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MEASURING THE IMPORTANCE OF WAREHOUSE LOCATION SELECTION CRITERIA USING BEST-WORST METHOD

Volkan ÇETİNKAYA[1]
Onur AKDAŞ[2]

ABSTRACT

Warehouse performance has a major role in improving the effectiveness of supply chain considering especially the location where the warehousing activities occur. Warehouse location selection criteria have been widely used by decision-makers and researchers to achieve operational efficiency and reduce operational costs in the supply chain. On the other hand, the location of the warehouse is usually evaluated and decided on individual basis. This research aims to reveal the importance levels of the warehouse selection criteria. In this context, the relative weights of the warehouse location selection criteria obtained from the literature were determined using the Best Worst Method (BWM), a multi criteria decision making method. A questionnaire form was sent to five warehouse professional experts in different companies including suppliers, manufacturers, and distributors in Turkey. As result of the study, it has been seen that the "Market" criterion (sub-criteria, market size and demand quantity) has a dominant effect on the selection of warehouse location compared to others.

Key Words: *Warehouse location selection, BWM (Best-Worst Method), importance of warehouse location criteria*

[1] Dr.,Dokuz Eylül University, Maritime Faculty, volkan.cetinkaya@deu.edu.tr Orcid no: 0000-0001-8921-1311

[2] Asst. Prof. Dr., Dokuz Eylül University, Maritime Faculty, onur.akdas@deu.edu.tr, Orcid no: 0000-0002-8622-6494

DEPO YERİ SEÇİM KRİTERLERİNİN ÖNEM DÜZEYİNİN BWM YÖNTEMİ İLE ÖLÇÜLMESİ

ÖZ

Depo performansı özellikle depolama aktivitelerinin gerçekleştirildiği lokasyon açısından tedarik zincirinin performansının arttırılmasında önemli bir role sahiptir. Depo yeri seçim kriterleri tedarik zincirinde operasyonel verimliliği sağlamak ve operasyonel maliyetleri azaltmak için karar vericiler ve araştırmacılar tarafından yaygın olarak kullanılmaktadır. Diğer taraftan, depo yeri seçimi kararı genellikle kişisel yargılara dayanılarak alınır. Bu çalışma depo yeri seçim kriterlerinin önem düzeylerinin ortaya konması amacını taşımaktadır. Bu kapsamda literatürden elde edilen depo yeri seçim kriterlerinin göreceli ağırlıkları çok kriterli karar verme yöntemi olan BWM yöntemi kullanılarak tespit edilmiştir. Çalışma kapsamında Türkiye'de yerleşik tedarikçiler, üreticiler ve dağıtıcılar olmak üzere farklı firmalardan beş depo uzmanına anket formu gönderilmiştir. Çalışmanın sonucunda 'Pazar' kriterinin (alt kriterleri pazar büyüklüğü ve talep miktarı) depo yeri seçiminde diğer kriterlere göre baskın bir etkiye sahip olduğu görülmüştür.

Keywords: *Depo yeri seçimi, BWM Metodu, depo yeri seçim kriterleri önem düzeyi*

1. INTRODUCTION

Warehousing system must be adequately synchronized with other supply chain activities and should correspond to all material and product needs in all stages of supply chain. The efficient and effective movement of goods from raw material sites to processing facilities, component fabrication plants, finished goods assembly plants, distribution centers, warehouses, retailers, and customers is critical in today's competitive environment (Demirel et al. 2010).

The warehouse site location decision has an intensive effect on the investment costs, operating costs and distribution strategy of the company that has an important role in increasing customer service level.

