

Article

DEA-Based PROMETHEE II Distribution-Center Productivity Model: Evaluation and Location Strategies Formulation

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Abstract: The current era of industrial economics necessitates warehouse and logistic distribution centers (DCs) to contribute productively toward an organization's success. Playing such a critical productive role implies that logistics activities must be practiced effectively and efficiently. However, the indistinguishability between effectiveness and efficiency leads to a somewhat shallow interpretation, and consequently, a diluted evaluation. Hence, this paper aims to develop a productivity evaluation model for nine DCs belonging to an international automotive vehicles and spare parts company. The developed model was set up based on two multi-criteria decision making (MCDM) approaches: the Preference Ranking Organization Method for Enrichment of Evaluations II (PROMETHEE II) and data envelopment analysis (DEA). PROMETHEE II was employed to evaluate the effectiveness, while the DEA was utilized in order to measure the efficiency of the investigated DCs. The resulting hybrid model collectively creates what can conceptually and practically be considered a productivity evaluation model. The results also provide six different strategies through which distribution center locations can be evaluated in order to implement potential future initiatives.



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Keywords: DEA; PROMETHEE II; distribution centers; logistic centers; warehouses; inventory; evaluation; productivity; location selection; strategies

1. Introduction

In the current industry 4.0 era, almost all fields of industry are characterized by sophisticated manufacturing approaches associated with various services that are fully dependent on rapid technological changes. Such a situation necessitates that warehouse and logistic distribution centers (DCs) accomplish their critical roles for the productive success of any organization. Such a productive role implies the use of well-established measurement approaches for effectiveness and efficiency while considering the differentiation among these approaches both conceptually and practically [1]. DCs are expected to perform effectively, thus enabling future evaluation of the extent to which they attain the strategic and/or operational objectives of the firm. DCs should also be operated efficiently, allowing firms to monitor to what extent DCs are capable of converting the different kinds of available resources into tangible, measurable forms of outputs. However, within the context of the relevant MCDM-based research applications [2–10], neither the original version of DCs, i.e., warehouses [11], nor the extended version of DCs (or what is currently known as logistic centers) [12] have provided robust evidence for handling the issue of the indistinguishability between effectiveness and efficiency (i.e., the two wings of productivity). In other words, none of the previous MCDM applications have attempted to research interweaving MCDM approaches in order to evaluate and/or select DCs, whether as warehouses [2,4,13] or as logistic centers [3,5–10,14–21], with regard to effectiveness and efficiency. Hence, this paper aims to develop a productivity evaluation model for a set of DCs belonging to an international automotive vehicles and spare parts firm located in the Middle East, North Africa, and Turkey (MENAT). The developed model was established based on the employment of two MCDM techniques: the Preference Ranking Organization Method for

Enrichment of Evaluations II (PROMETHEE II) and data envelopment analysis (DEA). PROMETHEE II was employed to evaluate the effectiveness of nine DCs based on seven criteria. The same criteria were then utilized to develop a DEA model in order to measure the efficiency of the investigated DCs. Finally, a strategic roadmap was created based on the developed productivity evaluation model to formulate six different strategies through which DC locations can be assessed. The rest of the paper is organized as follows: Section 2 presents the relevant literature and the utilized methods, PROMETHEE II and DEA, are then introduced in Section 3. The application, results and discussion, implications, and conclusions are presented in Sections 4–7, respectively.

2. Relevant Literature

Chen [22] emphasized that evaluating and selecting DCs represented one of the most difficult challenges facing logistics practitioners and accordingly developed a fuzzy-based MCDM model to deal with the various criteria for evaluating any set of DC locations. Amir et al. [23] developed a DC selection model based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and fuzzy goal programming. Awasthi et al. [24] stressed that the location of the DCs was an MCDM problem because decisions in such a situation involved a trade-off between being close to or far away from customers. In other words, decision-makers have to consider at least two conflicting issues: (1) the dilemma of traffic congestion within urban districts due to the closely located DCs and (2) the issue of the transportation costs associated with distant DCs. Accordingly, they employed 11 criteria to evaluate the locations of three DCs and selected the best among them using fuzzy TOPSIS. Chu and Hsu [25] developed a fuzzy-based MCDM model, which employed the approach of prioritizing maximizing and minimizing sets to resolve the issue of DC evaluation and selection using six criteria: expansion capability, materials acquirement, distance to market, human resources, space dimensions, and investment cost. Li and Wei [26] divided the four main criteria—economic, political, social, and ecological—into 12 sub-criteria to evaluate a set of DCs using the analytic hierarchy process (AHP) and 2-tuple hybrid ordered weighted averaging (THOWA). Recently, an innovative model was developed by combining two MCDM approaches: (1) single-valued complex neutrosophic set (SVCNS) and (2) TOPSIS [27]. The abovementioned MCDM research and applications were developed intentionally for DCs where such an MCDM dilemma could also be extended to cover the issue of evaluating and selecting warehouse and logistic center locations [11,28]. In this regard, further MCDM studies, particularly DEA and PROMETHEE applications, can be found in [29–38].

