some observations, it comes across as an appropriate method. Fuzzy sets are functions that determine each observation, defined as the membership of the observation to the set between 0 and 1. Observations that are very similar to each other and have a high degree of membership are located in the same cluster (Zeybekoğlu, 2018; Gönenç and Yüksel, 2021). Fuzzy clustering flexes the obligation of assigning each observation to only a single cluster and provides information about its membership to other clusters with certain membership degrees. In addition, these degrees of membership help reveal other complex relationships that exist between observations and clusters (Mansoori, 2011; Gönenç and Yüksel, 2021).

The fuzzy c-means algorithm is performed by minimizing an objective function defined for the clustering process. The fuzzy c-means algorithm is implemented as shown in Figure 1. Before starting the algorithm, it is necessary to define the data set (X), the number of clusters (c), the stopping criterion (ε), the fuzziness parameter (m) and the maximum number of iterations (τ) to create the initial membership matrix ($U^{(0)}$) with cluster prototypes ($V^{(0)}$) (Askari, 2021). The algorithm steps are given in Figure 1.

Figure 1. FCM algorithm steps (Askari, 2021)

FCM algorithm
Inputs : X, c, ε, m, τ
U = rand (c, n)
for t = 1 : τ

$$v_i = \frac{\sum_{j=1}^{n} u_{ij}^{m} x_j}{\sum_{j=1}^{n} u_{ij}^{m}} \quad \forall i \in [1, c]$$

$$u_{ij} = \left[\sum_{k=1}^{c} \left(\frac{\|x_j - v_i\|_A^2}{\|x_j - v_k\|_A^2} \right)^{\frac{1}{m-1}} \right]^{-1} \quad \forall i \in [1, c], \forall j \in [1, n]$$

if $\left\| V^{(t+1)} - V^{(t)} \right\| \leq \varepsilon$
Stop
else
end
end
Outputs : U, V

4. ANALYSIS AND FINDINGS

This study focuses on determining or selecting the location(s) warehouse(s) of the company that is the distributor of a food company in Düzce, the warehouse(s) in the province of Düzce, where the amount of demand is certain. In this context, the warehouse location of a company that distributes the products of a food business in Düzce province, in terms of demand centers, was determined with fuzzy c-means.

Table 1. Data Set (Durak And Yıldız, 2015)

Demand Points	X (Latitude)	Y (Longitude)	Demand Amount	Demand Points	X (Latitude)	Y (Longitude)	Demand Amount
1	40,77372	31,31514	5,1	23	40,86245	30,97886	1,5
2	40,91727	31,14724	5,6	24	40,89691	30,94141	1,8
3	40,76007	31,1104	5,6	25	40,83315	31,16538	1,8
4	40,96198	31,44497	5	26	40,83748	31,16701	1,7
5	40,84641	31,156	5,2	27	40,84661	30,93887	1,5
6	40,79874	30,97977	4,6	28	40,85524	31,1448	1,4
7	40,85224	31,02916	4,1	29	40,83843	31,16621	1,6
8	41,08889	31,12388	5,4	30	40,86061	31,04367	1,8
9	40,86297	31,16734	2	31	40,84263	31,16377	1,7
10	40,82893	31,18664	2,4	32	40,8331	31,16688	1,4
11	40,85027	31,16154	1,5	33	40,77624	30,99732	1,3
12	40,83635	31,16293	1,9	34	40,83784	31,16304	1,6
13	40,84383	31,16407	1,6	35	40,82751	31,18876	1,5
14	40,83911	31,16293	1,8	36	40,84761	31,13555	1,7
15	40,84028	31,15098	1,6	37	40,85148	31,12802	1,6
16	40,77641	30,99709	1,8	38	40,83531	31,15016	1,8
17	40,84253	31,16362	1,5	39	40,84232	31,17441	1,6
18	40,84704	31,1395	1,5	40	40,85941	31,15679	1,4
19	40,84307	31,15134	1,4	41	40,87616	31,10281	1,7
20	40,77755	31,3141	1,7	42	40,91144	31,22412	1,9
21	40,85725	30,9647	1,4	43	40,84729	31,16473	1,5
22	40,87931	30,95072	1,6	44	40,89846	31,19065	1,9

