logistics

MDPI

Article

Ranking and Challenges of Supply Chain Companies Using MCDM Methodology

Alaa Fouad Momena [1,*], Kamal Hossain Gazi [2], Mostafijur Rahaman [3], Anna Sobczak [4], Soheil Salahshour [5,6,7], Sankar Prasad Mondal [2] and Arijit Ghosh [8]

1 Department of Industrial Engineering, College of Engineering, Prince Sattam Bin Abdulaziz University, Al Kharj 11942, Saudi Arabia
2 Department of Applied Mathematics, Maulana Abul Kalam Azad University of Technology, Haringhata 741249, West Bengal, India; kamalgazi1996@gmail.com (K.H.G.); sankar.res07@gmail.com (S.P.M.)
3 Department of Mathematics, School of Liberal Arts & Sciences, Mohan Babu University, Tirupati 517102, Andhra Pradesh, India; imostafijurrahaman@gmail.com
4 Faculty of Economics, The Jacob of Paradies University, 66-400 Gorzów Wielkopolski, Poland; asobczak@ajp.edu.pl
5 Faculty of Engineering and Natural Sciences, Istanbul Okan University, Istanbul 34959, Turkey; soheil.salahshour@okan.edu.tr
6 Faculty of Engineering and Natural Sciences, Bahcesehir University, Istanbul 34488, Turkey
7 Department of Computer Science and Mathematics, Lebanese American University, Beirut 13-5053, Lebanon
8 Department of Mathematics, St. Xavier's College (Autonomous), Kolkata 700016, West Bengal, India; arijitghosh@sxccal.edu
* Correspondence: a.momena@psau.edu.sa

Abstract: *Background*: Supply chain companies have merits and demerits regarding operational and economic transactional policies. The effectiveness of supply chain companies corresponds to a cumulative score on a multi-criteria and perspectives-based evaluation. In this paper, we analyse the performances and challenges of several celebrated e-commerce companies to perceive their overall impression of supply chain management. *Method*: A mathematical model is framed as a multi-criteria decision-making (MCDM) problem with challenges as criteria and companies as alternatives. The criteria importance through inter-criteria correlation (CRITIC) method is used in this paper to adjust weights representing the available data. The ranking of e-commerce companies is evaluated using multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA) method. *Results*: This model investigates the most dependent criteria and sub-criteria for the adaptation challenges of supply chain companies (SCCs). Furthermore, the SCCs are prioritized based on various conflicting criteria. *Conclusion*: Various challenges of SCCs, like logistics constraints, disruptions in supply chains, issues with technology, ethical sourcing and inconsistency between the products' availability and the pace of consumption, are considered and analysed. We amassed the difficulties as criteria and sub-criteria in a numerical process using the MCDM approach. Additionally, the sensitivity and comparative of several optimal phenomena are analysed based on distinctive combinations of challenges in the ranking arena.

Keywords: supply chain management; supply chain companies; MCDM; CRITIC; MULTIMOORA

check for updates

Citation: Momena, A.F.; Gazi, K.H.; Rahaman, M.; Sobczak, A.; Salahshour, S.; Mondal, S.P.; Ghosh, A. Ranking and Challenges of Supply Chain Companies Using MCDM Methodology. *Logistics* **2024**, *8*, 87. https://doi.org/10.3390/logistics8030087

Academic Editors: Mladen Krstić, Željko Stević and Snežana Tadić

Received: 12 July 2024
Revised: 17 August 2024
Accepted: 2 September 2024
Published: 5 September 2024

1. Introduction

The supply chain includes the economic and operational activities to get a product from the warehouse and even in the production hub to the consumers. Therefore, supply chain management is about the materialization of policies regarding production, warehousing, transportation, retailing, and customer care in a coherent manner. Therefore, it can be regarded as one of the fundamental backbones related to global trade. As the scope of international commerce continues to broaden, an incursion of world-class factories and commercial establishments is evident. However, this expansion has simultaneously heightened the levels of competition within the market. Navigating this intensely competitive environment poses a substantial challenge for organizations striving to deliver products or services to customers cost-effectively, all without compromising on quality. E-commerce companies become influential players in the domain of supply chain management in the current era of internet-based e-transactions. However, every e-commerce carries some limitations and challenges while operating as a bridge between suppliers and consumers. So, the manifestation of challenges and ranking of supply chain networks will be of great importance to understand the cumulative effectiveness of supply chain networks.

A supply chain [1] constitutes an unbroken production and logistics management system for products or services, facilitating the seamless flow of raw materials through various stages to the ultimate delivery of finished products to customers. This network involves a series of interconnected suppliers, forming a chain that efficiently moves products from the initial suppliers to the organizations directly engaged with consumers. This collaborative process encompasses various stages, from procurement and manufacturing to distribution and delivery, with the ultimate goal of meeting customer demands in a well-coordinated manner. Supply chain management [2,3] finds applications across diverse domains, from manufacturing, retail, food industry, e-commerce, agriculture, and construction to healthcare systems and technology. It ensures the efficient coordination of processes, from obtaining raw materials to delivering finished products or services. Effective supply chain practices contribute to cost savings, improved customer satisfaction, and streamlined operations across different industries.

Multi-criteria decision-making (MCDM) methodologies are useful tools for supply chain companies and they are often utilized to evaluate conflicting criteria and sub-criteria. MCDM helps to make decisions by considering various complex criteria, which also depend on themselves. Supply chain companies consider MCDM techniques to navigate the complexity of contemporary supply networks when several frequently incompatible criteria are considered to make optimal decisions that complement their strategic goals. Previously MCDM was applied in supply chain companies in various studies, including Erceg, Ž. et al. [4], who used supply chain in wood management companies and Büyüközkan, G. et al. [5], who analyzed the supply chain challenges in a logistic company. Furthermore, Parthiban, P. et al. [6] utilized supplier selection, Sufiyan, M. et al. [7] applied it to a food supply chain, and Khan, S. et al. [8] conducted a risk factor analysis of a Halal food supply chain using MCDM methodologies.

1.1. Necessity of Ranking SCCs

Supply chain companies are contemporaries of today's business and economy. Different supply chain companies work on divergent backgrounds and have distinctive strengths. A commutative ranking and comparison among companies are needed for the fundamental issues addressed below:

1. Performance bench-marking: Performance bench-marking regarding supply chain companies includes divergent perspectives, like economic growth through transactions, consumers' satisfaction, and enhancement in the productivity of individual stockholders and companies overall. The method has significant necessities as a part of ranking because it analyzes the strengths and weaknesses of the supply chain organizations.
2. Customers' and investors' confidence: Perspectives and faiths of consumers and investors toward supply chain organizations heavily impact economic transactions. The retail activities and, overall, the economy become stronger when consumers' confidence levels increase. Thus, to plan a suitable supply chain design, the ranking of supply chains includes consumers and investors as an integral part.
3. Strategic planning: Strategic planning is one of the prerequisites for effective supply chains. Strategic planning, structured by decision-makers, controls on the whole supply mechanism reflecting an organization's goal. So, strategic planning accompanies the ranking of supply chain companies.