3. Methods

3.1. PROMETHEE II

The PROMETHEE method was developed for the first time in 1982 [39] and then further developed in 1985 [40,41]. It is now considered a well-known, applicable MCDM tool [42]. In order to practice PROMETHEE considering different MCDM situations, different versions within the corresponding literature have been developed, such as PROMETHEE I and PROMETHEE II. The former aims at providing a partial ordering for the investigated/involved alternatives, while the latter provides a full ranking of the alternatives [32]. According to several research studies and applications [32,42], the practical steps for PROMETHEE II can be listed as follows:

Step 1: Normalization of the decision matrix R_{ij} as follows:

$$R_{ij} = [(X_{ij}) - \min (X_{ij})] / [\max (X_{ij}) - \min (X_{ij})]$$

where X_{ij} is the performance measure of the i th alternative with respect to the j th criterion; $i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$. For non-beneficial criteria, the equation can be rewritten as follows:

$$R_{ij} = [\max (X_{ij}) - (X_{ij})] / [\max (X_{ij}) - \min (X_{ij})]$$

Step 2: Pairwise measurement of the evaluative differences among alternatives.

Step 3: Determination of the preference function, $P_j(i, i')$, using the following function:

$$P_j(i, i') = 0 \text{ if } R_{ij} \leq R_{i'j}$$

$$P_j(i, i') = (R_{ij} - R_{i'j}) \text{ if } R_{ij} > R_{i'j}$$

Step 4: Determination of the aggregated preference function $\pi(i, i')$ considering the weight of each criterion as follows:

$$\pi(i, i') = \sum_{j=1}^m [W_j * P_j(i, i')] / \sum_{j=1}^m W_j$$

where W_j is the weight that represents the relative importance of criterion j .

Step 5: Identification of the “leaving (positive) flow” and the “entering (negative) flow” as follows:

Leaving flow for alternative

$$i, \varphi^+(i) = \frac{1}{n-1} \sum_{i'=1}^n \pi(i, i'); (i \neq i')$$

Entering flow for alternative

$$i, \varphi^-(i) = \frac{1}{n-1} \sum_{i'=1}^n \pi(i', i); (i \neq i')$$

where n represents the number of involved alternatives; the “leaving flow” and the “entering flow” represent the extent to which a certain alternative is “dominating” the remaining alternatives and is “dominated” by the remaining alternatives, respectively.

Step 6: Determination of the net outranking flow for alternative i follows:

$$\varphi(i) = \varphi^+(i) - \varphi^-(i)$$

Step 7: Ranking of the involved alternatives according to the values of $\varphi(i)$; the alternative with the highest $\varphi(i)$ represents the best alternative, and so.

3.2. DEA

Data envelopment analysis (DEA) is a well-known known MCDM technique [43] that is commonly employed as a tool to measure the efficiency for different decision-making units within various industrial contexts [44], including the field of supply chain management (SCM) [45]. It has various forms of implementation, which facilitate the formulation of several kinds of models for different purposes. The output-oriented Charnes, Cooper, and Rhodes (CCR) model [46] can be written as follows:

$$\text{Max } \theta + \varepsilon \left(\sum_{i=1}^m S_i^- + \sum_{r=1}^s S_r^+ \right).$$

S. T:

$$\sum_{j=1}^n \lambda_j x_{ij} + S_i^- = x_{io}; i = 1, 2, \dots, m$$

$$\sum_{j=1}^n \lambda_j y_{rj} - S_r^+ = \theta y_{ro}; r = 1, 2, \dots, s$$

$$\lambda_j, S_i^-, S_r^+ \geq 0$$

where n represents the number of the decision-making units (DMUs), that is, the number of involved alternatives, such as the number of DCs in the current case. For each distribution center (DC (j), ($j = 1, 2, 3, \dots, n$), there are m inputs ($i = 1, 2, 3, \dots, m$), and s outputs ($r = 1, 2, 3, \dots, s$); y_{rj} represents the amount of output r produced by DC (j); y_{ro} represents the amount of output r produced by DC (j_o), that is, the DC that is being assessed; x_{ij} represents the amount of input i utilized by DC (j); x_{io} represents the amount of input i utilized by DC (j_o); λ_j represents the weight to be assigned to each DC. For DC (j_o), S_i^- represents the slack for input i ; S_r^+ represents the surplus for output r . In order to ensure positive slack and surplus for all inputs and outputs, a very small positive number (ϵ) is utilized in the model, as shown above. In such a case, the technical efficiency of any DC (j) is attained if, and only if, both of the stated conditions below are satisfied: All slacks (S_i^-) and surplus (S_r^+) = 0; and the efficiency score = $1/\theta = 1$.

4. Application

The relevant data were collected from nine DCs belonging to one of the most successful automotive vehicles and spare parts companies in the MENAT region.

4.1. Background

For more than 60 years, the company has practiced its unique operational “know-how” and has solid evidence for its success based on clear and unimpeachable performance measures, such as sustainable growth and breaking annual sales records in the MENAT region. The company created added value through its unique competitive advantages (e.g., industrial experience and professional commitment) as a business partner. It is now working as one of the main distributors worldwide for one of the most successful Japanese automotive companies in the world. It is able to effectively handle logistic functions such as order processing, warehousing, and distribution to guarantee the instantaneous availability of more than 140,000 vehicle parts locally and internationally. The company maintains a long-term relationship with customers by continuously providing regular services, warranty, repair services and by successfully completing more than one million transactions yearly. The company currently operates the largest automotive supply infrastructures in MENAT with a daily receiving/dispatching capability of about 1200 vehicles and warehousing capacity for 69,000 vehicles. The company is currently planning to double its monthly warehousing capacity as it can handle shipments of about 700 containers. In addition, an advanced barcoding scan technology is being utilized in order to control around 20,000 daily order lines shipped to maintain the “just-in-time” philosophy in managing spare parts picking systems.