Warehouse location is even more crucial as misguided location can cause disruptions in supply chain activities. Key supply chain goal is improving on-time delivery with minimum costs and efficiency. So, supply chain managers must select the warehouse location that verifies a balance between satisfying customer demands and enhancing efficiency in warehouse operations. Warehouse location selection is a complex process where multiple, both tangible and intangible, criteria need to be considered. Since the strategic objectives in cost reduction and customer service level

decisions warehouse location can be supported by a variety of models based on quantitative and qualitative factors (Vlachopoulou et al. 2001). One of the models put forward to evaluate location problem based on selected criteria is multiple criteria decision-making (MCDM) method. Many criteria have an impact on the selected warehouse location which makes this a typical multiple-criteria decision-making (MCDM) problem. MCDM effectively deals with the intricacy of decision-making process considering all decision criteria harmoniously. Although multi-criteria decision-making methods generally aims to rank the alternatives by using qualitative and quantitative criteria, it is necessary to rank the importance level of the criteria in the first steps of the method. To measure the importance of warehouse location selection criteria, this study aims to rank the criteria by using a multiple-criteria decision-making (MCDM) called BWM (Best-Worst Method) developed by (Rezaei, 2015). This study contributes to the warehouse location selection research subfield by answering the question of which criteria has the highest effect on location decision especially by using a new multi-criteria decision method. The criteria implemented in this study are obtained from literature and grouped into 5 main criteria. To determine the importance of main and sub-criteria and BWM (Best-Worst Method) is applied.

The remainder of this paper is structured as follows. The following section reviews the related literature on criteria regarding warehouse location selection problems. The methodology is detailed in Section 3 and analysis are described in Section 4. Finally, Section 5 summarizes the results of the study.

2. LITERATURE REVIEW

Location selection is an old and widely discussed decision-making science field referring to determination of specific operation location of economic facilities such as factories, freight and passenger terminals, distribution centers, warehouses and so on. According to Korpela and Tuominen (1996); the number of facilities and their location are the fundamental decisions forming the basics of logistics system design. Establishment of warehouses in a logistics system has important role on the efficiency of whole supply chain.

Farahani et al (2010) classified logistics-oriented location problems into four categories as: Optimization Problems, Single and Multiple Objective Location Problems, Deterministic and Non-Deterministic Problems and Continuous and Discrete Location Problems. Ballou (1981) revealed warehouse location as one of key decision area in logistics systems design process. The warehouse location decision is a process during which multiple criteria must be considered (Korpela and Tuominen,

1996). The location alternatives for warehouse can be evaluated by using a multiple criteria decision-making method (MCDM) considering qualitative and quantitative criteria. Many MCDM methods have been successfully applied by past research as decision making models to support warehouse location decision.

Traditional methods of the warehouse location selection process in the extended literature range from analytic hierarchical process (AHP), Simple Additive Weighting (SAW), Multi Objective Optimization on the basis of Ratio Analysis (MOORA), Multi-criteria Optimization and Compromise Solution (called VIKOR), Preference Ranking Organization Method (PROMETHEE), Grey Relational Analysis (GRA), Complex Proportional Assessment method with the applications of the Grey systems theory (COPRAS-G), to Elimination and Et Choice Translating Reality (ELECTRE). Korpela, J. and Tuominen, M. (1996) put forward that cost-oriented methods are not sufficient to develop logistics strategy and suggested to consider reliability, flexibility, and compatibility by using an AHP supported qualitative analysis. Garcia et al. (2014) developed a model based on AHP for agricultural product warehouses. Özcan et al. (2011) compared some MCDM techniques (AHP, TOPSIS, ELECTRE and Grey Theory) by implementing a warehouse location selection problem in Turkey. Singh et al. (2018) presented a fuzzy decision-making approach to deal with optimal location for a warehouse in different regions of Iran on the basis of different criteria. Demirel et al. (2010) identified 5 main criteria for warehouse location selection from the literature and using an additive operator for multi-criteria decision-making methods, named as Choquet Integral.