4. Operational improvement: Supply chain companies become contemporary in the daily lives of consumers. Due to the competitive coexistence of distinct companies, improvement in the operational ground is urgent. The operational improvement may be done by modifying inventory management, optimizing logistics and warehousing activities, embracing innovative technology and intelligence, etc. Adequately ranking supply chain companies may provide several aspects regarding operational improvement.
5. Innovation and adaptation: Several challenges arise due to the disruption in supply chain companies in terms of labor concerns, unpredictable demand and consumers' behavior. In this regard, companies give priority to innovations in operations and adaptations of impactful strategic planning for the supply chain. Ranking and comparisons among supply chain companies provide a clear picture of innovation and adaptation measures in distinct companies.
6. Supply chain resilience: Resilience in the supply chain stands for the ability of the organization to make adequate changes and recovery measures to overcome the situation due to the unprecedented strain in supply flow. It can minimize the negative impression of disruption on operations. So, ranking supply chains gives details about the resilience and its consequences linked to supply chain companies.

Ranking the above-mentioned points may provide competitive, advanced, and innovative economic perspectives regarding supply chain environments. A review of the existing operational capacity, its continuous improvement, and overall sustainable changes in the supply industry will have significant consequences for ranking among supply chain companies. The structural diagram of the supply chain is presented in Figure 1.

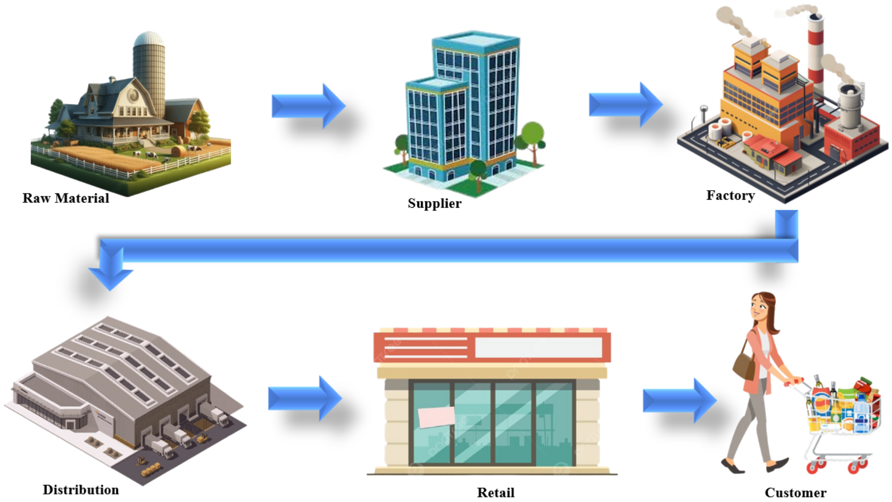

Figure 1. Structural flowchart of the supply chain.

1.2. MCDM as Optimization Tools

Multi-criteria decision-making (MCDM) techniques [9] are very powerful optimization tools. They are used to handle different complex decision-making problems [10] with multiple conflicting criteria and sub-criteria considered simultaneously. The role of MCDM methods is as follows:

a. MCDM methods can have the handling capacity of multiple conflicting criteria or objectives. Traditional optimization methods normally focus on a single objective function, whereas MCDM methods can handle several objectives concurrently.
b. MCDM techniques can support the analysis of trade-offs between criteria. It can examine the weight of the criteria and prioritize them based on results, thereby facilitating informed decision-making.
c. MCDM offers decision-makers structured approaches to determine and compare different alternatives based on multiple criteria. This is especially important when making decisions that require balancing conflicting goals.

d. There are mainly two categories of MCDM methodologies available, such as determining the weight of the criteria by Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), criteria importance through inter-criteria correlation (CRITIC), and so on, and making decisions based on the alternatives by Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Complex Proportional Assessment (COPRAS), multi-objective optimization based on ratio analysis plus full multiplicative form (MULTIMOORA), and many others.
e. Each MCDM methodology offers a different approach to structuring and solving multi-criteria problems, catering to different types of decision contexts.

1.3. Structure of This Paper

The structure of this study is presented in this section. The introduction of this research is presented in Section 1. The literature survey of this study is covered in Section 2. Used materials and methodology are described in Section 3. Different challenges for supply chain companies (SCCs) are discussed in Section 4 and various SCCs are described in Section 5. The model formulation and data collection of this study are presented in Section 6. Furthermore, the numerical illustration and discussion are covered in Section 7. Additionally, Section 8 examines the sensitivity analysis and comparative analysis in detail. Lastly, this study's conclusions and future research scope are discussed in Section 9.

2. Literature Review

The literature of this study is described in this section from different aspects. Firstly, the background of a supply chain company (SCC) and its management are discussed. After that, the brief literature on MCDM methods and different applications of MCDM methods used are also described.

2.1. Literature Survey on Supply Chain Companies (SCCs)

This section discusses the literature survey on supply chain companies (SCCs). It play a crucial role in ensuring the efficient movement of goods and services from manufacturers to consumers. These supply chains oversee the procurement of raw materials, manufacturing, shipping, logistics, retailing, and other facets of the supply chain. The supply chain is applied in numerous fields, including Dutta, P. et al. [11] who applied it in blockchain technology, Min, H. [12] utilized it in artificial intelligence, Ivanov, V. et al. [13] applied it in an analysis on Industry 4.0, and so on. Furthermore, more supply chain studies are discussed in Table 1.

Table 1. Some recent supply chain (SC) applications.

	Authors	Year	Supply Chain Technique	Application Area
[1]	Riahi, Y. et al.	2021	Supply Chain Operations Reference (SCOR) model	Applications for artificial intelligence
[14]	Blossey, G. et al.	2019	Case clusters	Blockchain technology
[15]	Leung, J. et al.	2014	IT innovation involves multiple processes	Application on Agile RFID
[16]	Sellitto, M. A. et al.	2015	SCOR-based model	Application in footwear industry
[2]	Kim, J. et al.	2019	SC Partnership efficiency and growth	Impact of blockchain technology
[17]	Ahmadi, A. et al.	2017	BOMILP model	Pharmaceutical management
[18]	Chen, J. et al.	2020	BDS and BCauotSCF	Applied in auto retail industry
[19]	Genovese, A. et al.	2017	General input–output model	Analysis of circular economy
[3]	Soheilirad, S. et al.	2018	Data envelopment analysis	Performance of supply chain
[20]	Raoui, H. et al.	2020	Linear and non-linear programming	Applications on soft computing, simulation, and optimization in supply chain

2.2. Literature of MCDM Methods

Multi-criteria decision-making (MCDM) makes an outstanding contribution to addressing the challenges posed by complex decision-making approaches. The initial perspective of MCDM is to determine the best option by critically considering and weighing various factors throughout the selection process. This approach includes a variety of tools and methods (such as AHP, CRITIC, ELECTRE, TOPSIS, VIKOR, WASPAS, MULTIMOORA, etc.), making it diverse across field contexts. The array of tools provided by MCDM serves as a structural framework, helping to provide the techniques needed to evaluate choices. As a result, these tools demonstrate the ability to engage decision-makers in more informed and comprehensive decision-making processes, especially in complex and versatile cases. In this context, we focus on two MCDM methods: the CRITIC (criteria importance through inter-criteria correlation) and MULTIMOORA (multi-objective optimization based on ratio analysis plus full multiplicative form) method. The subsequent discussion looks at the conceptual framework of the CRITIC and MULTIMOORA approaches, exploring their varied applications in numerous practical scenarios.

CRITIC was first introduced by Diakoulaki et al. [21]. This novel technique helps decision-makers determine the importance or weight of different criteria in making a decision. This method is used to judge the importance of numerous objectives by measuring their intensity of contrast and conflict. The contrast intensity is computed as the standard deviation (SD) of a specific objective measured across diverse topological frameworks. Greater contrast intensity implies a profound significance of the respective objective. Moreover, the correlation coefficient serves as a measure of conflict between two objectives, wherein a lower correlation implies a greater degree of conflict. The ultimate weight for each attribute is derived by integrating both the contrast intensity and conflict measurement. Here, we employ a decision matrix, scrutinizing variations in values and assessing the correlation between each pair of values.

