Research Article

Evaluation of factors affecting logistics performance in a global crisis environment with DEMATEL and BWM

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Abstract: One of the most important indicators of the economic welfare of the countries is the performance level of logistics operations. For this reason, the performance of logistics activities is susceptible to economic conditions. In recent years, the financial crisis environment, which has reached global dimensions due to the pandemic and war, has revealed that logistics management performances should be reevaluated. Therefore, it will be significant to reassess the critical factors that affect the logistics management performance domestically and globally at the country level. This study examined national and international critical factors impacting logistics management performance in the economic crisis environment. For this purpose, criteria determined from expert opinions and scientific literature review were evaluated by DEMATEL and BWM methods. The results obtained from these two methods were combined with the COPELAND method.As a consequence of the investigation, the factors impacting logistics performance were identified and interpreted in order of importance. The paper analyzes the factors impacting countries' logistics performance in the global economic crisis environment and presents an up-to-date evaluation.

Keywords: Global Crisis Environment, Logistics Performance, Criteria Weighting, DEMATEL, BWM, COPELAND.

Küresel kriz ortamında lojistik performansını etkileyen faktörlerin DEMATEL ve BWM ile değerlendirilmesi

Özet: Ülkelerin ekonomik refah seviyelerinin en önemli göstergelerinden biri lojistik faaliyetleri performans düzeyleridir. Bu sebeple lojistik faaliyetlerin performansı ekonomik şartlara oldukça duyarlıdır. Son yıllarda pandemi ve savaş etkisi ile küresel boyutlara ulaşan ekonomik kriz ortamı, lojistik yönetimi performanslarının yeniden gözden geçirilmesi gerektiğini açıkça göstermiştir. Dolayısıyla ülkeler düzeyinde ulusal ve küresel seviyede uluslararası lojistik yönetimi performansını etkileyen kritik faktörlerin yeniden değerlendirilmesi önemlidir. Bu çalışmada lojistik yönetimi performansını etkileyen ulusal ve uluslararası kritik faktörler ekonomik kriz ortamı için analiz edilmiştir. Bu amaçla uzman görüşleri ve bilimsel yazın taraması sonucu belirlenen faktörler DEMATEL ve BWM yöntemleri ile değerlendirilmiştir. Bu iki yöntemden elde edilen sonuçlar COPELAND yöntemi ile birleştirilmiştir. Analiz sonucunda küresel lojistik performansını etkileyen faktörler belirlenerek önem sıralarına göre yorumlanmıştır. Çalışmanın amacı, küresel ekonomik kriz ortamında ülkelerin lojistik performanslarını etkileyen faktörleri analiz ederek, güncel bir değerlendirme ortaya koymaktır.

Anahtar Kelimeler: Küresel Kriz Ortamı, Lojistik Performansı, Kriter Ağırlıklandırma, DEMATEL, BWM, COPELAND.

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1. Introduction

Logistics is the activities that allow the management of all kinds of information, money, raw material, and product flows from the production stage to the final consumption point. (Lambert et al., 1998). Supply chain management is the planning that includes all operations from raw material to consumption in the enterprise. Logistics management plans all operational processes of the same flow, except production. Logistics performance is distributing the finished goods to the appropriate place, at the preferred time, and to the right customer points, with the optimum amount and costs. (Markley and Davis, 2007).

The logistics of goods and services within the supply chain is an element in which businesses and countries make serious investments. Since conditions in the global economic system are constantly changing, companies must have a dynamic logistics management strategy to maintain their competitive advantage in international trade. Therefore, businesses need the highest efficiency strategies to adapt to new economic conditions and ensure sustainability. (Lebas, 1995).

Logistics operations in the global supply chain have the most crucial share of the increasing costs. Events such as pandemics, wars, and famines trigger economic crises, and countries have difficulty adapting to competition due to increasing costs. The safer and faster supply of goods and services will reduce costs. Therefore, countries that improve their logistics management performance will have a competitive advantage in a crisis.

In a crisis environment, logistics operations, which are the most important part of supply chain activities, can not be carried out effectively. The main reason for this is that the supply chain infrastructure, which is the most significant unit of the economic system, incorporates processes that are directly affected by serious conditions such as war, pandemic, famine. Therefore, it can be said that there is a direct relationship between economic development and logistics performance (Arvis et al, 2016). Although, to the best of our knowledge, there is less study in the scientific literature that directly examines logistics performance in a global crisis context, there are plenty of studies showing that countries' economies are directly related to logistics performance. In the studies such as (Levchenko, 2004; Djankov et al., 2006; Boopen, 2006; Korinek and Sourdin, 2011; Çekerol and Kurnaz, 2011; Jhawar and Garg, 2018; Sharipbekova and Raimbekov, 2018) it can be seen that logistics performance has effects on economic growth.

Some studies in the scientific literature examining the relationship between crisis situations and logistics management are included. In their study, Jüttner and Maklan examined supply chain flexibility in the global crisis environment. (Jüttner and Maklan, 2011). Blome and Schoenherr analyzed the supply chain operations of eight large companies in a crisis environment. (Blome and Schoenherr, 2011). Folinas et al. examined the impact of logistics activities during the recession in the Greek economy. (Folinas et al., 2018). In his study, Joseph analyzed the impact of the economic conditions that emerged during the epidemic period on the sustainability of supply chain management. (Joseph, 2021). Kalman and Toth analyzed the relationship between economic competitive advantage and logistics performance for four countries. (Kalman and Toth, 2021). Nguyen and Le examined the impact of financial crises on logistics performance for one hundred developing and developed countries. (Nguyen and Le, 2022).

Several indexes have been developed to measure the logistics performance of governments and enterprises at worldwide and national levels. Internationally known indexes can be listed as Agility Emerging Markets Logistics Index (AEMLI), Baltic Dry Index (BDI), Global Logistics Guide (GLG), Liner Shipping Connectivity Index (LSCI), and Logistics Performance Index (LPI). LPI is the most cited in scientific research among these indexes and was initially published by the World Bank in 2007. This index evaluates the quality of logistic services, transportation infrastructure, international transportation, on-time delivery, customs, and traceability of countries. (The World Bank, 2022).

Logistics performance can be defined as a measure by which the efficiency and quality of logistics activities are evaluated. The first thing to be done to increase the performance is correctly determining the performance measurement criteria. The other is to determine performance-enhancing strategies following the determined criteria (Wouters, 2009). Correct determination of performance criteria will contribute significantly to developing measurement and evaluation skills (Landers et al., 2008).

In scientific studies on logistics performance, it has been observed that multi-criteria decision-making methods (MCDM) and econometric methods are frequently used due to the multifaceted, complex structure of logistics activities and the high number of criteria. Some of these studies are (Chow et al., 1994; Caplice and Sheffi, 1995; Lai et al., 2002; Gunasekaran and Kobu, 2007; Qureshi et al., 2008; Hamdan and Rogers, 2008; Büyüközkan et al., 2009; Qureshi et al., 2009; Tezuka, 2011; Bonney and Jaber, 2013; Guarnieri et al., 2015; Watrobski, 2016; Marchet et al., 2017; Qaiser et al., 2017; Roy and Sengupta, 2018).

In studies examining logistics efficiency on the macro scale, it is seen that various comparative analyzes have been made with the help of MCDM and other econometric methods using LPI. (Kısa and Ayçin, 2019; Eygü and Kılınç, 2020; Manavgat and Demirci, 2021; Göğebakan, 2022). However, no study that reevaluates logistics performance criteria at the domestic and international levels in the current crisis conditions could be found in the literature.