As MCDM, Linear Programming is a frequent method being applied in location selection problems. Christofides and Beasley (1982) developed a dynamic mixed integer model with Lagrangean relaxation approach considering capacities of warehouses and compared studies about capacitated warehouse location problems. Chen et al. (2007) proposed a fuzzy decision-making method for the multiple conflict objectives problem in a supply chain network with demand uncertainties. MCDM and Linear Programming models has applied different criteria to select the best location for warehouse in supply chain. These criteria focus on cost, infrastructure, labor, market and government.

By reviewing the related literature, it is found that no such study conducted in the field of warehouse location selection by using BWM method.

Warehouse Location Selection Criteria

Multi-criteria decision making can be defined as the evaluation of the alternatives for the purpose of selection or ranking, using a number of

qualitative and/or quantitative criteria that have different measurement units (Özcan et al, 2011). According to Demirel et al. (2010) the location of a warehouse is generally one of the most important and strategic decision in the optimization of logistic systems and warehouse location is a long-term decision and is influenced by many quantitative and qualitative factors. Criteria those have the most frequency on warehouse location studies are listed in Table 1.

Table 1: Criteria for Warehouse Location Selection

Main Criteria	Sub-Criteria
COST Demirel et al. (2010), Santosa and Kresna (2015), Chen et al. (2007), Dey et al. (2017)	**C1-Establishing costs** Chen et al. (2007), Kelly and Marucheck (1984), Budak et al (2020), Santosa and Kresna (2015), He et al.(2017)
	C2-Distribution and Transportation costs Chen et al. (2007), Vlachopoulou et al.(2001), Garcia et al. (2014)
	C3-Handling costs (Demirel et al.(2010), Chen et al. (2007)
INFRASTRUCTURE Demirel et al. (2010), Singh et al. (2018)	**I1-Building** Colson and Dorigo (2004), Vlachopoulo et al. (2001), Shahparvari et al.. (2020), Colson and Dorigo (2014), Farahani et al. (2010)
	I2-Transportation infrastructure Żak and Węgliński (2014), Singh et al. (2018), Demirel et al (2010), Garcia et al (2014), He et al. (2017), Vlachopoulo et al. (2001), Colson and Dorigo (2014)
	I3-Proximity to ports and hubs Kang (2020)
	I4-Electricity, water and telecommunication Singh et al. (2018), Demirel et al.. (2010)
LABOR Demirel et al. (2010), Torabizadeh et al. (2020), Kang (2020)	**L1-Availability of labor force** Demirel et al. (2010), Kang (2020)
	L2-Skilled labor Demirel et al. (2010), Korpela and Touminen (1996), Melachrinoudis et al. (2005)
MARKET Kelly and Marucheck (1984) **(**Demirel et al. (2010), Singh et al. (2018), Dey et al. (2017), Kang (2020)	**M1-Proximity to customers, suppliers and producers (**Demirel et al. (2010), Vlachopoulou et al (2001), Kang, (2020), Shahparvari et al. (2020), Vlachopoulo et al. (2001), Dey et al. (2017), Garcia et al (2014), Özcan et al. (2011)
	M2- Lead times and responsiveness Demirel et al. (2010), Melachrinoudis et al.(2005), Chen et al. (2007)
	M3- Market size and demand quantity Singh et al. (2018), Chen et al. (2007), Santosa and Krosna (2015), Vlachopoulou et al. (2001), Christofides and Beasley (1982), Kelly and Marucheck (1984)
	M4- Scope for market growth Singh et al (2018)
GOVERNMENT Singh et al. (2018)	**G1-Land prices** Singh et al (2018), He et al. (2017)
	G2-Taxation policies Singh et al (2018), Melachrinoudis et al. (2005), He et al. (2017)
	G3-Incentives Singh et al (2018), Chen et al. (2007), Demirel et al. (2010)

3. METHODOLOGY

Research methodology of this study has two main stages. The first stage requires collecting warehouse location selection criteria through a literature review. The second stage is to use the BWM and ranking criteria by assigning their weights. A systematic survey of literature has been conducted to identify the criteria used in previous studies. Based on the previous literature, we focused on five main criteria and 16 sub-criteria the most frequently used on warehouse location selection studies.