4.2. DEA-Based PROMETHEE II Model Development

For this study, seven equally weighted criteria were employed in order to develop the proposed PROMETHEE II-DEA model. These criteria are listed and briefly described as follows:

- Vehicle Off Road (VOR)

The terminology Vehicle Off Road is commonly utilized to label idle vehicles that are in the process of repair due to the unavailability of certain parts, which consequently leads to an increase in the waiting time, and eventually, increases the number of dissatisfied customers. The VOR rate can be calculated as the number of VOR orders divided by the total number of orders as shown below.

- Number of Employees (NE)

This criterion is limited to the actual NE dedicated directly to certain critical aspects and functions inside the distribution center.

- Stock Efficiency (SE)

This criterion measures the extent to which a certain distribution center is operationally healthy by considering only the moving amount of stock. This can be measured by dividing

the total stock value, excluding the value of the over-stock as well as the value of the non-moving items, by the total stock value as shown below.

- Stock Month (SM)

This criterion aims to identify to what extent a certain distribution center is capable of covering the monthly demand (units on a monthly basis). This can be measured by dividing the on-hand stock quantity by the monthly demand quantity as shown below.

- Immediate Supply Job Card Fill Rate (JCFR) Task Achievement

This criterion is calculated by dividing the total number of job cards fully supplied from the shelves (stock) by the total job cards received/opened by the spare parts department on a daily basis as follows.

- Service Rate (SR)

This criterion can be measured by dividing the total number of customer orders fulfilled completely (closed) by the total number of customer orders.

- Guest Delight Index (GDI)

The guest delight index is a critical indicator that is usually prepared by the Customer Care Management Department. The GDI measures the customer satisfaction level through a daily feeding mechanism in each service/distribution center using different approaches such as direct phone calls, hard copy questionnaires, or electronic questionnaires.

The PROMETHEE II model developed herein was constructed to rank nine DCs considering the abovementioned criteria. Two criteria are considered as cost criteria in the sense that having lower values with respect to these criteria will be reflected in a better rank for the DC under assessment. These cost criteria include the NE and the VOR ratio. The remaining five criteria are considered as benefit criteria in the sense that having higher values with respect to these criteria will be reflected in a better rank for the DC under assessment. These criteria include SE, SM, SR, JCFR, and GDI.

Regarding the developed DEA model, the model was formulated in order to measure the efficiency of the nine DCs considering the same criteria. The purpose behind the employment of the DEA model is to examine each DC in order to determine the extent to which it can record or achieve maximum SE, SM, SR, JCFR, and GDI through utilizing a minimum NE and keeping the VOR ratio to the minimum as much as it can be. Consequently, the input measures for the developed output-oriented DEA model include the NE and the VOR ratio, while the remaining five criteria (SE, SM, SR, JCFR, and GDI) are considered as output measures. The collected data are presented in Table 1.

Table 1. Collected data.

DC	NE	SE	GDI	SR	SM	JCFR	VOR
LJC	7	51.7	98.1	75.17	1.1	91.9	0.03731
MKK	9	48.4	98	99.10	1.1	89.5	0.02173
PSC	6	62.2	94.5	92.40	1.8	79.3	0.03021
MKO	6	40.8	94.1	92.50	2.7	80.1	0.01655
MDR	11	66.9	93.6	93.30	1.5	95.2	0.01485
RRC	8	59.1	93.5	96.50	1.1	91.7	0.01934
RBC	2	9.6	90.6	91.30	2.4	77	0.01165
TFC	3	38.1	89.9	94.30	1.5	73	0.01552
MKR	13	21.9	89	96.30	1.1	87.2	0.01508

5. Results and Discussion

Table 2 presents the leaving flow $\varphi^+(i)$ and the entering flow $\varphi^-(i)$ for each DC, and accordingly, the final PROMETHEE II-based ranking of the nine DCs can be identified according to the final values for the $\varphi(i)$, as shown in the last two columns. Table 2 shows that MKO, MDR, MKK, RRC, PSC, RBC, TFC, LJC, and MKR are ranked from first to ninth, respectively.

Table 2. Leaving flow, entering flow, and the final PROMETHEE II-based ranking of the DCs.

DC	$\varphi^+(i)$	$\varphi^-(i)$	$\varphi(i)$	Rank
LJC	0.1867	0.3023	−0.1156	8
MKK	0.2192	0.1339	0.0853	3
PSC	0.1765	0.1722	0.0043	5
MKO	0.2370	0.1173	0.1197	1
MDR	0.2333	0.1175	0.1159	2
RRC	0.1846	0.1207	0.0639	4
RBC	0.2350	0.2362	−0.0012	6
TFC	0.1501	0.2219	−0.0718	7
MKR	0.0995	0.3000	−0.2005	9

Table 3 summarizes the results of the DEA model. Four (MKO, MDR, RBC, and TFC) out of nine DCs scored 1 as an efficiency score, which implies that, considering their input measures, there is no evidence of the inefficiency of these DCs. Specifically, each of them is capable of attaining a certain target for each output measure, considering the output measures in a manner that reflects the proportional differences among all DC input and output measures collectively. Put simply, these four DCs are the best at achieving higher SE, SR, SM, JCSR, and GDI, considering a relatively lower NE and VOR. The remaining DCs (RRC, MKR, PSC, MKK, and LJC) were ranked from fifth to ninth, respectively.