Several MCDM methods have been utilized to determine criteria weights in the literature. Among them, Best-Worst Method (BWM), Analytic Network Process (ANP), Decision Making Trial and Evaluation Laboratory (DEMATEL), Full Consistency Method (FUCOM), Criteria Importance Through Intercriteria Correlation (CRITIC), Step-Wise Weight Assessment Ratio Analysis (SWARA), and Analytic Hierarchy Process (AHP) (Ulu et al., 2022) can be listed.

DEMATEL is a method that can prioritize the criteria of a complex decision-making task by examining their effect levels on each other. The technique allows the criteria to be grouped as the cause and effect, then to determine their weights (Aksakal And Dağdeviren, 2010). DEMATEL evaluates complex criteria relationships and transforms them into a decision model with a causality dimension. The DEMATEL was chosen for this study because domestic and international performance criteria in logistics can have solid economic causal relationships with each other.

BWM is a more recent MCDM method based on initially selecting the best and worst criteria in the decision-making problem. Pairwise comparisons are performed only between the remaining criteria and the best and worst criteria, respectively. Shortly, criteria weighting can be done without a complete pairwise comparison between all criteria. Thus, if the number of criteria is high, it can produce a more consistent pairwise comparison. It has been chosen as an alternative solution method in this study because of its stated advantages, providing additional information about the most and least important criteria according to different experts, and being a novel approach. The aim is to strengthen the analysis by comparing criteria rankings by different methods.

The primary purpose of this study is to present the current evaluation of the factors affecting the performance of logistics activities, which were reshaped in the global crisis environment, with two different methods comparatively. For this purpose, DEMATEL and BWM were utilized to analyze both sets of criteria, and the results were evaluated. The values obtained from the two methods were combined and analyzed with the COPELAND method. Thus, the results obtained from the two methods were re-evaluated.There are various studies on the subject in the literature. The study is thought to contribute to the literature since it employs current domestic and international logistics performance criteria and analyzes the results comparatively by using two different practical methods.

2. Materials and methods

Logistics performance can be measured on a micro and macro scale and calculated using cost, time, speed, durability, and elasticity parameters. The logistics activities of companies at the domestic level and the logistics activities of countries at the international level were considered in this study. The study's logistics performance criteria were derived from current indices, a thorough scientific literature review, and expert opinions. Two sets of domestic and international criteria were obtained and analyzed.

Table 1. Critical factors affecting domestic logistics performance

No	***Criteria***	***Description***	***Reference***
1	Logistics Costs (D_1)	Logistics costs include transportation costs, risks, damages, customer service costs, administration costs, inventory-carrying costs, handling, packaging, etc.	Yean and Das (2016); Dang and Yeo (2018).
2	Logistics Infrastructure (D_2)	Transport infrastructure (air, sea, road, railway), container depots, handling equipment, and logistics centers	Kauppinen and Lindqvist (2006); Fechner (2010); Banomyong et al. (2015); Yean and Das (2016).
3	Technology and Telecommunication (D_3)	Global positioning by satellite, Warehouse management system, Transport management system, Online status tracking, Enterprise resource planning, Port management system, Multimodal transit connectivity, Infrastructure connections, containerization level, etc.	Kauppinen and Lindqvist (2006); Dang and Yeo, (2018).
4	Institutional Frameworks (D_4)	Customs policies and clearance, regulations and directions, environmental avoidance and guidance, corruption issues, and the number of agencies.	Kauppinen and Lindqvist (2006); Lu and Lin (2012); Banomyong et al. (2015); Dang and Yeo, (2018).
5	Logistics Services (D_5)	Transportation services (air, sea, railway, etc.), forwarding services, warehouse services, customs agencies, customs bonds, lead time, etc.	Banomyong et al., (2015); Karim et al. (2018); Dang and Yeo, (2018).
6	Human Resources (D_6)	The quality of logistics education and labor force, logistics research and development	Kauppinen and Lindqvist (2006); Dang and Yeo, (2018).
7	International Cooperation (D_7)	Strengthening cooperation among international with domestic enterprises, raising alertness of state enterprises and agencies on logistics.	Yean and Das (2016).
8	Finance Services (D_8)	Accessibility of insurance and banking, effective monetary policy	Dang and Yeo, (2018).
9	Digital Transformation (D_9)	Integration of logistics infrastructure and services into the digital environment	AEMLI, (2022).

Table 1 lists nine key criteria that have been decided to influence logistics performance at the national level. In recent years, when the impact of the global crisis was evident, the changes in traditional logistics systems due to the developing technology and the increasing importance of the global supply chain guide to the inclusion of *"Technology and Telecommunication," "International Cooperation"*, and *"Digital Transformation."*

Likewise, Table 2 includes nine essential criteria chosen to influence logistics performance at the international level. With the globalization of companies, government administrations, customs and port services, and increasing digitalization, the effects of the new business model were deemed appropriate to include in the study. For this purpose, *"Domestic Logistics Opportunities"*, *"International Logistics Opportunities,"* and *"Digital Readiness"* criteria were appended to the international criteria set, in addition to the widely accepted LPI index in the literature.

Table 2. Critical factors affecting international logistics performance

No	*Criteria*	*Description*	*Reference*
1	Customs (I_1)	Procedure before import or export internationally, the efficiency of border management authorization	LPI, (2018).
2	Logistics Infrastructure (I_2)	The standard of transportation and commercial infrastructure.	LPI, (2018).
3	International Shipments (I_3)	The ease with which competitively priced shipments can be adjusted	LPI, (2018).
4	Logistics Quality and Competence (I_4)	The quality and competence of logistics services	LPI, (2018).
5	Tracking and Tracing (I_5)	The skill to trace and track consignments	LPI, (2018).
6	Timeliness (I_6)	The regularity with which shipments deliver consignee within expected delivery times or scheduled	LPI, (2018).
7	Domestic Logistics Opportunities (I_7))	Logistics markets, economy, income equality, population, urbanization, business clusters	AEMLI, (2022).
8	International Logistics Opportunities (I_8)	International logistics markets, infrastructure connectedness, and quality	AEMLI, (2022).
9	Digital Readiness (I_9)	Digital business models and online commerce, digital skills, and human capital, emissions intensity, entrepreneurial risk, renewable energy mix	AEMLI, (2022).

2.1 DEMATEL

The DEcision-MAking Trial and Evaluation Laboratory (DEMATEL) is an effective method for analyzing complex decision-making problems (Gabus and Fontela, 1972). It can characterize the internal relationships of the criteria involved in the decision-making as a network. A model describing the interrelationships between the criteria is obtained. One of the essential advantages of DEMATEL is that it can decouple the criteria into groups in the form of cause-and-effect criteria.

Cause criteria are high priority criteria that have more impact on others. On the other hand, effect criteria are those that are more influenced and considered to be of low priority. DEMATEL is a method that can rank or prioritize the criteria in the decision problem by considering the nature of relations between the criteria and the strength of these relations. Identifying the critical ones among the criteria is one of the crucial aspects of the method. The internal relationships captured from the analysis can be presented more effectively with visual tools such as an impact diagram and a relationship map.

(Si et al., 2018) offers a very comprehensive literature review about DEMATEL. In some research, the DEMATEL approach is implemented with other methods for specific purposes. For example, (Gölcük and Baykasoğlu, 2016) thoroughly investigated criteria interaction in Multiple-Attribute Decision Making methods and reviewed DEMATEL and Analytical Network Process hybridization in this setting.

Different variations of the classical DEMATEL technique have been created to address issues with ambiguity and vagueness in decision-making, such as Fuzzy DEMATEL (Chang et al., 2011), Grey DEMATEL (Bouzon et al., 2018), Neutrosophic DEMATEL (Kilic et al., 2021), Intuitionistic Fuzzy DEMATEL (Büyüközkan et al., 2017), Spherical DEMATEL (Özdemirci et al., 2023).