The CRITIC method finds practical applications across a variety of MCDM domains. Its versatility is evident in its effective utilization in various fields, showcasing its flexibility and relevance. The study conducted by Peng, X. et al. [22] addresses this comparison in the Pythagorean fuzzy environment with a novel score function. Objective weight is calculated via the CRITIC method. The Pythagorean fuzzy decision-making algorithm was developed and validity is demonstrated through 5G evaluation and sensitivity analysis. Ghorabaee, M. K. et al. [23] introduced a novel method integrating CRITIC and WASPAS to assess 3PL providers using IT2FSs, offering a comprehensive approach for evaluation. Rostamzadeh et al. [24] designed an integrated fuzzy TOPSIS-CRITIC method to evaluate sustainable supply chain risk management (SSCRM) in their framework. The article contributed by Jawad Ali [25] handles comparison issues in a spherical fuzzy environment, proposing a new score function based on the CRITIC-MARCOS method. Novel spherical fuzzy operations, conversion formulas, and applications for smartphone selection problems are discussed. Mohamadghasemi et al. [26] employed a multi-objective stochastic CRITIC–TOPSIS method to tackle the shipboard crane selection issue effectively. In [27], a GRP method for PUL-MAGDM is developed and uses CRITIC to determine attribute weights. A numerical example validated the extended method for hospital site selection. Haktanır and Kahraman [28] introduced an integrated CRITIC and REGIME methodology using single-valued PFSs to leverage their advantage in handling ambiguity. New scales were developed and applied to the wearable health technology (WHT) selection problem. Recently, various applications of the CRITIC method have emerged. Ertemel, A. V. et al. [29] introduced a fuzzy MCDM method using Pythagorean fuzzy sets to assess adolescent smartphone addiction. In this article, the CRITIC method determines criteria importance objectively, and TOPSIS ranks addiction levels. Kaur et al. [30] developed the CRITIC-TOPSIS-based MCDM method in a Neutrosophic environment for aircraft selection, a significant contribution to decision-making. Chaurasiya and Jain [31] proposed a Hybrid MCDM method on a Pythagorean fuzzy set for banking management software applications.

Menekse, A. et al. [32] evaluated automotive additive manufacturing options using Pythagorean fuzzy CRITIC EDAS, enhancing decision-making in the industry's technological advancements. The CRITIC method has more numerous applications in many different areas for various purposes. Researchers have shown its adaptability in solving diverse problems and simplifying complexities. Through their work, complex practical issues have become more manageable. Table 2 presents a compilation of recent studies conducted by several researchers focusing on the CRITIC method and its applications across diverse domains.

Table 2. Literature on CRITIC techniques with their details.

	Authors	Year	Uncertainty	MCDM Methods	Application Area
[22]	Peng, X. et al.	2019	Pythagorean fuzzy set	CoCoSo, CRITIC	5G industry
[33]	Krishnan, A.R. et al.	2021	NA	CRITIC, D-CRITIC	Smartphone selection problem
[34]	Rani, P. et al.	2021	Neutrosophic fuzzy set	CRITIC, MULTIMOORA	Food waste treatment method (FWTM) selection
[30]	Kaur, G. et al.	2023	Neutrosophic fuzzy set	CRITIC, TOPSIS	Aircraft selection
[26]	Mohamadghase-mi, A. et al.	2020	Interval type-2 fuzzy set	CRITIC, TOPSIS	Shipboard crane selection
[35]	Alrababah and Gan	2023	NA	VIKOR, CRITIC	Perspective rankings in customer reviews
[36]	Shanthi, S. A. et al.	2022	Picture fuzzy soft set	CRITIC, TOPSIS	Selection of best variety of chili
[37]	Liu, Q.	2022	Intuitionistic fuzzy set (IFS)	CRITIC, TOPSIS	Corporate environmental performance (CEP)
[24]	Rostamzadeh, R. et al.	2018	Fuzzy set	CRITIC, TOPSIS	Risk management
[25]	Jawad Ali	2021	Spherical fuzzy set	CRITIC, MARCOS	Smartphone selection problem
[38]	Liu, P. et al.	2022	Bipolar complex fuzzy set	CRITIC, WASPAS	Green supplier selection (GSS)
[23]	Ghorabaee, M. K. et al.	2017	Interval type-2 fuzzy sets	CRITIC, WASPAS	Evaluation of 3PL provider
[39]	Mishra, A.R. et al.	2021	Fuzzy set	CRITIC, EDAS	S3PRLP selection problem
[32]	Menekse, A. et al.	2023	Fuzzy set	CRITIC, EDAS	Manufacturing process selection

The Multi-Objective Optimization on the basis of a Ratio Analysis (MOORA) method offers multipurpose solutions for decision-making in complex supply chain scenarios. From warehouse site selection, renewable energy projects, etc., to supplier and design choices, MOORA proves invaluable for optimizing decisions across varied domains within the supply chain environment. When natural gas is transferred through pipelines, there are some safety risks in building and running these extensive systems. To deal with this problem, Mete, S. [40] proposed an integrated approach combining Failure Mode and Effect Analysis (FMEA), AHP, and MOORA in a Pythagorean fuzzy environment for evaluating occupational risks during the construction of natural gas pipelines. Today, digital fabrication, also known as 3D printing, constructs objects from geometric models through continuous layering using Fused Deposition Modeling (FDM) technology. Maity, M. et al. [41] discussed the ANP–MOORA-based approach for selecting FDM 3D printer filament in detail, considering various factors for optimal choice. The study by Yagmahan and Yılmaz [42] introduces integrated MCDM for robust Electric Vehicle Charging Stations (EVCSs) site evaluation and enhances the decision-making process for alternative locations. Miç et al. [43] developed a decision-making model combining TOPSIS, WASPAS, and MULTIMOORA methods to select university locations effectively. Poongavanam, G. et al. [44] conduct a comparative study on selecting the ideal refrigerant to replace R134a in vehicle air conditioning systems through various multi-criteria decision-making (MCDM) techniques.

Brauers, W. K. M. and Zavadskas, E. K. [45] introduced the MULTIMOORA method in 2010 and applied it in analysis to an instrument in transition economies. The MULTIMOORA methodology is used in numerous fields. Brauers, W. et al. [46] used the MULTIMOORA methodology in the bank sector for buying properties. Brauers, W. et al. [47] used the robustness of the MULTIMOORA method and rank alternatives. Furthermore, the MULTIMOORA method was applied in technological fields by Dahooie, J. H. et al. [48]

and in the selection of materials in biomedical firms by Hafezalkotob, A. et al. [49]. Mandal, U. K. et al. [50] applied the MULTIMOORA method in the manufacturing sector in an uncertain environment. Furthermore, Zhang, Z. et al. [51] used this method in the technology of energy storage. Additionally, the MULTIMOORA technique was utilized in site selection by Lin, M. et al. [52] in the station for car sharing and Miç, P. et al. [43] in an educational institute. On the other hand, Chen, Y. et al. [53] and Liu, P. et al. [54] used extended MULTIMOORA in computer numerical control (CNC) machine tool selection and sustainable supplier selection. Table 3 compiles recent studies by various researchers on the MULTIMOORA method and its diverse applications across different fields.

Table 3. Literature on MOORA techniques with their details.