Table 3. Results of the DEA model.

DC	Efficiency Score	Rank	Potential Improvements for Output and Input Measures						
			SE	GDI	SR	SM	JCFR	NE	VOR
LJC	0.582	9	+71%	+113%	+192%	+218%	+85%	...	−2%
MKK	0.727	8	+37%	+39%	+40%	+124%	+37%	...	...
PSC	0.832	7	+20%	+85%	+98%	+62%	+79%	...	...
MKO	1	1	...	...	...	...	...	...	...
MDR	1	1	...	...	...	...	...	...	...
RRC	0.932	5	+7%	+24%	+23%	+73%	+13%	...	...
RBC	1	1	...	...	...	...	...	...	...
TFC	1	1	...	...	...	...	...	...	...
MKR	0.881	6	+13%	+26%	+17%	+150%	+13%	−65%	...

Table 3 also illustrates potential improvements, computed via the Frontier Analyst software, for each DC to each measure. The tendency is to provide potential improvements corresponding to outputs rather than inputs due to the output orientation setting of the developed DEA model. Such an output orientation model tends to provide feedback on improvements for the inefficient units (inefficient DCs) by recommending certain increases in each output measure while attempting to maintain the same level of inputs. If these increases are not sufficient to achieve 100% efficiency for the unit under assessment, the model then recommends potential improvements to input measures. To illustrate, the efficiency score for LJC is 0.582, which indicates the lowest efficiency recorded among the listed DCs (i.e., it is ranked ninth (Table 3)). Such a score reveals significant potential for improvements. In order to improve the LJC efficiency and record the maximum efficiency score (i.e., 1 or 100% efficiency), SE, GDI, SR, SM, and JCER should increase by 71%, 113%, 192%, 218%, and 85%, respectively. Additionally, VOR should decrease by 2%. All potential improvements for all inefficient DCs are shown in Table 3.

A graphical comparison between the two different ranking lists for the nine DCs is shown in Figure 1. Although MKO is ranked first in both (i.e., the PROMETHEE II and DEA models), the efficiency of the remaining DCs reveals interesting changes in their rank on the DEA compared to their prior PROMETHEE II rank. For example, RBC and TFC jump from the sixth and seventh positions in PROMETHEE II to the first position on the DEA list. In contrast, MKK scores the second-lowest efficiency value on the DEA, which is relatively far away from its rank on the PROMETHEE II (third). Such a ranking discrepancy prompted further investigation to determine the extent to which PROMETHEE II results (i.e., effectiveness scores) can be influenced by efficiency scores resulting from the DEA model. In order to conduct such an investigation, the PROMETHEE II results had to be normalized to avoid dealing with negative values. As shown in Table 4, each DC's normalized PROMETHEE II score can be computed by deducting the minimum $\varphi(i)$ from the corresponding $\varphi(i)$; the resulting value is then divided by the difference between the maximum $\varphi(i)$ and the minimum $\varphi(i)$. The normalized PROMETHEE II scores are then multiplied by the corresponding DEA scores to get what we termed the final DEA-based PROMETHEE II scores. In other words, the original PROMETHEE II scores (i.e., effectiveness scores) were adjusted/fine-tuned by considering the influence of the efficiency scores generated by DEA to get the final DEA-based PROMETHEE II scores (i.e., productivity scores). Figure 2 illustrates the influence of efficiency by comparing the PROMETHEE II, the DEA, and the DEA-based PROMETHEE II ranking lists. Although the comparison between PROMETHEE II and the DEA-based PROMETHEE II ranking lists reveals that the first two positions and the last three positions are similar in both ranking lists, the remaining DCs show a jumps or drop of one position in the final DEA-based PROMETHEE II ranking list.