The DEMATEL approach is frequently employed to offer insightful information to practitioners and decision-makers in various application fields. The following is a list of studies that use the classical DEMATEL as an analysis tool in particular areas like supply chain and logistics. Determining barriers that need to be removed to implement sustainable supply chains in textile and apparel industries

(Vishwakarma et al., 2022), examining the relationships between the components of sustainable logistics, and identifying the crucial and causal elements affecting its adoption (Parhi et al., 2022). Finding the essential factors in the automotive aftermarket logistics operations planning by considering interdependency among factors (Hsieh and Zhang, 2022). Assessing the most vital metrics for service quality of smart ports and their links in the post pandemic environment (Hsu et al., 2023). Evaluating the third-party logistics (3PL) providers' contribution rates concerning service quality and DEMATEL aided in detecting the importance of segmented jobs in the service process (Du, 2023).

The stages followed by classical DEMATEL can be given as follows (Tzeng et al., 2007; Wu, 2008; Uygun et al., 2015):

1) Obtaining Direct Relationship Matrix

To obtain the Direct Relationship Matrix (M), experts are requested to indicate how much each criterion affects other criteria. The scale consists of values 0 (any influence), 1 (low influence), 2 (medium influence), and 4 (very strong influence), respectively. As a criterion does not affect itself, all main diagonal elements in the matrix are equal to zero. If there is more than one expert, the arithmetic mean of the expert opinions is used. In a decision problem consisting of n criteria, m_{ij} is the value that shows how much criterion i affects criterion j (Eq. 1)

$$\mathbf{M} = \begin{bmatrix} m_{11} & \cdots & m_{1j} & \cdots & m_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ m_{i1} & \cdots & m_{ij} & \cdots & m_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ m_{n1} & \cdots & m_{nj} & \cdots & m_{nn} \end{bmatrix}_{n\times n} \quad ; \quad i,j \in \{1,\dots,n\} \qquad \textbf{(1)}$$

2) Creating the Normalized Direct Relation Matrix

Direct Relation Matrix (M) is converted to the Normalized Direct Relation Matrix (D) as Eq. 2.

$$D = \frac{M}{k} \qquad \textbf{(2)}$$

The totals of the rows and columns are computed separately. The largest of these sums (k) is determined as in Eq. 3 and used for normalization. So, there is at least one i such that $\sum_{j=1}^{n} m_{ij} \leq k$.

$$k = \max\left(\max_{1\leq i\leq n} \sum_{j=1}^{n} z_{ij} \, , \max_{1\leq j\leq n} \sum_{i=1}^{n} z_{ij} \right) \qquad \textbf{(3)}$$

As a result of the normalization operation, the values of each element in $D = [d_{ij}]_{n\times n}$ becomes $0 \leq d_{ij} \leq 1$ and $0 \leq \left(\sum_i d_{ij}, \sum_j d_{ij}\right) < 1$. Also, at least one column $\sum_j d_{ij}$ or one row $\sum_i d_{ij}$ equals 1.

3) Attaining the Total Relation Matrix

Total Relation Matrix (T) is used to create the full impact of the criteria. Indirect impacts between criteria are assessed using the powers of D matrix. This matrix shows the gradual reduction of indirect effects. Also, it guarantees convergent matrix inversion solutions that resemble an absorbing Markov chain matrix (Hsu et al., 2013).

$$\begin{aligned} T &= D^1 + D^2 + D^3 + \cdots + D^h \\ &= D(I + D + D^2 + D^3 + \cdots + D^{h-1})(I - D)(I - D)^{-1} \\ &= D(I - D^h)(I - D)^{-1} \end{aligned} \qquad \textbf{(4)}$$

In Eq. 4, I is denoted as the identity matrix. When $\lim D^h = [0]_{n\times n}$ and $h \to \infty$, Total Relation Matrix is generated as follows:

$$T = \lim_{h=\infty}\left(D + D^2 + \cdots + D^h\right) = \sum_{h=1}^{\infty} D^h = D(I-D)^{-1} \quad \textbf{(5)}$$

where t_{ij} indicates the amount of total direct relation of i th criterion in j th criterion.

4) Calculating Cause and Effect Values

Cause and effect values are determined by the sum of rows and columns of T matrix represented as R and C, respectively. The formulation for these values is shown in Eq. 6 and Eq. 7.

The r_i is the sum of the i th row and shows the cause value of the criterion i on other criteria. It represents the total of direct and indirect effects dispatching from criterion i to the other factors.

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \quad ; \quad i = 1, \dots, n \quad \textbf{(6)}$$

Similarly, the c_j is the sum of the j th column and shows the effect of the criterion j on other criteria. It is the total of direct and indirect effects criterion i is receiving from other criteria. In Eq. 7, T denotes the transpose operation.

$$C = \left[c_j\right]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n}^{T} \quad ; \quad j = 1, \dots, n \quad \textbf{(7)}$$

For the $i = j$ and $i, j \in \{1,2, \dots, n\}$, $r_i + c_j$ indicates the impact of the i th criterion (how crucial it is to others). So, a greater $r_i + c_j$ value indicates that the criterion has more interaction with other criteria. Similarly, a smaller $r_i + c_j$ is an indication that i th criterion has less interaction with others.

Additionally, $r_i - c_j$ values are utilized to classify criteria as groups of cause and effect. In case of $r_i - c_j$ is positive for a criterion, this criterion is identified as a causal criterion. Conversely, in the case of $r_i - c_j$ is negative, it is an effect criterion.

5) Calculating the Threshold Value

A threshold value is used to make the findings easy to read and keep the system's complexity under control. Usually, the threshold value θ is calculated as the average of elements in the Total Relation Matrix as in Eq. 8. Here, $N = n \times n$ is the total number of elements in this matrix. In some situations, the decision-makers or experts can also determine the threshold value by brainstorming.

$$\theta = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{N}, \quad i, j \in \{1,2, \dots, n\} \quad \textbf{(8)}$$

The threshold value is utilized when plotting the interrelationship map. Only the relationships on the total direct relationship matrix with a value greater than the threshold are considered interdependencies between criteria. In this way, it is aimed to eliminate and filter criteria that have a minor impact on others.

6) Plotting Interrelationship Map

Relations that surpass the threshold value are presented in the interrelationship map, with $R + C$ values on the horizontal axis and $R - C$ values on the vertical axis, respectively. The $R + C$ value is called *"Prominence"* and illustrates the strength of influences that are given and received of the criterion. In a nutshell, *"Prominence"* indicates the degree of the criterion's central role in the system. $(R - C)$ value is called *"Relation"* and gives the net effect the criterion contributes.

Decision-makers can graphically discover the intricate causal relationships between criteria and highlight valuable insights for decision-making by exploring the Interrelationship Map.