	Authors	Year	Uncertainty	MCDM Methods	Application Area
[52]	Lin, M. et al.	2020	Picture fuzzy set	MULTIMOORA	Location selection for car sharing station
[55]	Zhao, H. et al.	2016	Interval-valued intuitionistic fuzzy set	MULTIMOORA	Risk management in steel production process
[48]	Dahooie, J. H. et al.	2019	Fuzzy set	MULTIMOORA, CCSD	Technological forecasting method selection
[56]	Mishra, A.R. et al.	2022	q-rung orthopair fuzzy sets	MULTIMOORA	Solid waste disposal (SWD) method selection
[57]	Tian, C. et al.	2022	Picture fuzzy set	MULTIMOORA	Selection of medical institution
[58]	Arslankaya, S. et al.	2021	Fuzzy set	AHP, MOORA	Green supplier selection in steel door industry
[59]	Ramezanzade, M. et al.	2021	Fuzzy set	Entropy, F-MOORA, F-VIKOR, F-EDAS, F-ARAS	Renewable Energy Projects
[60]	Fattahi, R. et al.	2018	Fuzzy set	AHP, MULTIMOORA	Risk of occupational accidents in Kerman steel industrial plant
[40]	Mete, S.	2019	Pythagorean fuzzy set	AHP, MOORA	Occupational risks in pipeline construction
[34]	Rani, P. et al.	2021	Neutrosophic fuzzy set	CRITIC, MULTIMOORA	Food waste treatment method (FWTM) selection
[61]	Alkan, Ö. et al.	2020	Fuzzy set	Entropy, COPRAS, MULTIMOORA	Renewable energy sources in Turkey
[62]	Bera, A.K. et al.	2019	Interval type-2 fuzzy set	TOPSIS, MOORA	Supplier selection
[63]	Khorshidi, M. et al.	2022	Fuzzy set	DEMATEL, MOORA	Solar power plant location selection
[64]	Gupta, K. et al.	2022	Fuzzy set	FAHP, CODAS, MOORA	Type 2 Diabetes Mellitus health applications
[65]	Saraji, M. K. et al.	2021	Hesitant fuzzy set	SWARA, MULTIMOORA	E-learning in higher education institutions during pandemic
[66]	Siddiqui, Z. A. et al.	2023	Fuzzy set	FCEM-MULTIMOORA-FG	Blockchain technology
[67]	Saluja, R.S. et al.	2023	Fuzzy set	MULTIMOORA	Welding process selection

3. Materials and Methodology

This section describes the mathematical procedure of the MCDM methodologies. There were two MCDM methods used in this study, namely the CRITIC and MULTIMOORA techniques. The CRITIC method was used to determine the criteria and sub-criteria weight, which were utilized in further ranking evaluation. Then, the ranking of the alternatives by the MULTIMOORA-based MCDM method is described as follows.

The reason for choosing the CRITIC method with other MCDM methods is due to its objective and data-driven tactic of defining the weight of criteria. Unlike subjective weighting approaches, which depend on expert preferences or opinions (like AHP), the CRITIC method computes criteria weights based on the contrast intensity of respective criteria in view of both the inconsistency of the criterion and its correlation with others.

The reason for choosing the MULTIMOORA method with other MCDM methods is due to its inclusive, robust, and flexible tactic. It mixes three different evaluation styles:

the ratio system, the reference point approach, and the full multiplicative form. This incorporation allows it to be interpreted from several decision-making standpoints and delivers more dependable and consistent results. Unlike single-method approaches like TOPSIS, it propositions a balanced assessment by considering dissimilar evaluation criteria, reducing the potential for unfairness.

3.1. Criteria Importance through Inter-Criteria Correlation (CRITIC) Method

The criteria importance through inter-criteria correlation (CRITIC) technique was first introduced by Diakoulaki, D. et al. [21] in 1995. The CRITIC based multi-criteria decision-making (MCDM) method is a mathematical procedure to determine the weight of the criteria in a complex decision-making problem by considering various criteria and sub-criteria. This approach is frequently utilized to assist with decision-making across the MCDM problems. The CRITIC method is used in various application fields, like technology [22], different selection problems [33,34], and so on. The mathematical process of the CRITIC method is explained as follows.

In this study, we consider q to be the number of criteria associated with p, the number of alternatives. Furthermore, we assume that, for every criterion j, there is an s_j number of sub-criteria and an n number of decision-makers (DMs) gives data in linguistic terms in an unbiased process. Therefore, the decision matrices are constructed by dth DMs, which are $p \times q$ and $p \times s_j$ orders for criteria and sub-criteria, respectively. The mathematical interpretation of the CRITIC methodology is as follows:

I. Establish decision matrix:
The decision matrix is constructed by dth DM for the criteria as

$$\mathscr{D}_d = \begin{bmatrix} (\mathscr{L}_{11})_d & (\mathscr{L}_{12})_d & \dots & (\mathscr{L}_{1j})_d & \dots & (\mathscr{L}_{1q})_d \\ (\mathscr{L}_{21})_d & (\mathscr{L}_{22})_d & \dots & (\mathscr{L}_{2j})_d & \dots & (\mathscr{L}_{2q})_d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\mathscr{L}_{i1})_d & (\mathscr{L}_{i2})_d & \dots & (\mathscr{L}_{ij})_d & \dots & (\mathscr{L}_{iq})_d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\mathscr{L}_{p1})_d & (\mathscr{L}_{p2})_d & \dots & (\mathscr{L}_{pj})_d & \dots & (\mathscr{L}_{pq})_d \end{bmatrix}_{p \times q} \quad (1)$$

where $j = 1, 2, \dots, q$ and $i = 1, 2, \dots, p$ and for the sub-criteria of the kth criteria as

$$\mathscr{D}_d^{k_j} = \begin{bmatrix} (\mathscr{L}_{11_j})_d & (\mathscr{L}_{12_j})_d & \dots & (\mathscr{L}_{1k_j})_d & \dots & (\mathscr{L}_{1s_j})_d \\ (\mathscr{L}_{21_j})_d & (\mathscr{L}_{22_j})_d & \dots & (\mathscr{L}_{2k_j})_d & \dots & (\mathscr{L}_{2s_j})_d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\mathscr{L}_{i1_j})_d & (\mathscr{L}_{i2_j})_d & \dots & (\mathscr{L}_{ik_j})_d & \dots & (\mathscr{L}_{is_j})_d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\mathscr{L}_{p1_j})_d & (\mathscr{L}_{p2_j})_d & \dots & (\mathscr{L}_{pk_j})_d & \dots & (\mathscr{L}_{ps_j})_d \end{bmatrix}_{p \times s_j} \quad (2)$$

where $k_j = 1_j, 2_j, \dots, s_j$, and $i = 1, 2, \dots, p$. Every entry $((\mathscr{L}_{ij})_d)$ is the linguistic term of a rating given by dth DMs on ith alternatives based on jth criteria and $d = 1, 2, \dots, n$. For computational complexity, we only consider the decision matrix $(\mathscr{D}_d)$ for the criteria and the numerical procedure of the decision matrix $(\mathscr{D}_d^{k_j})$ for the sub-criteria is the same as the decision matrix $(\mathscr{D}_d)$ for the criteria.