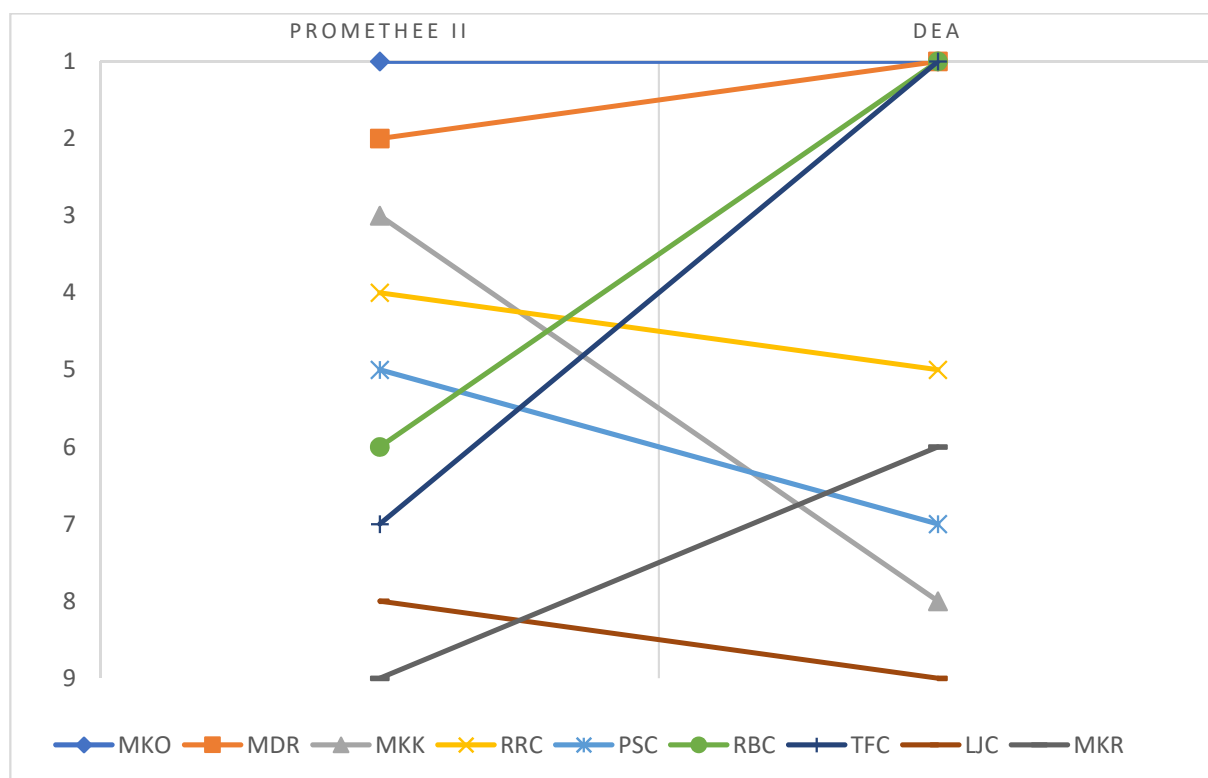
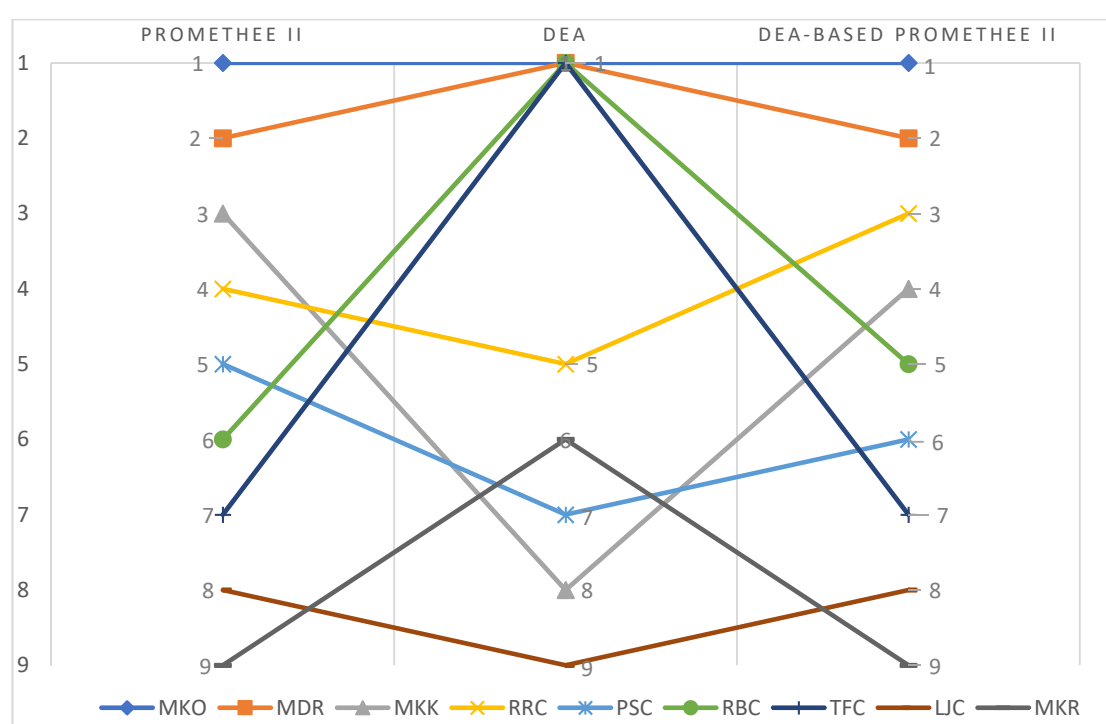


Figure 1. DCs ranking comparison with respect to PROMETHEE II and DEA.

Table 4. Normalized PROMETHEE II results and the final DEA-based PROMETHEE II score.