7) Determining the Weights of Criteria

Typically, a normalizing process establishes the criteria importance weights based on the Prominence $(R + C)$ values (Si et al., 2018), as seen in Eq. 9.

$$\omega_i = \frac{r_i + c_i}{\sum_{i=1}^{n} r_i + c_i}, \quad i = 1,2 \ldots n. \qquad \textbf{(9)}$$

(Dalalah et al., 2011) proposed another formula (Eq. 10-11) to measure the importance of criteria. ω_i represents the vector length starting from the origin to each criterion on the Interrelationship Map.

$$s_i = \sqrt{(r_i + c_i)^2 + (r_i - c_i)^2}, \quad i = 1,2 \ldots n \qquad \textbf{(10)}$$

To reach the final weights of criteria to be employed in the analysis following normalization step is applied.

$$\omega_i = \frac{s_i}{\sum_{i=1}^{n}(s_i)}, \quad \forall i = 1,2,\ldots,n, \qquad \textbf{(11)}$$

2.2 BWM

BMW (Rezaei, 2015) is a multi-criteria decision-making method that uses a pairwise comparison. The usage of BWM has been growing in recent years since it has some advantages over Analytical Hierarchy Process, the most common method to calculate criteria weights through pairwise comparisons. The formulation of the BWM is easy to capture and apply. The central part of the BMW technique is the presumption that we consider a reference point whenever we compare two items in our daily lives. So, the foundation of BMW is identifying the best and worst criteria in the decision-making problem and the comparison of these to the other criteria (reference comparisons) (Rezaei, 2020). Except for reference comparisons, no pairwise comparisons are performed. Unlike the AHP method, which employs matrices for pairwise comparisons, BWM uses vectors. As a result, if there are n criteria in the decision-making task, there are $2n - 3$ comparisons in the BWM, while there are $n(n-1)/2$ comparisons in the AHP. Since fewer comparisons are conducted, the problem of inconsistency is alleviated. Moreover, contrary to methods such as DEMATEL, which is also one of the weight calculation methods, in BWM, it is possible to gain a consistency ratio that indicates the reliability of comparisons.

The BWM method can be employed alone to weigh the criteria and rank the alternatives. It can also be utilized in a hybrid fashion, in which case only the weighing step is carried out while other techniques are implemented to rank the alternatives. Or, as in this research, it can be used solely for criteria weighting. Examples of recent studies where the criteria weighting is the main focus are included as follows: Putting weight on each of the six indicators that go into the Logistics Performance Index (Rezaei et al., 2018); assessing the prospects and difficulties in Russia's renewable energy industry by allocating weights to the listed criteria under professional judgments (Agyekum et al., 2021); weighing the major aspects influencing traffic accidents (Ulu et al., 2022); analyzing the outcomes of various weighting techniques for the six critical elements of a smart city (Ekin and Sarul, 2022); the weighting of the eight competitiveness evaluation criteria for different self-directed ship category for the route of transportation in Arctic (Munim et al., 2022).

A very comprehensive survey on applications of the BWM is provided by (Mi et al., 2019). A bibliometric analysis of BMW, advantages, and formulation of the method, integrations of BMW with other MCDM methods, challenges, and future research guidelines are given in-depth in this study.

The mathematical steps of the approach are described in detail by following (Rezaei, 2016; Beemsterboer et al., 2018; Rezaei et al., 2018).

1) Determining Decision Criteria Set (C)

The set of criteria is important for choosing the best alternative or ranking the alternatives. In the first stage, the criteria set $c_1, c_2, \dots c_n$ consisting of n criteria is determined. For this purpose, conducting a literature review, brainstorming, or consulting expert opinions may be necessary. Since different expert groups may have different viewpoints, acquiring different criteria for the same subject is possible.

2) Identifying the Best (B) and the Worst (W) Criteria.

At this stage, the experts are questioned to determine the criteria that they consider the most important (best) and least important (worst) among the criteria. No pairwise comparison is made at this stage; only the best and worst criteria are determined. If an expert has more than one best or worst criterion, that expert can arbitrarily choose one to be the best or worst.

3) Creating Best-to-Others Vector

The value of a_{ij} indicates the level at which the expert prefers criterion i over criterion j. Generally, a Likert scale represents a preference ranging from 1: equal importance to 9: absolute preference.

The Best-to-Others vector (A_B), which specifies the preference for the best criterion over all the other criteria, is formed as in Eq. 12. A_{Bj} denotes the preference of the best criterion B over the criterion j.

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}) \qquad \textbf{(12)}$$

4) Creating the Others-to-Worst Vector

The Others-to-Worst vector (A_W) that shows the preference of all the criteria over the worst criterion (W) is created as in Eq. 13 where A_{jW} gives the preference of the criterion j over the worst criterion.

$$A_W = (a_{1W}, a_{2W}, \dots, a_{nW})^T \qquad \textbf{(13)}$$

5) Finding the Optimal Weights

The optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ are calculated by following steps. First of all, for each pair of w_B/w_j and w_j/w_W, equalities $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$ must be satisfied. According to Best Worst Method, the optimal weights are located where these conditions are met. For that purpose, a solution minimizing the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ for all j is searched. Thus, it is a min-max problem. Additional constraints are: the sum of the weights must be 1, and each weight must be greater than or equal to zero. This nonlinear optimization setting can be expressed as follow (Model 1):

$$\begin{aligned} &\min \xi \\ &\text{such that} \\ &\left|\frac{w_B}{w_j} - a_{Bj}\right| \le \xi, \quad \forall j \\ &\left|\frac{w_j}{w_W} - a_{jW}\right| \le \xi, \quad \forall j \\ &\sum_j w_j = 1 \\ &w_j \ge 0, \text{ for all } j \end{aligned} \qquad \textbf{Model 1}$$

In cases where the number of criteria exceeds three, Model 1 gives multiple optimal solutions. In that case, the lower and upper bounds for the weights can be determined by converting the optimization problem into two optimization problems where the objective functions are min and max, respectively. Thus, the decision maker can determine the optimal weight from this specified range. Another approach is to use the center of the range as the weight. It is appropriate to set the weights as a range for situations where it would be helpful to discuss the conclusion. However, in cases where flexibility is not aimed and a unique optimum $(w_1^*, w_2^*, \ldots, w_n^*)$ is desired, the nonlinear problem is converted to a linear model (Model 2). Model 2 is a good linear approximation of Model 1.

$$\begin{aligned} &\min \xi^L \\ &\text{such that} \\ &\left|w_B - a_{Bj} w_j\right| \le \xi^L, \quad \forall j \\ &\left|w_j - a_{jW} w_W\right| \le \xi^L, \quad \forall j \\ &\sum_j w_j = 1 \\ &w_j \ge 0, \quad \forall j \end{aligned} \qquad \textbf{Model 2}$$

6) Consistency Check

In the BWM method, the equality of $a_{Bj} \times a_{jW} = a_{BW}$ must be satisfied for all criteria j to accept the comparisons as entirely consistent. Here, a_{Bj}, a_{jW} and a_{BW} denotes the preferences of the best criterion over j th criterion, j th criterion over the worst criterion, and best criterion over the worst criterion, respectively. But it is unlikely to obtain complete consistency in comparisons.

The Consistency Ratio (CR) (Eq. 14) is computed to quantify consistency.

$$Consistency\ Ratio\ (CR) = \frac{\xi^*}{Consistency\ Index} \qquad \textbf{(14)}$$

Consistency index values from Table 3 (Rezaei, 2015) are used to find the Consistency Ratio. (CR) takes values in the range [0,1]. Consistency is high if the result is closer to zero, and expert comparisons are more reliable.

Table 3. Scores for consistency index

a_{Bw}	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Consistency Index (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

A threshold value is needed to show which values are acceptable. This threshold value is found by examining Table 4 (Liang et al., 2020).