3.1.Best-Worst Method (BWM)

In this section, we present the multi-criteria decision-making method (MCDM), called BWM (Best-Worst Method) used in this study.

Multi-criteria decision-making methods deal with the process of making decisions in presence of multiple criteria (Rezaei et al., 2015). Different MCDM methods can be applied to rank criteria and evaluate the alternatives. In this study, a multi-criteria decision-making method called BWM (Best-Worst Method) and developed by Rezaei (2015) is applied to determine the subjective importance weights of warehouse location selection criteria. In this method, the decision-maker (DM) selects the best and worst decision criteria from among the available criteria; then, using paired comparisons, determines the priority of the best criterion over each of other criteria as well as the priority of each criterion over the worst criterion. Then, a programming model is formed, and the optimal weights of the criteria are obtained by solving the model (Amiri et al., 2020).

BWM (Best-Worst Method) is selected in this study because of two relevant concerns faced in pairwise comparison problems. The first concern related to other MCDM techniques is that the number of comparisons makes the comparison process lengthier and the second one is inconsistency between comparisons because of lack of concentration. Instead of a complete pairwise comparison matrix, the BWM requires fewer comparisons, since the comparison is conducted in a very structured way (Rezaei et al., 2018). According to Amiri et al. (2020); (BWM) is one of the most important methods for determining the weights of criteria or options in multi-criteria decision-making (MCDM) and has attracted the attention of many researchers due to its advantages such as fewer numbers of comparisons and higher consistency rate. As a result, BWM requires fewer pair comparisons than previous methods such as AHP and also offers more consistent comparisons (Amiri et al., 2020).

Although BWM is relatively a new method, it has been used by number of authors in different selection problem studies. Pamucar Ecer and Ecer (2020) used BWM for sustainable supplier selection while Gupta and Barua (2017) used the method for supplier selection on the base of supplier's green innovation ability. Hosseini et al. (2021) utilized BWM for weighting criteria in their sustainable supplier selection study. BWM has also been used by Qian et al. (2021) for selection green 3PL logistics service provider. BWM has been used to evaluate selection criteria in logistics and supply chain. While Sharma et al. (2021) evaluated criteria of barriers in Big Data Analytics in supply chain, Kaviani et al. (2020) used the method to evaluate barriers to successful implementation of reverse logistics in automotive industry. Rezaei et al. (2018) has measured the subjective importance of logistics performance index criteria.

Studies that have employed the BWM reached different numbers of the sample. Arsu and Uğuz Arsu (2021) carried out their BWM studies with five experts to assess the set of criteria on personnel selection process. Bilgiç et al. (2021) identified renewable energy resource investment criteria by BWM by taking the feedbacks of five experts. In addition, Koca and Akçakaya (2021) have also employed BWM with the response of five expert in the field of Design of Wearable Technological Products. Kalpoe et al. (2020) also identified the technology acceptance model of e-commerce users by analyzing the six experts' answers to the questions asked by BWM approach.

The BWM has five steps to determine the weights. The steps as given by Rezaei (2015) are explained below:

Step 1: Determination of a set of decision criteria. In this step, we consider $\{c_1, c_2, c_3, \dots, c_n\}$ that should be used to arrive at a decision.

Step 2: Determination of the best and the worst criteria through decision criteria and creation of Best-to-Other's vector:

Step 3: Determination of the preference of the best criterion over all the other criteria using a number between 1 and 9.

$\boldsymbol{A_B}=(\boldsymbol{a_{B1}}, \boldsymbol{a_{B2}}, \dots., \boldsymbol{a_{Bn}})$ where$(\boldsymbol{a_{Bj}})$ indicates the preference of the best criterion *B* over criterion *j*.

Step 4: Determination of the preference of all the criteria over the worst criterion using a number between 1 and 9.