II. Decode the linguistic terms:
All the data given by DMs in linguistic terms $((\mathscr{L}_{ij})_d)$ are decoded in crisp value $((\mathscr{C}_{ij})_d)$ by Table 4. Then, the decision matrices $\mathscr{D}_d$ and $\mathscr{D}_d^{k_j}$ defined in Equation (1) and Equation (2), respectively, are converted into crisp values. The crisp decision matrix is formed as

$$\mathscr{D}_d^c = \begin{bmatrix} (\mathscr{C}_{11})_d & (\mathscr{C}_{12})_d & \cdots & (\mathscr{C}_{1j})_d & \cdots & (\mathscr{C}_{1q})_d \\ (\mathscr{C}_{21})_d & (\mathscr{C}_{22})_d & \cdots & (\mathscr{C}_{2j})_d & \cdots & (\mathscr{C}_{2q})_d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\mathscr{C}_{i1})_d & (\mathscr{C}_{i2})_d & \cdots & (\mathscr{C}_{ij})_d & \cdots & (\mathscr{C}_{iq})_d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (\mathscr{C}_{p1})_d & (\mathscr{C}_{p2})_d & \cdots & (\mathscr{C}_{pj})_d & \cdots & (\mathscr{C}_{pq})_d \end{bmatrix}_{p \times q} \tag{3}$$

where $j = 1, 2, \ldots, q$, $i = 1, 2, \ldots, p$, and $d = 1, 2, \ldots, n$.

III. Aggregate the decision matrices:
Assemble all the n decision matrices into one decision matrix by merging the crisp values of every decision matrix using Equation (4), as follows:

$$(\mathscr{C}_{ij}) = \sqrt[n]{\prod_{d=1}^{n} (\mathscr{C}_{ij})_d} \tag{4}$$

and the aggregated decision matrix $(\mathscr{D}^c)$ is formed as

$$\mathscr{D}^c = \begin{bmatrix} \mathscr{C}_{11} & \mathscr{C}_{12} & \cdots & \mathscr{C}_{1j} & \cdots & \mathscr{C}_{1q} \\ \mathscr{C}_{21} & \mathscr{C}_{22} & \cdots & \mathscr{C}_{2j} & \cdots & \mathscr{C}_{2q} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathscr{C}_{i1} & \mathscr{C}_{i2} & \cdots & \mathscr{C}_{ij} & \cdots & \mathscr{C}_{iq} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathscr{C}_{p1} & \mathscr{C}_{p2} & \cdots & \mathscr{C}_{pj} & \cdots & \mathscr{C}_{pq} \end{bmatrix}_{p \times q} \tag{5}$$

where $j = 1, 2, \ldots, q$ and $i = 1, 2, \ldots, p$.

IV. Normalize the aggregated decision matrix:
The normalized decision matrix $(\mathscr{D}_n^c)$ from the aggregated decision matrix $(\mathscr{D}^c)$ is evaluated by following Equation (6), as follows:

$$\mathscr{C}_{ij}{}' = \frac{\mathscr{C}_{ij} - \mathscr{C}_j^-}{\mathscr{C}_j^+ - \mathscr{C}_j^-} \tag{6}$$

where

$$\begin{cases} \mathscr{C}_j^+ = \max\limits_{i=1,2,\ldots,p} \mathscr{C}_{ij} \\ \mathscr{C}_j^- = \min\limits_{i=1,2,\ldots,p} \mathscr{C}_{ij} \end{cases}$$

with $j = 1, 2, \ldots, q$ and $i = 1, 2, \ldots, p$.

V. Determine the standard deviation (σ_q):
Determine the standard deviation σ_j for every criteria by Equation (7), as

$$\sigma_j = \sqrt{\frac{\sum\limits_{j=1,2,\ldots,q} \left(\mathscr{C}_{ij}{}' - \overline{\mathscr{C}_{ij}}\right)}{q-1}} \tag{7}$$

where $\overline{\mathscr{C}_{ij}}$ is the population mean, q is the size of the population (i.e., number of criteria), $i = 1, 2, \ldots, p$, and $j = 1, 2, \ldots, q$.

VI. Evaluate the linear correlation coefficient between two criteria:
Calculate the linear correlation coefficient between the criteria j and j'. Determine the symmetric correlation matrix of $q \times q$ order with elements $\mathscr{O}_{jj'}$ and defined as

$$\mathscr{O}_{jj'} = \left[\mathscr{D}_{jj'}\right]_{q\times q} \tag{8}$$

which is the linear correlation coefficient in between two vectors $\mathscr{C}_j$ and $\mathscr{C}_{j'}$ and correlation coefficient between criteria j and criteria j' denoted by $\mathscr{D}_{jj'}$.

VII. Calculate the conflict created by the criteria:
Further, determine the measure of the conflict created using the criteria j based on the decision situation defined by the rest of the criteria.

$$\mathscr{E}_{jj'} = \sum_{j'=1}^{q}\left(1 - \mathscr{D}_{jj'}\right) \tag{9}$$

VIII. Measure the quantity of the information concerning each criteria:
Evaluate the quantity of information for every criterion using

$$C_j = \sigma_j \times \mathscr{E}_{jj'} \tag{10}$$

for criteria $j = 1, 2, \ldots, q$.

IX. Find the objective weight:
The weight of the jth criteria denoted as C_j^{lw} is defined as follows:

$$C_j^{lw} = \frac{C_j}{\sum_{j=1}^{q} C_j} \tag{11}$$

Therefore, Equation (11) describes the local criteria weight (C_j^{lw}) for every criteria j where $j = 1, 2, \ldots, q$. Similarly, we can determine the local sub-criteria weight for each sub-criteria for each criterion. Then, the global weight of the criteria (C_j^{gw}) and sub-criteria $(C_{k_j}^{gw})$ is determined as follows:

$$C_{k_j}^{gw} = C_j^{lw} \times C_{k_j}^{lw} \tag{12}$$

and

$$C_j^{gw} = \sum_{k_j=1}^{s_j} C_{k_j}^{gw} \tag{13}$$

where C_j^{lw} and $C_{k_j}^{lw}$ are the local criteria and sub-criteria weight of the criteria j, respectively, and $j = 1, 2, \ldots, q$ and $k_j = 1_j, 2_j, \ldots, s_j$.

3.2. Multi-Objective Optimization Based on Ratio Analysis Plus Full Multiplicative Form (MULTIMOORA) Method

The multi-objective optimization based on ratio analysis plus full multiplicative form (MULTIMOORA) technique was invented by Brauers, W. K. M. and Zavadskas, E. K. [45] in 2010. The MULTIMOORA is a ranking-based MCDM method that is a mathematical methodology to calculate the rank of the alternatives by considering multiple conflicting criteria and sub-criteria. This method is used in numerous fields, including car sharing station selection [52], risk management systems [55], waste management framework [56], supplier selection [58], and so on. The mathematical procedure of the MULTIMOORA method is described as follows.

Here, we consider q to be the number of criteria; with each criterion j, there is an s_j number of associated sub-criteria. Furthermore, a p number of alternatives are ranked based on an n number of decision-maker (DM) data. Then, the decision matrix is a $p \times q$ order and $p \times s_j$ order for the criteria and sub-criteria of jth criteria, respectively. The theoretical representation of the MULTIMOORA method is as follows:

A. Structured decision matrix:

Formulate the decision matrices for criteria $(\mathscr{D}_d)$ and sub-criteria $(\mathscr{D}_d^{k_j})$ for criteria j by the dth DM as shown in Equations (1) and (2) where $d = 1, 2, \ldots, n$.

B. Decode the linguistic terms:

The DMs, given data in linguistic terms on $(\mathscr{L}_{ij})_d$ or $(\mathscr{L}_{ik_j})_d$, convert into the crisp number $(\mathscr{C}_{ij})_d$ or $(\mathscr{C}_{ik_j})_d$, respectively, based on Table 4. The crisp decision matrix $(\mathscr{D}_d^c)$ is shown in Equation (3).