Table 4. The threshold for different mixtures of the count of criteria and scale

	Criteria Count						
(a_{BW})	***3***	***4***	***5***	***6***	***7***	***8***	***9***
3	0.2087	0.2087	0.2087	0.2087	0.2087	0.2087	0.2087
4	0.1581	0.2352	0.2738	0.2928	0.3102	0.3154	0.3273
5	0.2111	0.2848	0.3019	0.3309	0.3479	0.3611	0.3741
6	0.2164	0.2922	0.3565	0.3924	0.4061	0.4168	0.4225
7	0.2090	0.3313	0.3734	0.3931	0.4035	0.4108	0.4298
8	0.2267	0.3409	0.4029	0.4230	0.4379	0.4543	0.4599
9	0.2122	0.3653	0.4055	0.4225	0.4445	0.4587	0.4747

For example, if a decision-making problem consists of 9 criteria and the maximum value in the pairwise comparison system is 7, then according to Table 4, the threshold value is 0,4298, which means that values of CR below 0,4298 are accepted as an indicator of a good comparison.

On the other hand, if linear programming (Model 2) is used to handle the problem, the value ξ^{L^*} (optimal value of the objective function) can be used as an approximation of the Consistency Ratio.

2.3 COPELAND

COPELAND method is one of the widely used methods for combining rankings obtained from different MCDM methods. For this purpose, pairwise comparisons of alternatives are used to obtain a COPELAND score for each alternative based on the number of wins and losses. Using this score, the alternatives are ranked. The steps of the method are as follows (Çakır, 2017; Karakaş Geyik et al., 2022; Ergun et al., 2022):

1) Creating the superiority matrix

i : the rank value of the alternative in the row, j : the rank value of the alternative in the column, k : index of the MCDM method, $r_k(A_i)$: the rank value of alternative i according to method k. By employing pairwise comparisons between ranks of alternatives, the superiority of alternative i over alternative j that is denoted as $f_k(i,j)$ is calculated.

$$f_k(i,j) = \begin{cases} r_k(A_i) < r_k(A_j) \wedge i \neq j \Rightarrow 1 \\ r_k(A_i) > r_k(A_j) \wedge i \neq j \Rightarrow 0 \\ r_k(A_i) = r_k(A_j) \wedge i \neq j \Rightarrow 0 \end{cases} \quad \textbf{(15)}$$

2) Calculating overall superiorities

m : the total number of MCDM methods. $S(i,j)$: Overall superiority of alternative i to alternative j.

$$S(i,j) = \sum_{k=1}^{m} f_k(i,j) \quad \textbf{(16)}$$

3) Determination of win, loss, and tie conditions

$G(i,j)$ gives win, loss, and tie conditions of alternative i over alternative j

$$G(i,j) = \begin{cases} S(i,j) > S(j,i) \wedge i \neq j \Rightarrow 1 \\ S(i,j) = S(j,i) \wedge i \neq j \Rightarrow \frac{1}{2} \\ S(i,j) < S(j,i) \wedge i \neq j \Rightarrow -1 \end{cases} \quad \textbf{(17)}$$

4) Calculating the COPELAND score

n : total number of alternatives, GP_i : win score alternative i, and YP_i : loss score for alternative i

$$\begin{aligned} GP_i &= \textstyle\sum_{i=1}^{n} G(i,j), \quad G(i,j) > 0 \\ YP_i &= \textstyle\sum_{i=1}^{n} G(i,j), \quad G(i,j) < 0 \end{aligned} \quad \textbf{(18)}$$

CP_i: COPELAND score of alternative i is:

$$CP_i = GP_i + YP_i \quad \textbf{(19)}$$

3. Results

At this point in the study, analyses are conducted utilizing DEMATEL and BWM methodologies on two sets of domestic and international logistics performance criteria. The two methodologies' results are presented separately.

3.1. DEMATEL Results

Firstly, the analysis of the criteria sets for domestic and international logistics activities was carried out by DEMATEL. The criteria sets were presented to the opinion of 6 experts in supply chain management and logistics for pairwise comparison. Experts scored the level of interaction between the criteria using a scale of 0 (any influence) and 4 (very high influence). Table 5 gives the direct relationship matrix computed by taking the expert opinions averages for both sets of criteria. Following the computation steps of the method, cause and effect criteria were determined. Later, the weighted ordering of criteria was presented.

Table 5. Direct relationship matrices for domestic and international criteria

C_D	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
D_1	0,00	2,67	2,00	2,67	3,33	2,17	3,00	3,33	1,67
D_2	3,33	0,00	2,67	2,83	3,67	2,33	2,50	1,67	3,00
D_3	3,50	3,00	0,00	2,67	3,00	1,83	3,00	2,67	3,83
D_4	3,17	3,17	2,00	0,00	2,83	1,83	2,50	2,00	2,83
D_5	3,83	3,17	2,17	2,33	0,00	2,17	2,50	3,00	3,17
D_6	2,50	1,83	1,67	2,00	2,67	0,00	2,17	1,83	2,67
D_7	2,83	2,67	2,67	2,83	3,17	2,50	0,00	2,50	2,67
D_8	3,00	1,83	2,67	2,00	2,50	1,33	2,17	0,00	2,33
D_9	3,17	2,67	3,50	2,83	3,00	2,00	2,50	2,67	0,00
C_I	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9
I_1	0,00	2,83	3,83	2,67	2,33	3,50	1,50	4,00	2,33
I_2	3,17	0,00	3,33	3,50	3,67	3,83	3,33	3,33	2,67
I_3	3,83	2,33	0,00	2,83	3,17	3,00	1,67	3,67	2,00
I_4	1,83	2,33	2,83	0,00	3,33	3,33	3,00	3,17	2,50
I_5	2,33	2,67	3,17	2,83	0,00	3,33	3,17	3,50	2,67
I_6	2,17	2,00	3,00	3,67	3,17	0,00	2,50	3,00	1,83
I_7	1,17	2,83	2,00	3,33	2,83	2,33	0,00	1,50	1,67
I_8	3,50	3,33	3,50	3,17	2,67	2,50	2,17	0,00	2,00
I_9	2,17	2,83	2,83	2,67	2,83	2,67	2,00	2,00	0,00

Row and column sums were computed separately for domestic and international direct relationship matrices. The normalized direct relationship matrices (Table 6) were constructed by multiplying the direct relationship matrix by the largest of sums ($k = 25.33$ for domestic criteria and $k = 26.83$ for international criteria).

Table 6. The normalized direct relationship matrices for domestic and international criteria.

C_D	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
D_1	0,00	0,11	0,08	0,11	0,13	0,09	0,12	0,13	0,07
D_2	0,13	0,00	0,11	0,11	0,14	0,09	0,10	0,07	0,12
D_3	0,14	0,12	0,00	0,11	0,12	0,07	0,12	0,11	0,15
D_4	0,13	0,13	0,08	0,00	0,11	0,07	0,10	0,08	0,11
D_5	0,15	0,13	0,09	0,09	0,00	0,09	0,10	0,12	0,13
D_6	0,10	0,07	0,07	0,08	0,11	0,00	0,09	0,07	0,11
D_7	0,11	0,11	0,11	0,11	0,13	0,10	0,00	0,10	0,11
D_8	0,12	0,07	0,11	0,08	0,10	0,05	0,09	0,00	0,09
D_9	0,13	0,11	0,14	0,11	0,12	0,08	0,10	0,11	0,00
C_I	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9
I_1	0,00	0,11	0,14	0,10	0,09	0,13	0,06	0,15	0,09
I_2	0,12	0,00	0,12	0,13	0,14	0,14	0,12	0,12	0,10
I_3	0,14	0,09	0,00	0,11	0,12	0,11	0,06	0,14	0,07
I_4	0,07	0,09	0,11	0,00	0,12	0,12	0,11	0,12	0,09
I_5	0,09	0,10	0,12	0,11	0,00	0,12	0,12	0,13	0,10
I_6	0,08	0,07	0,11	0,14	0,12	0,00	0,09	0,11	0,07
I_7	0,04	0,11	0,07	0,12	0,11	0,09	0,00	0,06	0,06
I_8	0,13	0,12	0,13	0,12	0,10	0,09	0,08	0,00	0,07
I_9	0,08	0,11	0,11	0,10	0,11	0,10	0,07	0,07	0,00

Applying Eq. 5, the Total Relationship matrices (Table 7) were gained.