$\boldsymbol{A_W}=(\boldsymbol{a_{1W}}, \boldsymbol{a_{2W}}, \dots., \boldsymbol{a_{nW}})^{\boldsymbol{T}}$ where (a_{jW})indicates the preference of criterion *j* over the worst criterion.

Step 5: Finding the optimal weights. $(w_1^*, w_2^*, \dots \dots w_n^*)$

Optimal weights can be obtained when maximum absolute differences for all j is minimized. If we also consider that the sum of the weights must be equal to 1 and none of the weights can be negative, the following minimax model is obtained:

$$\min max_j \{|w_B - a_{Bj} w_j| , |w_j - a_{jW} w_W|\}$$
$$\text{s.t. } \sum_j w_j = 1$$
$$w_j \geq 0, \text{ for all } j$$

This problem can be solved by converting it to a linear programming model shown below:

Min ς^L

s.t.

$|w_B - a_{Bj} w_j| \leq \varsigma^L$ for all j

$|w_j - a_{jW} w_W| \leq \varsigma^L$ for all j

$\sum_j w_j = 1$

$$w_j \geq 0, \text{ for all } j$$

Consistency (ς^L) of comparisons close to 0 is desired (Rezaei, 2016).

3.2. Data Collection

We designed a BWM questionnaire form in which five main criteria and sixteen sub-criteria definitions exist. BWM questionnaire form were sent twelve warehousing experts (warehouse managers of BCO's (Benefical Cargo Owners) and wholesalers) in different sectors via e-mail and LinkedIn. All experts were selected precisely to get satisfactory outcome from the research considering that professional experience in the industry. Of these twelve experts, five completed questionnaire and sent it back. We can define five experts in this study as professionals who have on average 18,2 years of managerial experience in warehousing operations. Table 2 shows the years of experience, affiliated industry actors (Digital Supply Chain Provider, Beneficial Cargo Owner, 3rd Party Logistics Provider) and the positions (Manager, Warehouse Manager) of the participants.

Table 2: Profile of the Participants

No. of the Participants	Experience in the Industry	Affiliated Industry Actor, Position
1	30 years	Digital Supply Chain Provider, Manager
2	22 years	Beneficial Cargo Owner (BCO), Warehouse Manager
3	15 years	BCO, Supply Chain Chief
4	14 years	3rd Party Logistics Provider, Warehouse Manager
5	10 years	3rd Party Logistics Provider ,Warehouse Manager

In the questionnaire form, firstly warehousing experts were asked to write down the best and the worst criteria through 5 main criteria. The

experts then were asked to determine the preference of the best criterion over the other criteria and the preference of the worst criterion over the other criteria. The same process was conducted within each criteria group for the evaluation of sub-criteria.

4. RESULTS AND DISCUSSION

In this section, we discuss the results of the study including the weights and analysis of the weights about the importance level of warehouse location selection criteria.

Regarding analysis of 5 main criteria, 4 of 5 experts have indicated 'Market' and 'Government' to be the most important criterion and 'least important criterion respectively. Table 3 shows the frequencies of criteria selected to be most and least important by the experts.

Table 3: Frequencies of Criteria to Be Selected to Be Most and Least Important by Experts

Main criterion	Number of experts indicating as most important	Number of experts indicating as least important	Sub-criterion	Number of experts indicating as most important	Number of experts indicating as least important
Cost	1	-	**C1**	-	2
			C2	5	-
			C3	-	3
Infrastructure	-	-	**I1**	-	1
			I2	5	-
			I3	-	-
			I4	-	4
Labor	-	1	**L1**	5	-
			L2	-	5
Market	4	-	**M1**		2
			M2		
			M3	5	-
			M4	-	3
Government	-	4	**G1**	-	1
			G2	1	4
			G3	4	-

The five main criteria and sixteen sub-criteria through each other were rated by five respondents. Average consistency (ς^{L}) values for all comparison satisfy the desired limit ($\varsigma^{L} < 0.10$). Importance weight of each criterion were averaged after evaluation of comparison scores of each respondent. Table 4 indicates the average weights and ranks.