DC	$\varphi(i)$	$Max \varphi(i)$	$Min \varphi(i)$	$\frac{[\varphi(i) - Min \varphi(i)]}{[Max \varphi(i) - Min \varphi(i)]}$	DEA Efficiency Score	DEA-Based PROMETHEE II Score
MKO	0.1197	0.119747		1.0000	1	1.0000
MDR	0.1159	...		0.9879	1	0.9879
MKK	0.0853			0.8924	0.727	0.6488
RRC	0.0639			0.8255	0.932	0.7693
PSC	0.0043			0.6395	0.832	0.5321
RBC	−0.0012			0.6223	1	0.6223
TFC	−0.0718			0.4020	1	0.4020
LJC	−0.1156			0.2652	0.582	0.1543
MKR	−0.2005		−0.20051	0.0000	0.881	0.0000

**Figure 2.** DCs ranking comparison with respect to PROMETHEE II, DEA, and DEA-based PROMETHEE II.

The employment of the DEA as a fine-tuning instrument to adjust the previously implemented MCDM model, such as PROMETHEE II in the current study, can be considered as a unique contribution within the context of MCDM applications. Although such attempts are not commonly investigated in the MCDM literature, the results presented herein are compatible with two previously published works that assert a similarly unique involvement and employment of DEA with TOPSIS [44] and VIKOR [47] under fuzzy environments. Indubitably, the existence of such applications provides a sort of validation of the outcomes discussed in this paper. Several previous research works were carefully selected and are listed in Table 5 in order to enrich the discussion in terms of how these previous studies contribute differently compared to the current study, and considering the use of DEA and PROMETHEE [29–38].

Table 5. List of selected previous research with points of discussion.

Title of Previous Studies	Publication Date	MCDM Theoretical Base & Assumptions (Context, Criteria, Alternatives, Decision Making Units (DMU), ... etc.)	Methodology (MCDM Tools and Techniques)	Dissimilarities in the Contribution Compared to the Current Study (Including Any Potential Improvements to Be Handled in Further/Future Studies, Gaps/Aspects not Covered, or Motives for Further Investigations)
An integrated benchmarking approach to distribution center performance using DEA modelling [29].	2002	Context: Distribution Center Performance; Criteria: 3 inputs (fleet size, experience, and the mean order throughput time in days (MOT)); and 4 outputs (sales volume of 4 different products); Alternatives: Distribution Centers.	DEA	Use of DEA alone (i.e., efficiency focused model) All outputs focused on sales volumes
Freight village design using the multicriteria method PROMETHEE [30].	2007	Context: Freight village design; Criteria: freight village layout, the cross-docking options of the modules and direct railway access, and the circulation conditions; Alternatives: three alternative designs of the freight village layout are compared by means of multicriteria analysis	PROMETHEE	The context of the “freight village” is more generic and comprehensive compared to the context of the “distribution centers” Based on a single technique (PROMETHEE)
Evaluating Efficiency and Effectiveness of Logistics Infrastructure Based on PCA-DEA Approach in China [31].	2009	Context: Logistics Infrastructure; Criteria: 6 inputs (number of staff and employed workers in transport, possession of civil motor vehicles, possession of watercraft, railway density, waterway density, highway density) and 2 outputs (freight traffic, and turnover volume of freight traffic); Alternatives: logistics infrastructure for 31 major regions (23 provinces, 4 municipalities, and 4 autonomous regions) in China	Principal Component Analysis (PCA) and DEA	Logistics infrastructure and location oriented, not performance oriented. Not clarified—how the effectiveness has been measured (as DEA is commonly, and scientifically, known to be employed to measure the efficiency (i.e., not effectiveness)
Facility Location Selection using PROMETHEE II Method [32].	2010	Context: Facility Location Selection Problem; Criteria: (closeness of market, closeness to raw material, land transportation, air transportation, cost of labor, availability of labor, community education, and business climate); Alternatives: 3 locations	PROMETHEE	The criteria are suitable for a selection model, not for performance evaluation. Based on a single technique (PROMETHEE) Efficiency not considered
Fuzzy AHP-PROMETHEE methodology to select bus garage location: a case study for a firm in the urban passenger transport sector in Istanbul [33].	2011	Context: Garage Location Selection Problem (busses); 6 main Criteria: (cost, infrastructure, accessibility, social and economic structure, macro factors, and environmental factors); Alternatives: 3 garage locations	Fuzzy AHP and PROMETHEE	Irrelevant context Selection focused (i.e., not evaluation) Efficiency not considered

Table 5. Cont.