Table 7. Total relationship matrices (Threshold value for domestic=0,54, and international=0,55)

C_D	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
D_1	0,54	0,55	0,49	0,53	0,63	0,44	0,55	0,55	0,53
D_2	0,69	0,49	0,54	0,57	0,68	0,46	0,56	0,52	0,61
D_3	0,73	0,62	0,48	0,59	0,69	0,47	0,60	0,58	0,66
D_4	0,64	0,56	0,49	0,43	0,61	0,42	0,53	0,50	0,57
D_5	0,71	0,60	0,53	0,55	0,55	0,46	0,56	0,57	0,61
D_6	0,55	0,46	0,42	0,44	0,53	0,30	0,45	0,44	0,49
D_7	0,67	0,57	0,54	0,56	0,65	0,46	0,46	0,54	0,59
D_8	0,58	0,47	0,46	0,46	0,54	0,36	0,47	0,38	0,50
D_9	0,69	0,59	0,58	0,57	0,66	0,46	0,57	0,56	0,51
C_I	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9
I_1	0,45	0,55	0,65	0,62	0,60	0,64	0,48	0,66	0,47
I_2	0,61	0,52	0,71	0,72	0,71	0,72	0,60	0,71	0,53
I_3	0,56	0,53	0,52	0,61	0,61	0,62	0,48	0,64	0,45
I_4	0,49	0,52	0,60	0,51	0,61	0,62	0,51	0,61	0,46
I_5	0,53	0,55	0,64	0,63	0,52	0,64	0,54	0,65	0,48
I_6	0,49	0,49	0,59	0,61	0,58	0,49	0,48	0,59	0,43
I_7	0,39	0,45	0,48	0,53	0,50	0,49	0,34	0,46	0,36
I_8	0,56	0,57	0,64	0,63	0,60	0,61	0,50	0,53	0,46
I_9	0,47	0,50	0,56	0,55	0,55	0,55	0,44	0,53	0,34

The total relationship matrix shows entire direct and indirect relationships among criteria. Since there are nine criteria in each criterion set, there are 81 relations for each class. That is, the total number of relationships is high. The relationships between some criteria are not very important. To determine the critical relationships and to examine the relationships more efficiently, the threshold values were calculated by taking the averages of the matrices. As a result, the international criteria set's threshold value was 0.55, while it was 0.54 for the domestic criteria set. Interrelationships above the threshold value are shown in grey color in Table 7. Certain circumstances can be observed clearly when the total relationship matrix is examined. For instance, it is seen that the D_6 criterion does not get a significant effect from other criteria, and at the same time, it does not significantly affect other variables except for the D_1 criterion. Also, D_3, D_5 and D_9 appear to affect the greatest number of criteria above the threshold value. I_7 does not have a significant impact on any criteria. Criterion I_9 does not get a significant impact from any of the other criteria, and the only criterion where the I_7 criterion gets a significant effect, is I_2. Moreover, the criterion that significantly impacts the highest number of criteria seems to be I_2.

Prominence and Relation values calculated according to the data obtained from the total relationship matrix are shown in Table 8. According to these values, the criteria are grouped into Cause and Effect groups. In addition, the order of importance of each criterion is given. The criteria weights were computed using Equations (10) - (11).

Table 8. Criteria in Cause-and-Effect groups and their rankings.

C_D	*R*	*C*	*R+C (Prominence)*	*R-C (Relation)*	*Cause/Effect Group*	*Weight*	*Rank*
D_1	4,81	4,55	9,36	0,26	**Cause**	0,1058	8
D_2	5,12	4,68	9,80	0,43	**Cause**	0,1108	4
D_3	5,43	5,39	10,82	0,04	**Cause**	0,1222	1
D_4	4,75	5,42	10,17	-0,66	Effect	0,1152	3
D_5	5,15	5,29	10,43	-0,14	Effect	0,1179	2
D_6	4,09	5,38	9,47	-1,30	Effect	0,1080	6
D_7	5,05	4,35	9,40	0,70	**Cause**	0,1065	7
D_8	4,22	5,37	9,59	-1,15	Effect	0,1091	5
D_9	5,18	3,99	9,17	1,19	**Cause**	0,1044	9
C_I	*R*	*C*	*R + C (Prominence)*	*R - C (Relation)*	*Cause/Effect Group*	*Weight*	*Rank*
I_1	5,12	4,55	9,67	0,57	**Cause**	0,1089	7
I_2	5,83	4,68	10,52	1,15	**Cause**	0,1189	1
I_3	5,02	5,39	10,41	-0,37	Effect	0,1170	4
I_4	4,92	5,42	10,34	-0,50	Effect	0,1163	5
I_5	5,19	5,29	10,48	-0,10	Effect	0,1178	2
I_6	4,74	5,38	10,12	-0,64	Effect	0,1140	6
I_7	4,01	4,35	8,36	-0,35	Effect	0,0940	9
I_8	5,10	5,37	10,46	-0,27	Effect	0,1176	3
I_9	4,49	3,99	8,48	0,50	**Cause**	0,0955	8

Considering the domestic set, the criteria in the cause group are (D_1, D_2, D_3, D_7, and D_9). The remaining criteria are in the effect group. The cause criteria are (I_1, I_2, and I_9) for the international set. Based on the prominence values, the criteria that have the most interrelationship with other criteria in the domestic set are D_3, D_5, and D_4 respectively. At the same time, these criteria are in the first three places in the weight ranking order. While D_3 is in the cause group, which is identified as the most crucial criterion, D_5 and D_4 are in the effect group. Considering the prominence values, the criteria that have the most interrelationship with the other criteria in the international set were determined as I_2, I_5, and I_8 respectively. They also form the top three in the weight ranking order. It is seen that the weights of the criteria in both sets are close to each other, showing that the criteria have similar importance.

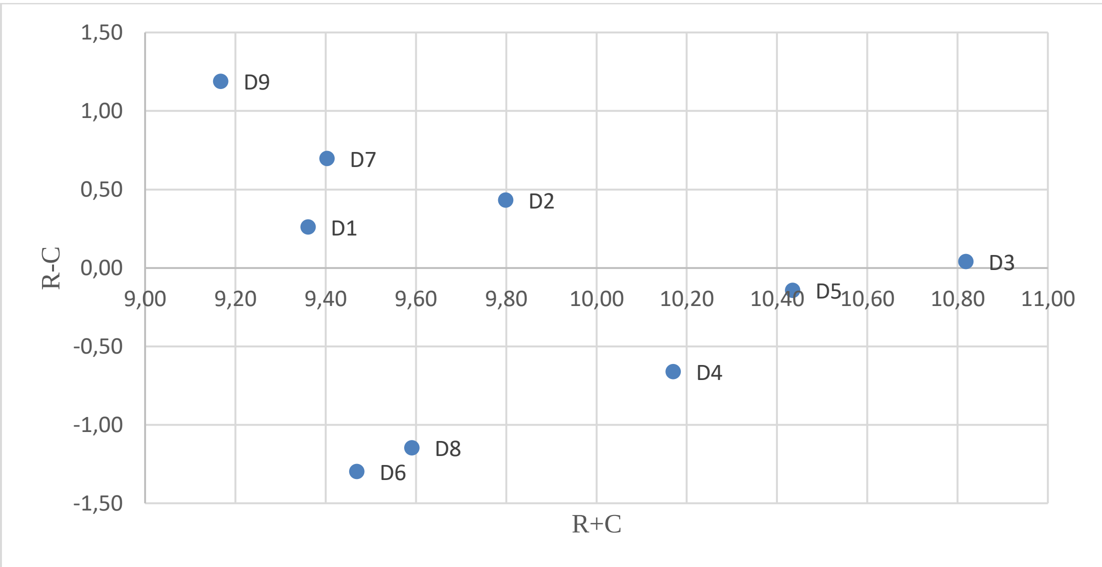
Table 9 shows the order of importance based on the weights computed by DEMATEL for the domestic and international criteria.