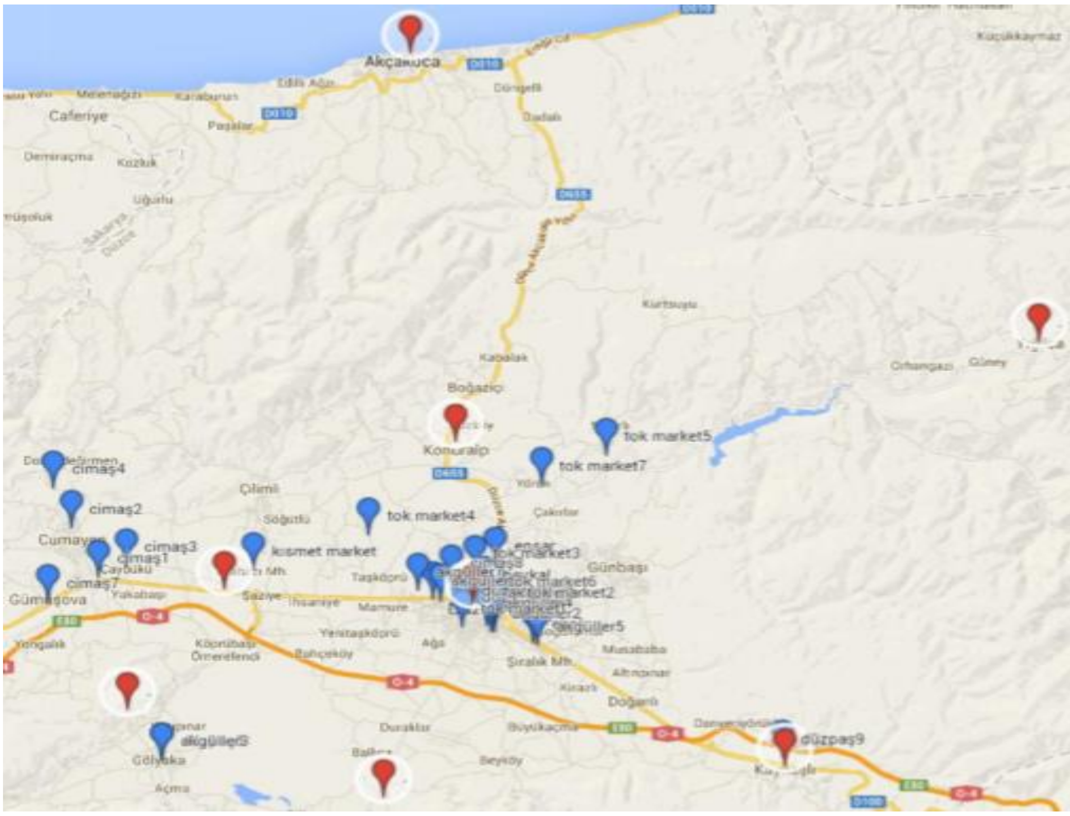
The company carries out transportation to 44 different demand points according to a certain amount of demand. After determining the demand amounts in the company's demand centers, the coordinates of the demand centers were determined and the establishment location of two different warehouses was selected in such a way as to minimize the cost depending on the distance and the amount of demand. In Table 1, the demand quantities, latitude (X), and longitude (Y) coordinates of the demand points are given (Durak and Yıldız, 2015).

The distributions of a total of 44 demand centers are shown in Figure 2.

As shown in Figure 2, most of the demand centers are located close to the city center. Those with red location colors indicate the first eight demand centers with a demand quantity of more than 4 units. The blue colored locations show the demand centers numbered 9 and 44.