Table 4: Weights and Rankings for Main and Sub-Criteria

Main criterion	Weight score	Rank	Sub-criterion	Weight score	Rank
Cost	0.33	2	**C1**	0.14	3
			C2	0.68	1
			C3	0.18	2
Infrastructure	0.15	3	**I1**	0.13	3
			I2	0.34	2
			I3	0.45	1
			I4	0.08	4
Labor	0.11	4	**L1**	0.81	1
			L2	0.19	2
Market	0.34	1	**M1**	0.18	3
			M2	0.26	2
			M3	0.47	1
			M4	0.09	4
Government	0.07	5	**G1**	0.30	2
			G2	0.26	3
			G3	0.44	1

Most respondents considered **'Market'** and '**Cost**' as the most important criteria followed by **'Infrastructure',** as seen in the final weights. **'Government'** and '**Labor'** has the lowest weight on the base of respondents' importance evaluation. Within each main criterion group, the criteria considered to be the most important sub-criterion are '**Distribution and transportation cost'**, '**Proximity to ports and hubs'**, '**Availability of labor force'**, '**Market volume and demand quantity'** and '**Incentives'.** That **Distribution and transportation cost'**, '**Proximity to ports and hubs'** are ranked first in their own groups reinforces the importance of these two criteria in the selection of warehouse location. The importance of '**Market'** as a main criterion and **'Market size and demand quantity'** as a sub-criterion implies that warehouse managers pay more attention on economies of scale and cube-utilization while managing warehouse processes. In **'Labor'** main criteria group, two sub-criteria significantly differ from each-other considering weight scores. Most experts assigned the highest priority to '**Availability of labor force'.** However, according to Jhawar et al. (2014) it is one of the most severe and immediate requirements for skill development in warehouse segment in logistics systems. The requirement for skilled labor could be crucial for some sectors like; electronics or food-beverage. The ranked fifth main criterion is **'Government'**. We can conclude from the expert opinions that incentives of land and fall of the land prices could emerge a location to set up a warehouse in addition to 'Market volume and demand quantity' and 'Distribution and transportation cost' criteria.

5. CONCLUSIONS AND RECOMMENDATIONS

Warehouse location decisions have long become a crucial component of supply chain systems considering the importance of warehousing function in whole supply chain. Most of the location decisions are made in complex environments where there are so many criteria. MCDM techniques can overcome this complexity by indicating the importance of warehouse location criteria. In this study, as a MCDM, BWM is used to analyze the warehouse location criteria. Evaluating the weight of each criterion using BWM contributes to the literature on warehouse location.

From the BWM results, we can conclude the first-ranking criterion getting the most influence on selection of warehouse location is **'Market'**. '**Cost'** has been identified as another doinant criterion in the BWM Analysis. Besides these two key criteria, '**Infrastructure' and 'Labor'** cannot be ignored, as those criteria help in selecting the right location for

warehouse. Governmental criteria group, consisting of 'Land prices' Taxation policies' and 'Incentives' sub-criteria is supportive.

This study provides many implications for academia and managers of companies. Conducting BWM has employed a novel approach for warehouse location problem in warehousing literature. The logistics managers of supply chains can consider these important criteria for their warehouse site location problems.

As every research work, this study has a significant limitation. Our study is focused on primarily warehouse location selection problems in Turkey and BWM comparisons were made by only Turkish warehouse managers. For better and generalized results, future studies can be conducted by getting connections with warehouse managers across two or three countries.

For further studies, firstly it is important to conduct other MCDM methods. Secondly, It is clear that many of these criteria can cause interrelation. DEMATEL technique can be adopted in future studies in order to investigate the interrelation between warehouse location selection criteria.

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