Table 9. Ranking of the weights for domestic and international criteria (DEMATEL Method)

Domestic Criteria			*International Criteria*		
Criteria	**Weight**	***Rank***	***Criteria***	***Weight***	***Rank***
D3	0,1222	1	I2	0,1189	1
D5	0,1179	2	I5	0,1178	2
D4	0,1152	3	I8	0,1176	3
D2	0,1108	4	I3	0,1170	4
D8	0,1091	5	I4	0,1163	5
D6	0,1080	6	I6	0,1140	6
D7	0,1065	7	I1	0,1089	7
D1	0,1058	8	I9	0,0955	8
D9	0,1044	9	I7	0,0940	9

Cause and Effect Diagram for domestic criteria can be viewed in Figure 1.

Figure 1. Domestic Criteria- Cause and Effect Diagram



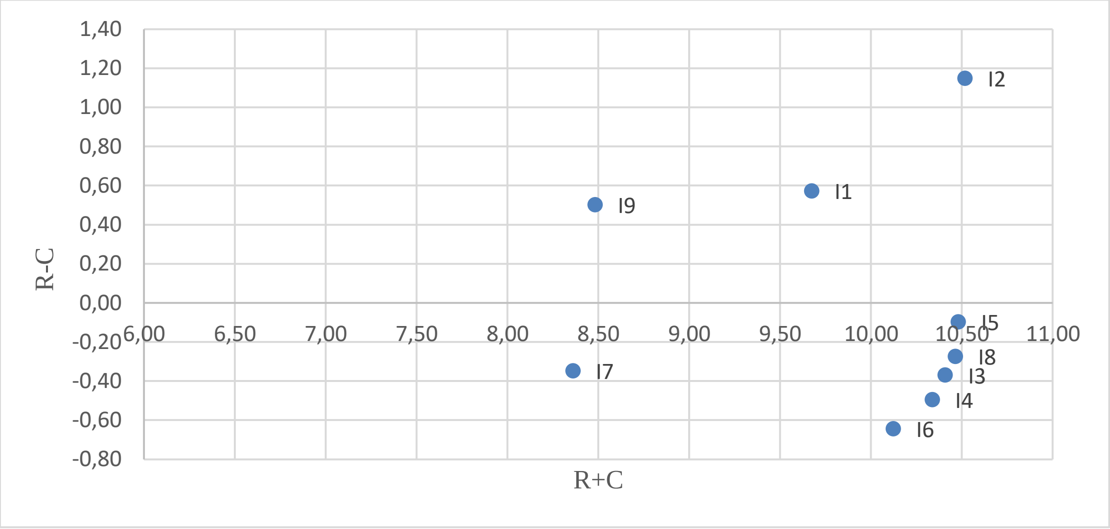
When the $R + C$ (Prominence) average is considered, the criteria on the Cause-and-Effect Diagram can be divided into four quadrants (Si et al., 2018). The $R + C$ average for the domestic class was found to be 9.80. Those with a Prominence value greater or equal to the average were regarded as *"High Prominence,"* and the others were regarded as *"Low Prominence"*. Those with positive $R - C$ (Relation) values were referred to as *"High Relation"* and others were referred to as *"Low Relation."* These four subgroups provide more detailed information regarding the characteristics of the criteria, as shown in Table 10.

Table 10. Subgroups of domestic criteria

Zone	***Explanation***	***Criteria***
Zone 1	Core elements or interconnected givers (High visibility and high relationship)	D_2, D_3
Zone II	Driving elements or independent givers (Low visibility but high relationship)	D_1, D_7, D_9
Zone III	Independent elements or independent receivers (Low visibility and low relationship)	D_6, D_8
Zone IV	Impact elements or interconnected receivers (High visibility but low relationships)	D_4, D_5

Figure 2 presents the Cause and Effect Diagram for international criteria.

Figure 2. Cause and Effect Diagram for international criteria



The average Prominence for the international criteria is 9,87. Based on this average value, quadrants (zones) and their corresponding explanations are presented in Table 11.

Table 11. Subgroups of international criteria

Quadrant	***Explanation***	***Criteria***
Zone 1	Core elements or interconnected givers (High visibility and high relationship)	I_2
Zone II	Driving elements or independent givers (Low visibility but high relationship)	I_1, I_9
Zone III	Independent elements or independent receivers (Low visibility and low relationship)	I_7
Zone IV	Impact elements or interconnected receivers (High visibility but low relationship)	I_3, I_4, I_5, I_6, I_8

3.2. BWM Results

As an alternative method, the weights of domestic and international criteria for logistics performance were computed by the BWM method as the study's second phase. Firstly, experts specified the best and worst criteria for two criteria sets. Then, reference comparisons were performed on these criteria sets. Finally, the criteria were ranked based on the weights computed.

When Table 12 is examined, it is observed that four experts chose D_1, one expert selected D_5 and D_7 as the best criteria for the domestic set. While three experts chose D_7 as the worst domestic criterion, two experts chose D_8 and one expert chose D_6. While there is no consensus for the best criterion in the international set, all experts chose the I_7 criterion for the worst criterion. Also, Table 12 shows that the values of ξ^* (objective function values obtained as a result of solving the optimization models) are less than the corresponding threshold values. It is concluded that all comparisons are consistent. For both criteria sets, the most consistent evaluation belongs to Expert 5, whose ξ^* value is closest to 0.

Table 12. The best and worst criteria, according to expert opinions.

Expert	***The best criterion***	***The worst criterion***	ξ^*	***Threshold***	***Consistency***
1	D_1	D_7	0,0889	0,2087	Consistent
2	D_7	D_8	0,1294	0,4298	Consistent
3	D_1	D_8	0,1398	0,4747	Consistent
4	D_5	D_6	0,1458	0,4298	Consistent
5	D_1	D_7	0,0469	0,3741	Consistent
6	D_1	D_7	0,0694	0,4298	Consistent
Expert	***The best criterion***	***The worst criterion***	ξ^*	***Threshold***	***Consistency***
1	I_3	I_7	0,0647	0,3741	Consistent
2	I_2	I_7	0,2186	0,4599	Consistent
3	I_4	I_7	0,1665	0,4298	Consistent
4	I_8	I_7	0,1921	0,3741	Consistent
5	I_3	I_7	0,0562	0,3741	Consistent
6	I_1	I_7	0,0904	0,4225	Consistent

Table 13 and Table 14 present the vectors obtained as a result of the best-to-others and others-to-worst comparisons made by each expert for the domestic and international criteria sets. A Likert scale with values between 1 and 9 was used for reference comparisons.

Table 13. Best to others pairwise comparison vectors for all experts.