C. Construct the aggregated decision matrix:

Merge all n DM opinions into one decision matrix by using Equation (4) and aggregated decision matrix $(\mathscr{D}^c)$ forms in Equation (5). Further calculations are evaluated for criteria only and sub-criteria calculations can be evaluated in similar ways.

D. Evaluate normalized decision matrix:

The normalized decision matrix $(\mathscr{D}_n^c)$ is determined from the aggregated decision matrix $(\mathscr{D}^c)$ using Equation (14), as follows:

$$\mathscr{C}_{ij}{}' = \frac{\mathscr{C}_{ij}}{\sqrt{\sum_{i=1}^{p} \left(\mathscr{C}_{ij}\right)^2}} \tag{14}$$

where $j = 1, 2, \ldots, q$.

E. Determine weighted normalized decision matrix:

The weighted normalized decision matrix is calculated from the normalized decision matrix $(\mathscr{D}_n^c)$, criteria weight (C_j^{gw}), and sub-criteria weights $(C_{k_j}^{gw})$ using Equation (15), as follows:

$$\mathscr{C}_{ij}^{w} = C_j^{gw} \times \mathscr{C}_{ij}{}' \tag{15}$$

where $j = 1, 2, \ldots, q$. The weights of the criteria (C_j^{gw}) and sub-criteria $(C_{k_j}^{gw})$ are global weight-evaluated in Equation (13) and Equation (12), respectively.

F. MOORA ratio approach:

The MOORA ratio approach conduct by calculating the performance value of the different alternatives. The ratio approach of each alternative is determined by Equation (16), as

$$\mathscr{R}_i = \sum_{j=1}^{q'} \mathscr{C}_{ij}^{w} - \sum_{j=q'+1}^{q} \mathscr{C}_{ij}^{w} \tag{16}$$

for $i = 1, 2, \ldots, p$. Here, we consider that, without loss of generality, the first q' criteria $(j = 1, 2, \ldots, q')$ are beneficial criteria and the remaining $(q - q')$ criteria $(j = q' + 1, q' + 2, \ldots, q)$ are non-beneficial criteria.

G. MOORA significance coefficient approach:

The MOORA significance coefficient approach $(\mathscr{S}_i)$ is performed by computing the value of the significance coefficient $(\mathcal{S}_j^c)$ and followed by Equation (17):

$$\mathscr{S}_i = \sum_{j=1}^{q'} \left(\mathcal{S}_j^c \times \mathscr{C}_{ij}^{w}\right) - \sum_{j=q'+1}^{q} \left(\mathcal{S}_j^c \times \mathscr{C}_{ij}^{w}\right) \tag{17}$$

for $i = 1, 2, \ldots, p$ and $j = 1, 2, \ldots, q$. The significance coefficient $(\mathcal{S}_j^c)$ is the normalized global criteria and sub-criteria weight evaluated in the previous section. Furthermore, the first q' criteria $(j = 1, 2, \ldots, q')$ are beneficial criteria, i.e., higher values are desirable, and the remaining $(q - q')$ criteria $(j = q' + 1, q' + 2, \ldots, q)$ are non-beneficial criteria, i.e., lower values are desirable.

H. MOORA reference point approach:

The MOORA reference point approach $(\mathscr{P}_i)$ is achieved by calculating the reference point (r_j) and Equation (18), as follows:

$$\mathscr{P}_i = \sum_{j=1}^{q} \left| r_j - \mathscr{C}_{ij}^w \right| \tag{18}$$

where $i = 1, 2, \ldots, p$ and $j = 1, 2, \ldots, q$. The reference point value (r_j) for $j = 1, 2, \ldots, q$ is determined by Equation (19), as

$$r_j = \begin{cases} \max\limits_{i=1}^{p} \mathscr{C}_{ij}^w & \text{when } j \text{ be beneficial criteria; i.e., } j \in \{1, 2, \ldots, q'\} \\ \min\limits_{i=1}^{p} \mathscr{C}_{ij}^w & \text{when } j \text{ be non-beneficial criteria; i.e., } j \in \{q'+1, q'+2, \ldots, q\} \end{cases} \tag{19}$$

I. MOORA full multiplication approach:
The MOORA full multiplication approach $(\mathscr{F}_i)$ is conducted using Equation (20), as follows:

$$\mathscr{F}_i = \frac{\prod_{j=1}^{q'} \mathscr{C}_{ij}^w}{\prod_{j=q'+1}^{q} \mathscr{C}_{ij}^w} \tag{20}$$

where $i = 1, 2, \ldots, p$ and $j = 1, 2, \ldots, q$. We consider that the first q' criteria $(j = 1, 2, \ldots, q')$ are beneficial criteria and the remaining $(q - q')$ criteria $(j = q'+1, q'+2, \ldots, q)$ are non-beneficial criteria.

J. MULTIMOORA approach:
The traditional MULTIMOORA approach may result in unacceptable identical levels during pairwise comparison and circular reasoning methods, since it depends on human comparison for the ultimate ranking procedure. Brauers, W. et al. [47] proposed dominance theory, which consolidated the cardinal value and ordinal value (i.e., the utility value and ranking, respectively) of each subordinate method of MULTIMOORA. Therefore, applying the enhanced Borda rule [53] rather than the dominance theory has more benefits. Here, the presented the Borda rule to evaluate the rank coefficient $(\mathscr{M}_i)$ in Equation (21) is as follows:

$$\mathscr{M}_i = \frac{\lambda_1(p + 1 - R(\mathscr{R}_i)) - \lambda_2(\mathscr{S}_i) - \lambda_3 R(\mathscr{P}_i) + \lambda_4(p + 1 - R(\mathscr{F}_i))}{\frac{p(p+1)}{2}} \tag{21}$$

where $\{R(t); t \in \{\mathscr{R}_i, \mathscr{S}_i, \mathscr{P}_i, \mathscr{F}_i\}\}$ is the rank of the alternatives determined in previous steps and $\lambda_t; t = 1, 2, 3, 4$ are the arbitrary constants. Finally, we rank the alternatives by MALTIMOORA methods by the rank coefficient values $(\mathscr{M}_i)$ in decreasing order.

Table 4. Linguistic variables and their corresponding crisp value.

Linguistic Terms	Crisp Value (CV)
Absolutely More Important (AMI)	9
Much More Important (MMI)	8
More Important (MI)	7
Slightly More Important (SMI)	6
Equally Important (EI)	5
Slightly Less Important (SLI)	4
Less Important (LI)	3
Much Less Important (MLI)	2
Absolutely Less Important (ALI)	1

3.3. Pseudo-Code of the Proposed Model

The Pseudo-code of this study model is presented here. We construct the structure with a q number of criteria and s_j number of sub-criteria for each criterion j associated with a p number of alternatives. There is an n number of decision-makers (DMs) who give data sets in linguistic terms, which convert into crisp numbers using Table 4. Then, the decision matrix is constructed with $p \times q$ order and $p \times s_j$ order for criteria and sub-criteria, respectively. Two MCDM methods are applied to calculate the criteria and sub-criteria weight and rank the alternatives. The n number of decision matrices for criteria and sub-criteria are considered as input data and the Pseudo-code of this study is described as follows.