Title of Previous Studies	Publication Date	MCDM Theoretical Base & Assumptions (Context, Criteria, Alternatives, Decision Making Units (DMU), . . . etc.)	Methodology (MCDM Tools and Techniques)	Dissimilarities in the Contribution Compared to the Current Study (Including Any Potential Improvements to Be Handled in Further/Future Studies, Gaps/Aspects not Covered, or Motives for Further Investigations)
Use of Promethee method to determine the best alternative for warehouse storage location assignment [34].	2014	Context: warehouse storage location assignment; Criteria: space, picking (the total distance travelled when the pick is issued from a single command), total cost of picking a single command, time to products (the round trip), the average time it takes to serve a client, and the average time it takes to serve a group; Alternatives: Warehouses	PROMETHEE	Warehouse functions focus on storing, which is limited compared to the distribution centers functions Location oriented, not performance oriented Use of PROMETHEE alone
A framework for measuring transport efficiency in distribution centers [35].	2016	Context: transport efficiency in distribution centers; Criteria: 3 inputs (number of vehicles, fuel costs and total vehicle time in operation) and 3 outputs (total distance driven, tons shipped, and vehicle utilization); Alternatives: Distribution Centers	DEA	Concentration on transportation (i.e., other productivity aspects were not considered due to the scope of the study) Use of DEA alone (i.e., efficiency focused model)
Visual management of performance with PROMETHEE productivity analysis [36].	2018	Context: Facility Productivity of British Universities; Criteria: 2 inputs (Staff and Facilities spent) and 7 outputs (student satisfaction, research quality, admissions service, graduate prospects, graduates' achievement, completion rate, and the total number of students); Alternatives: The British Universities	PROMETHEE Productivity Analysis (PPA)	Irrelevant application to the “distribution centers”. Although a graphical representation was provided in order to “distinguish between efficient, effective, frugal and ineffective actions” in the proposed approach [36], it focused mainly on the efficiency (outputs/inputs) rather than the effectiveness (i.e., not well linked with the simple definition of productivity that considers both efficiency and effectiveness).
Measuring performance of government-supported drug warehouses using DEA to improve quality of drug distribution [37].	2020	Context: Drug warehouses; Criteria: 4 inputs (warehouse storage capacity, temperature-controlled storage capacity, number of skilled employees and operational cost) and 6 outputs (fill rate, number of generic drugs, volume of drugs, consumption points, inventory turns ratio and time efficiency); Alternatives: Warehouses.	DEA	Warehousing orientation (for drugs), which is relatively different from the distributing orientation (automotive spare parts industry) Focusing on efficiency only via the utilization of DEA alone
A novel hybrid fuzzy PROMETHEE-IDEA approach to efficiency evaluation [38].	2021	Context: Facility EU national steel sectors; Criteria: 3 inputs (number of employees, cost of labor, electricity consumption) and 3 outputs (production value, cost of emissions trading, and net export of the final products); Alternatives: 6 selected sectors (6 EU Countries)	DEA and PROMETHEE	The application was built based on an example that considers 6 different EU steel sectors, which is relatively irrelevant application. Although both DEA & PROMETHEE were employed, the focus was on efficiency (the consideration of outputs/inputs), not on the effectiveness (the achievement with respect to each criterion)

6. Implications of DCs Locations

In order to aid practitioners and/or decision-makers and provide them with strategic directions for future strategic moves toward initiatives to improve the listed DCs, the final DEA-based PROMETHEE II scores (i.e., productivity scores) were plotted with the distance of each distribution center from the main warehouse, as shown in Figure 3. This aims to formulate different strategies under which all strategic initiatives for improvement can be implemented in the sense that the different circumstances of each distribution center are appropriately considered. To illustrate, six different strategies can be formulated according to the situation of each distribution center, as shown in Figure 3. In other words, the different locations, which are associated with different productivity scores (Figure 3) necessitate formulating MCDM-based strategies for resource allocation. Such an approach is somewhat similar to what has been previously discussed in the literature within different contexts, such as strategic quality management (SQM) [48], green supply chain management (GSCM), and supply chain finance (SCF) [49].

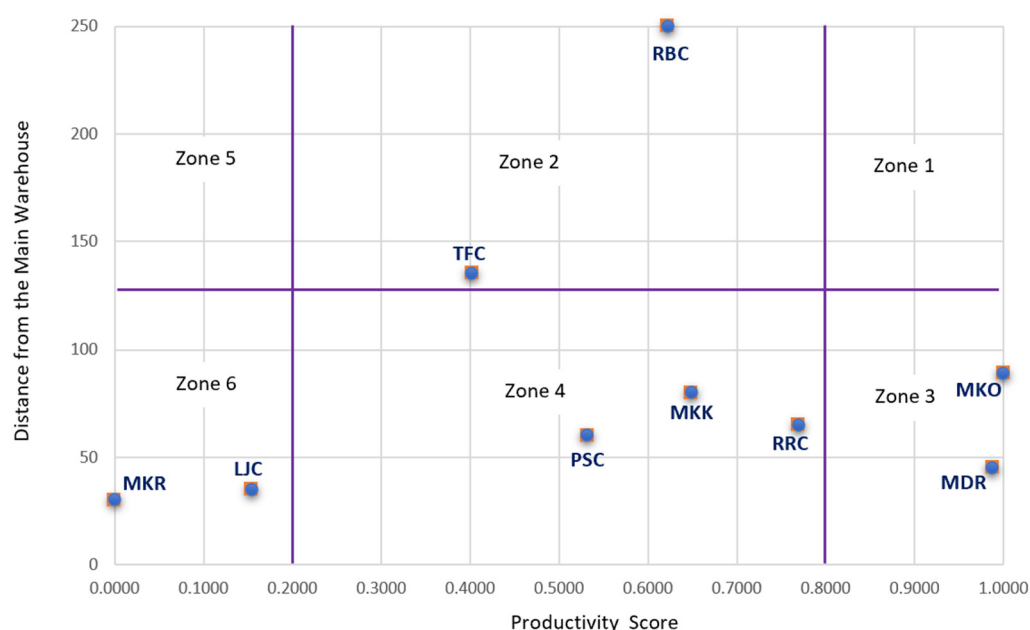


Figure 3. DC zone identification based on their locations and productivity scores.