Expert	***Best to Others***	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
1	D_1	1	2	4	5	2	3	3	2	5
2	D_7	3	7	7	9	9	7	1	7	9
3	D_1	1	7	5	5	7	6	7	9	7
4	D_5	5	3	5	3	1	7	3	3	3
5	D_1	1	1	3	3	2	5	5	1	2
6	D_1	1	1	3	3	3	4	7	3	6
Expert	***Best to Others***	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9
1	I_3	2	4	1	3	3	4	5	2	5
2	I_2	6	1	9	9	8	8	8	8	7
3	I_4	5	7	8	1	5	3	7	5	5
4	I_8	5	5	5	5	3	3	5	1	3
5	I_3	3	5	1	3	5	2	5	1	2
6	I_1	1	3	3	5	5	3	6	3	5

Table 14. Others to the Worst pairwise comparison vectors for all experts

Expert No	***1***	***2***	***3***	***4***	***5***	***6***
Others to the Worst	D_7	D_8	D_8	D_6	D_7	D_7
D_1	5	5	9	7	7	7
D_2	4	2	7	5	5	5
D_3	4	3	5	5	3	5
D_4	2	3	7	3	2	3
D_5	5	5	8	6	5	6
D_6	2	2	5	6	3	6
D_7	1	7	5	1	1	1
D_8	3	1	1	4	3	4
D_9	3	4	3	2	3	2
Others to the Worst	I_7	I_7	I_7	I_7	I_7	I_7
I_1	4	3	7	1	5	6
I_2	4	3	6	7	3	5
I_3	6	5	8	1	5	5
I_4	2	5	5	9	2	4
I_5	3	3	3	7	3	4
I_6	3	5	7	7	5	6
I_7	1	1	1	1	1	1
I_8	5	5	7	1	7	7
I_9	2	2	3	7	5	5

The BWM approach generated a weight value for each domestic and international criterion through coherent pairwise comparisons and the solution of the optimization model. Table 15 displays the ranking of the criteria based on these calculated weights.

Table 15. Ranking of the weights for domestic and international criteria (BWM Method)

Domestic Criteria			***International Criteria***		
Criteria	**Weight**	**Rank**	**Criteria**	**Weight**	**Rank**
D_1	0,2120	1	I_8	0,1533	1
D_2	0,1372	2	I_2	0,1314	2
D_5	0,1241	3	I_3	0,1280	3
D_7	0,0991	4	I_1	0,1225	4
D_8	0,0980	5	I_4	0,1194	5
D_4	0,0888	6	I_6	0,1160	6
D_3	0,0855	7	I_9	0,0967	7
D_9	0,0817	8	I_5	0,0890	8
D_6	0,0735	9	I_7	0,0437	9

The COPELAND method was applied to combine the rankings obtained from the DEMATEL and BWM methods. Table 16 and Table 17 include the common rankings obtained by the COPELAND method for Domestic and International criteria, respectively.

Table 16. Ranking of the weights for domestic criteria obtained from DEMATEL, BWM and COPELAND

	DEMATEL	**BWM**	**COPELAND**
D_1	8	1	4
D_2	4	2	2
D_3	1	7	3
D_4	3	6	5
D_5	2	3	1
D_6	6	9	8
D_7	7	4	7
D_8	5	5	6
D_9	9	8	9

Spearman Rank Correlation was calculated to show the similarity of the combined ranking obtained by the COPELAND method with the other two methods. Accordingly, while the correlation between the final ranking given by the COPELAND method and the DEMATEL ranking is 0,72, this value was obtained as 0,65 by the BWM method.

Table 17. Ranking of the weights for international criteria obtained from DEMATEL, BWM and COPELAND

	DEMATEL	BWM	COPELAND
I_1	7	4	6
I_2	1	2	1
I_3	4	3	3
I_4	5	5	5
I_5	2	8	4
I_6	6	6	6
I_7	9	9	9
I_8	3	1	2
I_9	9	8	9

Spearman rank correlation between DEMATEL and COPELAND was 0.94. For BWM and COPELAND correlation was obtained as 0.80. These results show that the methods produce more similar results for international criteria than for domestic criteria.

4. Discussion

The pandemic, war, large-scale fires, and other adverse conditions that have emerged in recent years have caused countries to make strategic logistics management decisions. In this sense, improving the significant criteria affecting logistics performance has become an important goal. Countries that improve their logistics performance will be able to have national and international economic sustainability. The first step to expand their logistics performance will be to determine the criteria that affect the performance and to analyze their importance levels using practical methods.

This study determined the criteria affecting logistics performance in two classes (domestic and international) and analyzed them by two MCDM methods. Criteria compiled from current scientific literature, national/global indexes, and reports were investigated using expert opinions. As an analysis method, DEMATEL was preferred to evaluate the relationships between complex criteria regarding causality. This method was considered appropriate since the performance criteria in logistics have solid causal relationships with each other. The study also used the BWM method as an alternative comparison method since it provides consistent results by making fewer pairwise comparisons. The results obtained with these two methods were combined with the COPELAND method, which is one of the most frequently used methods for this purpose in the literature.

The findings have shown the relative weights of the importance rankings of domestic and international performance criteria. According to DEMATEL's findings, *"Technology and Telecommunication"* **(**D_3) is the most critical domestic performance criterion. Rankings obtained is $D_3 > D_5 > D_4 > D_2 > D_8 > D_6 > D_7 > D_1 > D_9$. For international performance, the most important criterion is *"Logistics Infrastructure"* **(**I_2) and the final ranking is $I_2 > I_5 > I_8 > I_3 > I_4 > I_6 > I_1 > I_9 > I_7$. According to BWM findings, the most critical domestic performance criterion is *"Logistics Costs"* **(**D_1), while the final ranking is $D_1 > D_2 > D_5 > D_7 > D_8 > D_4 > D_3 > D_9 > D_6$. The most important of the international performance criterion is determined as *"International Logistics Opportunities"* **(**I_8), the final ranking is $I_8 > I_2 > I_3 > I_1 > I_4 > I_6 > I_9 > I_5 > I_7$. The results show that the criteria rankings are different for both methods within the scope of domestic and international evaluations. This variation may result from the two methodologies' different approaches. COPELAND presented a new evaluation using the results of both. This feature allowed the two methods used to be repeated and evaluated jointly. In COPELAND's view, Logistics Services (D_5) is the critical domestic logistics performance criterion. Logistics service expenditures have gained importance due to increasing energy costs in the crisis environment. For international performance, *"Logistics Infrastructure"* **(**I_2) was analyzed as the most important criterion. This result is consistent with DEMATEL and shows how important what is offered as logistics is in terms of logistics sustainability.

According to the study's results, it is understood that the most effective ones among the domestic logistics performance criteria are *"Technology and Telecommunication"* and *"Logistics Costs."* Today, due to the increasing importance of technology investments in the logistics sector, *"Technology and Telecommunication"* is regarded as the most crucial criterion by DEMATEL. BWM presents *"Logistics Costs"* as the most critical criterion due to the cost increases in a crisis. It is seen that the most effective ones among the international performance criteria are *"Logistics Infrastructure"* and *"Logistics Opportunities."*

In the international supply chain system, it is understood that the *"Logistics Infrastructure"* criterion, according to the DEMATEL method, is preferred as the most critical criterion due to the high demand and supply shortage that emerged under the crisis conditions. Similarly, it can be interpreted that the BWM method presented the *"Logistics Opportunities"* criteria as the most important due to the international effect of the economic opportunities created by the uncertain environment.

Accordingly, governments should revise their infrastructure and technology investments and assess new logistics options to improve domestic and international logistics performance. In light of current assessments, it will be crucial for the management of sustainable supply chains that the logistics activities are reorganized in uncertain environments, such as pandemics, war, and famine.

Researchers' Contribution Rate Statement

The contribution rates of the authors in the study are equal.

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There are no conflicts of interest to disclose for the writers.

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