The fuzzy c-averages algorithm method, which is a fuzzy logic method, was used in the location selection of two different warehouses. Fuzzy C-Mean (FCM) is a clustering algorithm that divides the dataset into a certain number of clusters or classes. However, like the traditional k-means algorithm, instead of assigning each data point to exactly one cluster, FCM determines the degree of belonging of each data point to each cluster. These degrees of belonging take values between 0 and 1 and represent the probability that a data point belongs to each cluster. Thanks to this feature, FCM is used in data sets containing uncertainty and in cases where each data point can be associated with more than one cluster.

Figure 2. Demand Center Distributions (Durak and Yıldız, 2015)



In this context, with the data set given in Table 1, the location selection problem of two different warehouses were analyzed with the fuzzy c-means algorithm in the MATLAB software program. While performing the clustering analysis, the number of clusters was determined to be two because the number of warehouses to be opened by the company was two. The defuzzification parameter m'=1.5 is taken. This parameter controls the amount of fuzziness in the classification process. If m′ is large, the fuzziness increases; if m is small, the fuzziness decreases; and if m′ = 1, the solution is a classical clustering solution.

In the solution to the problem, the numbers were fuzzified using latitude, longitude, and demand information. Table 2 shows some of the fuzzy numbers of the input parameters for warehouse location selection.

Table 2. Fuzzy Numbers

Demand Points	**X (Latitude)**	**Y (Longitude)**	**Demand Amount**
0,000	0,992	0,995	0,910
0,024	0,995	0,990	1,000
0,070	0,991	0,989	1,000
:	:	:	:
1,000	0,995	0,991	0,339

Then, the settlement centers of the warehouses were found according to the number of warehouses, which is 2, in the Matlab program and are given in Table 3.

Table 3. FCM Warehouse Centers Result

Warehouse Number	**Cluster Center**	
1	0,268965205563019	0,109602263419721
2	0,273739106622053	0,467115610322341

Then, it was determined which demand center would serve the warehouse centers found by the FCM method. Table 4 shows the warehouse centers and the demand points distributed to the warehouse centers.

Table 4. FCM Solution Result

Warehouse Number	**Demand Center Distributions**	**Warehouse Center**
1	6 – 7 – 16 – 21 – 22 – 23 – 24 – 27 – 30 – 33	10
2	1-2-3-4-5-8-9-10-11-12-13-14-15-17-18-19-20-25-26-28-29-31-32-34-35-36-37-38-39-40-41-42-43-44	34

In Table 4, the first warehouse location meets the needs of 10 service points, while the second warehouse location meets the needs of 34 demand points.

5. CONCLUSIONS

This study examined the warehouse location selection process using the fuzzy c-means method. Our findings show that the fuzzy C-means algorithm is a powerful tool to obtain accurate and precise results in the warehouse location selection process. In addition, it is important to carefully adjust the parameters of the algorithm in order to obtain more accurate results under certain conditions.

In the study, two warehouse locations were allocated to the company with a total of 44 demand points, and a proposal was presented for the logistics network structure of the company. As a result, the optimum warehouse locations for two warehouse locations were demand point 13 and demand point 23. For this reason, it will be advantageous for the company to place its warehouses close to the center of the places where demand points are clustered. Among the warehouses to be established, the first warehouse location meets the needs of 10 demand points, while the second warehouse location meets the needs of 34 demand point. The reason for this is that it optimizes demand and distance.

The reason why in this study the approximate distance was calculated using the Euclidean distance formula is that there is no Geographic Information System in Düzce province. For this reason, the minimum number of warehouse locations and the actual distances for determining their location will affect the result. However, Manhattan distance and Euclidean distance are widely used methods in the literature, and it is seen that they reach similar solutions.

An additional consideration not addressed in the present study pertains to the omission of certain criteria influencing warehouse location decisions. This omission is attributed to the impracticability of accessing these criteria within the scope of the study. For example, variables such as land costs, establishment expenses, legal procedures, etc., which affect facility decisions, were not taken into account.

The results of this study can serve as an informative resource for logistics managers and decision-makers in the warehouse location selection process. The fuzzy c-means method provides an effective way to handle uncertainty and complexity and is an important method that can be used to improve decision-making processes in logistics management. Therefore, it offers an important Basti making processes in logistics management.

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