INPUT: Decision matrices
OUTPUT: Rank the alternatives
COMPUTE: Weight of the criteria and sub-criteria
INITIALIZE: Crisp numbers
OPERATION: CRITIC and MULTIMOORA

CONSTRUCT Assemble all DM data and establish n number of decision matrices
AGGREGATION Merge the n number of decision matrices into one decision matrix

FOR CRITIC
    NORMALIZATION Normalize the decision matrix
        EVALUATE Standard deviation and linear correlation coefficient are computed
            DETERMINE Calculate the quantity of the information
        FIND Evaluate the local criteria and sub-criteria weight
END CRITIC

COMPUTE GLOBAL WEIGHT Determine global weight of the criteria and sub-criteria using the local weight of it

FOR MULTIMOORA
    COMPUTE Evaluate weighted normalized decision matrix
        MOORA Ration Calculate the rank of the alternatives by Ratio analysis
            MOORA Significance Evaluate the rank of the alternatives by significance approach
                MOORA Reference Point Determine the rank of the alternatives by reference point method
                    MOORA Full Multiplication Find out the rank of the alternatives by full multiplication technique
            MULTIMOORA Finally, assemble all four rank to rank the alternatives
END MULTIMOORA

4. Challenges for Supply Chain Companies (SCCs) (as Criteria)

There are different types of volatility in supply chain management. The challenges in supply management are due to several natural factors and external factors. The process of identifying the difficulties that supply chain organizations comprises a blend of stakeholder interaction, industry study and expert consultations. Inputs are collected via several surveys and interviews. The impact of the identified criteria on cost management, supply chain efficiency, customer satisfaction, and adaptability are taken into account when filtering and prioritizing them. This systematic approach promises that the most important and relevant issues are successfully identified.

4.1. Supply Chain Disruptions (C_1)

Disruption in supply chains is referred to as the interruption in supply flow. It includes issues in production, sale, and transportation. The supply chain and logistics management can be ruined due to several obstacles like pandemics, geopolitical warfare, and natural calamities. Disruption for the mentioned reasons are a major failure of well-designed supply chains providing end-to-end supply connectivity from the production hub to consumers.

4.1.1. Pandemic Impact (C_{1A})

The whole world has recently faced a pandemic due to COVID-19, which left a massive impact on socio-economic growth and sustainability across the globe in this century. The pandemic has an immense impact on supply chain disruptions for several causes. Many preventive measures, including social distancing, closure of retailing and shopping enterprises, and restrictions on public gatherings within territories by respective governments caused a huge downfall in the supply activities [68,69]. The conciliation of international borders to prevent the pandemic's exposure also created massive interruptions for supply chain activities. For example, the pandemic due to COVID-19 resulted in a decrease of up to eighty percent in the automobile part export by China to the United States [70].

4.1.2. Geopolitical Tensions (C_{1B})

Geopolitical conflict is a hindrance for the sustainable economic growth of several nations. It also badly impacted the supply chain systems in divergent ways. The most contemporary geopolitical conflict is the Russia–Ukraine war, having a strong negative influence on the supply chain management. Both Ukraine and Russia are enriched with wheat production and many African nations depend on the supply of foods from these countries. According to a study by Hossain et al. [71], about forty-seven million people are impacted by food insecurity, hunger, and malnutrition as an immediate consequence of the Russia–Ukraine conflict.

4.1.3. Natural Disasters (C_{1C})

Natural disasters like earthquakes and floods smash economic activity and communications in disaster-prone areas. Cavallo et al. [72] analyzed data from MIT regarding major earthquakes in Chile in 2010 and in Japan in 2011. Their findings established that the calamities have immediate influences on product availability. Inventory become diminished within a very small period of time. The inflation comes as a derivative of the collapse in the supply flow.

4.2. Logistics Challenges (C_2)

The present-day global economy has a significant dependence upon logistics management for achieving sustainable growth. Customers' expectations, specifically regarding fast shipping, are one the fundamental logistics challenges. It may be a major concern for unpleasant communications among share holders in supply chains. Thus, logistics is an integral and instrumental part of supply chain scenarios. It consists of the hindrances mentioned below.

4.2.1. Port Congestion (C_{2A})

Port congestion is an unpleasant scenario associated with several African ports having immense disruptions of logistics and supply chain. It includes delay, queuing, and extra time of voyage or dwelling between ships, escalating into a loss of trade and disrupting trade agreements. According to a study by the World Bank [73], several influences including cargo and transactional and operational dwell times cause port congestion in the sub-Saharan trade environment.

4.2.2. Transportation Costs (C_{2B})

Transportation is the most significant issue regarding the communication within supply chain phenomena. Disruptions in transportation may damage the supply and logistic mechanism. Furthermore, transportation cost is impacting the variable for supply chain strategy. Albertzeth et al. [74] contributed a cost-effective approach regarding transportation-related issues with the supply chain.

4.3. Demand and Supply Imbalances (C_3)

Demand is the most indeterministic issue connected with inventory and supply chain strategies. So, there may be gaps between demand and supply, which is a matter of concern for supply chain scenarios. The imbalances may arise for the following reasons.

4.3.1. Fluctuating Demand (C_{3A})

The consumers' attitudes towards certain products may be impacted by many decision variables. Time, pricing, and stocks in showrooms are some influential issues that control the demand. In many supply chain model, demand is considered as polynomial function of time [75]. However, time may be more crucial, having an instantaneous impact on demand [76]. Furthermore, low price [77] and availability of products in a showroom [78] may attract demand, which makes the demand to be a fluctuating one.

4.3.2. Inventory Management (C_{3B})

Inventory means stocks in terms of raw materials and semi-finished or finished products. In inventory management scenarios, the production or ordering lot should be optimized to obtain the highest gain with an uninterrupted supply. The strategies regarding the inventory lot may be called warehousing. In this context, Ramaa et al. [79] contributed a critical study on the influence of inventory strategies on supply scenarios.

4.4. Technological and Cybersecurity Issues (C_4)

Information technology, digitalization of trade, and internet involvement provide the supply chain mechanism with an immense boost. However, the digital movement also includes the following challenges.

4.4.1. Digital Transformation (C_{4A})

The traditional supply chain and logistic activities went through a paradigm sift towards digitalization in the last few decades. The move towards digital trade has changed the entire landscape of supply chains and economic communications. In this context, Dong et al. [80] measured the impacts and challenges of digitalization on the food supply chain with an objective of sustainable optimization.

4.4.2. Cybersecurity Threats (C_{4B})

The increasingly monotonic nature of internet processes several drawbacks in day-to-day livelihood. Internet-based communication and transaction are almost unavoidable in contemporary supply chain scenarios. Thus, cybersecurity becomes a matter of great concern for digital trading and transactions. An empirical study in this regard was done by Solfa [81], addressing the impacts of cybersecurity and risk in digital trading.

4.5. Sustainability and Ethical Sourcing (C_5)

Any economic growth is subjected to scrutiny on sustainable and ethical grounds. Today's consumers are very fond of sustainable products. Sustainable sourcing concerns both the suppliers and supplies produced, in the landscapes of ethical and environmentally friendly considerations. It lessens the menaces of the negative impacts of production, logistics, and transportation on the environment and human civilization.

4.5.1. Environmental Regulations (C_{5A})

Green technology, pollution, and carbon emissions are some environment-related issues in supply chain management. So, coherence with such an issue is also a challenge in this regard. Turken et al. [82] formulated a strategic supply chain model concerning the carbon emission tax, emission-permissible trading, and green technology.

4.5.2. Ethical Sourcing (C_{5B})

Ethical sourcing and transparency in the supply chain matter a lot. Chen and Slotnick [83] discussed the relativity of the competing nature of supply chains based on ethical grounds. In their study, they found that the market share of a supply chain with ethical sources was enhanced compared to another with non-disclosed sources.