- **Strategy 1**

A strategy that should be executed for the DCs located within Zone 1, as shown in Figure 3. These DCs attained relatively (i.e., compared to other DCs) higher productivity scores (>0.8) despite being located far from the main warehouse. Minimum resources should be dedicated to these DCs. Efforts should aim at maintaining a maximum productivity score. Internal processes should be considered the best practices for any DC located within Zone 2 and Zone 5 as they are all relatively far from the main warehouse. Generally, all other DCs located in other zones should be benchmarked against those located in Zone 1. None of the investigated DCs were located within Zone 1.

- **Strategy 2**

A strategy that should be executed for the DCs located within Zone 2, as shown in Figure 3. For instance, RBC, which is located within this zone, attained a relatively moderate productivity score (between 0.2 and 0.8) while still being geographically located extremely far away from the main warehouse. Its far location may provide some explanation. Consequently, resources should be allocated for the purpose of overcoming obstacles associated with location. This may implicitly improve the productivity score. Any score

improvement to any DC located in this zone (i.e., RBC and TFC) will result in them entering Zone 1 in an attempt to attain the maximum productivity score.

- **Strategy 3**

A strategy that should be executed for the DCs located within Zone 3, as shown in Figure 3. These DCs attained relatively (i.e., compared to other DCs) higher productivity scores (>0.8) as they were located relatively close to the main warehouse (<125 km). Resources for this strategy should be allocated for the purpose of benchmarking the best practice within the corresponding zone. The required resources might be minimal, as in the case of MKO, or sufficiently provided to fulfill their need to follow the best practices, as in the case of MDR (Figure 3). The best practice within this zone is represented by MKO; consequently, efforts should be dedicated to maintaining the same level of productivity. Additionally, the best practice in this zone should be prepared to accommodate cases in which the main warehouse relocates far away (125–250 km) since there is no evidence on which to judge its current productivity score (i.e., productivity = 1 or 100%).

- **Strategy 4**

A strategy that should be executed for the DCs located within Zone 4, as shown in Figure 3. These DCs—RRC, MKK, and PSC—attained relatively moderate productivity scores (between 0.2 and 0.8) as they were located relatively close to the main warehouse (<125 Km). Resources should be allocated for the purpose of improving productivity scores, and accordingly, to enter Zone 3 to attain maximum productivity scores. The required resources are based on the DC, according to their situation (Figure 3). The DCs within this zone should also consider that they have the competitive advantage of being relatively close to the main warehouse, and consequently, must be challenged and more efficient in regard to the resource utilization/mobilization required for productivity score improvement.

- **Strategy 5**

A strategy that should be executed for the DCs located within Zone 5, as shown in Figure 3. The DCs located within this zone attained low productivity scores (<0.2) as they were located extremely far away from the main warehouse. Such distances cannot be easily justified for resource allocation due to the low productivity scores of these DCs. However, if such locations are considered as exceptions by decision-makers, huge resources must be allocated to overcome obstacles relevant to their location and to benchmark against the best practices in order to improve productivity scores. In such situations, the potential for better future DC performance should justify the decision to allocate additional resources.

- **Strategy 6**

A strategy that should be executed for the DCs located within Zone 6, as shown in Figure 3. These DCs—LJC and MKR—attained low productivity scores (<0.2) despite being located relatively close to the main warehouse (<125 km). Such a situation indicates the misuse of resources, and accordingly, additional resource allocation is not logically justified. Decision-makers may consider various options in such a situation, including deactivating these centers, re-engineering their internal processes, or converting/downgrading them to warehouses serving other DCs. In either case, resources should not be wasted on such unproductive DCs.

7. Conclusions

The SCM literature is abundant with research that is oriented toward performance evaluation, efficiency and/or effectiveness measurement, and productivity management utilizing different approaches. However, these approaches have their own specific technical interpretations. While the performance evaluation field can be seen as the umbrella under which productivity measurement approaches represent the cornerstone of any practical and/or technical-based industry, the indistinguishability between effectiveness and efficiency (i.e., the two wings of productivity) leads to a somewhat shallow interpretation, and consequently, a diluted evaluation. This paper handles this dilemma by providing the

practical implementation of two MCDM techniques in order to capture the productivity level in nine DCs. By utilizing seven different measurement criteria, the effectiveness of the investigated DCs was measured by the developed PROMETHEE II model. The efficiency scores were then generated by utilizing DEA in order to fine-tune the PROMETHEE II results. The resulting hybrid model collectively creates what can be termed a DEA-based PROMETHEE II model, which is conceptually and practically illustrated in this paper as a productivity evaluation model. Different strategic directions have been innovatively formulated to assess DC locations, with consideration of their current productivity performance, for any future improvement initiatives. In particular, two DCs (MKO and MDR) were located in Zone 3 indicating that relatively, they were the most productive among the nine DCs. The results also indicated that RBC was performing very well although it was located relatively far away from the main warehouse. Two DCs (MKR and LJC) were located in Zone 6 with low productivity scores although they were located relatively close to the main warehouse. Such low productivity scores indicate the misuse of resources, and consequently, resources should not be allocated to these unproductive DCs. The remaining DCs were found to be in need of considerable improvement. Although the employment of the nine DCs in this study facilitates the attainment of the desired practical contributions and implications, future research and applications should not be limited to a few centers. Furthermore, it would be beneficial to expand such applications to handle various forms of inventories, such as warehouses and logistic centers.

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