To address these challenges, companies are adopting various strategies such as diversifying their supplier base, investing in supply chain technologies, enhancing collaboration with partners, and focusing on sustainability initiatives. Resilience and agility have become key priorities in supply chain management to better navigate the uncertainties and complexities of the modern global market.

5. Different Supply Chain Companies (SCCs) (as Alternatives)

Supply chain organizations have the responsibility of creating optimal strategies regarding the collection of raw materials, production, warehousing, selling, and shipping of products from logistics to awaiting consumers. The complicated process includes artificial intelligence, blockchain, and the involvement of robots in addition to human resources. The supply chain industry faced a robust change in the last few decades across regional boundaries all over the world. India, a nation with a growing economy, also saw a revolutionary advancement in the mentioned realm with the enhancement of e-commerce-based trading. In this section, we give an overview of some notable e-commerce companies from both global and Indian perspectives.

5.1. Amazon

Amazon is one of the largest multi-national tech giants for logistic and supply chain activities founded by Jeff Bezos in 1994. It provides selling opportunities on the Amazon platform to third-party sellers. It also supplies its own products on the same platform. The supply chain mechanism in Amazon works with numerous fulfillment and distribution centers, impactful data analytics, and advanced uses of robots and drones. The logistic services in this company include Amazon Air, Amazon Flex, Amazon Logistics, Amazon Prime Air, etc.

5.2. Walmart

Walmart is another American-based multinational company operating a chain of hypermarkets, discount department stores, and grocery stores. It was founded by the Sam brothers in 1962. Besides being a selling platform for third-party companies, it produces numerous products itself, having immense demand from consumers. The company uses advanced technology like blockchain and Hyperledger fabric for transparent and reliable communications.

5.3. DHL

DHL is another global giant in the supply chain, which has dominant markets in the Indian subcontinent and south-east Asia, having huge resources and facilities. India is becoming a manufacturing and supply chain hub for the globe, where e-commerce-based trading becomes instrumental. DHL provides services like courier serv ices, package delivery, and express mail.

5.4. Blue Cart

Blue Cart is one of the prime supply chain and logistics companies in India. It provides services like courier delivery, warehousing, and transportation. Blue Cart shows concern for environmental issues by implementing carbon footprint reduction initiatives through environmentally friendly vehicles and packaging associations. Concerning green technology, this company makes a goal of a sustainable supply chain mechanism.

5.5. Ekart

Ekart was associated with Flipkart for its supply chain unit. In contemporary times, Ekart has become an independent leader among the logistics companies based in India. The strengths of this company include reliable delivery and fulfillment services. With its advanced technology-driven mechanism, Ekart provides a hassle-free experience for the consumers.

6. Model Structure and Data Collection

This section discusses the model formulation and data collection of this study.

6.1. Model Structure

Key challenges regarding operational policies of supply chain mechanism were taken as criteria and sub-criteria for ranking the supply chain companies on cumulative impressions. Five criteria and eleven sub-criteria were considered to manifest the numerical simulation of the proposed mathematical model in Section 4. Supply chain companies were considered as alternatives in the ranking-based analysis in Section 5. However, instead of the real names of e-commerce companies, we preferred anonymous names like Company A, Company B, Company C, Company D, and Company E for numerical evaluations.

The criteria and sub-criteria of the mathematical models are represented by a 5×5-order square-shaped decision matrix and 5×11-order rectangular decision matrix, respectively, for MCDM-based numerical simulations.

6.2. Data Collection for This Research

This section discussed the data sources and their authenticity. Data sets were collected from four decision-makers (DMs) who are experts and unbiased in their decisions. DMs have given data in linguistic terms and transformed them into a crisp number using Table 4. Four decision-makers were considered from different fields, and DMs were a supply chain company chief executive officer (CEO), supply chain company general manager (GM), and a researcher and a professor researching the supply chain. All data are shown in a decision matrix format in Table 5 with the decision matrix based on criteria and sub-criteria in a combined form.

Table 5. Decision matrix between criteria and sub-criteria vs. alternative by DMs.

	Criteria and Sub-Criteria vs. Alternative	C_1	C_{1A}	C_{1B}	C_{1C}	C_2	C_{2A}	C_{2B}	C_3	C_{3A}	C_{3B}	C_4	C_{4A}	C_{4B}	C_5	C_{5A}	C_{5B}
DM_1	Company A (S_A)	MI	AMI	SMI	AMI	MI	SMI	SMI	AMI	LI	EI	SMI	MLI	SMI	LI	EI	LI
	Company B (S_B)	AMI	AMI	AMI	AMI	MI	EI	EI	MI	SLI	SLI	SMI	EI	SLI	EI	MLI	SLI
	Company C (S_C)	AMI	MMI	MMI	MMI	MI	SLI	SLI	AMI	MLI	LI	EI	SLI	EI	SLI	LI	EI
	Company D (S_D)	MI	MI	MI	AMI	AMI	LI	MLI	MI	SLI	SMI	MI	EI	LI	SMI	SMI	LI
	Company E (S_E)	MI	MI	MI	MMI	AMI	MLI	LI	SLI	MLI	EI	EI	SMI	MLI	EI	SLI	SMI

	Criteria and Sub-Criteria vs. Alternative	C_1	C_{1A}	C_{1B}	C_{1C}	C_2	C_{2A}	C_{2B}	C_3	C_{3A}	C_{3B}	C_4	C_{4A}	C_{4B}	C_5	C_{5A}	C_{5B}
DM_2	Company A (S_A)	SMI	MMI	MI	MMI	MMI	EI	EI	MI	MLI	SLI	SLI	SLI	SLI	SLI	SMI	EI
	Company B (S_B)	MMI	MI	MMI	MI	SMI	SMI	SLI	SMI	LI	LI	MLI	SMI	ALI	SLI	SLI	SMI
	Company C (S_C)	MMI	MMI	MI	MI	MMI	LI	EI	MI	ALI	MLI	SLI	LI	SLI	EI	EI	MLI
	Company D (S_D)	EI	SMI	MMI	SMI	MMI	SMI	SLI	MMI	LI	MLI	SMI	SLI	LI	MI	LI	SLI
	Company E (S_E)	MMI	MMI	MI	MI	MI	ALI	SMI	EI	SLI	LI	SLI	EI	SLI	SLI	SLI	SLI

	Criteria and Sub-Criteria vs. Alternative	C_1	C_{1A}	C_{1B}	C_{1C}	C_2	C_{2A}	C_{2B}	C_3	C_{3A}	C_{3B}	C_4	C_{4A}	C_{4B}	C_5	C_{5A}	C_{5B}
DM_3	Company A (S_A)	MMI	MI	EI	MI	MMI	SLI	SLI	SMI	ALI	LI	EI	LI	EI	MLI	SLI	SMI
	Company B (S_B)	MI	SMI	MI	AMI	MI	SMI	LI	EI	LI	MLI	LI	SLI	LI	SMI	EI	LI
	Company C (S_C)	MI	AMI	SMI	MMI	SMI	MLI	LI	SMI	MLI	ALI	SLI	EI	SMI	EI	SMI	ALI
	Company D (S_D)	SMI	MMI	AMI	MI	MI	LI	SMI	MI	SLI	SLI	SLI	MLI	SLI	SMI	MLI	SMI
	Company E (S_E)	MI	AMI	SMI	SMI	SMI	SLI	MI	SLI	MLI	EI	LI	ALI	EI	SLI	EI	EI

	Criteria and Sub-Criteria vs. Alternative	C_1	C_{1A}	C_{1B}	C_{1C}	C_2	C_{2A}	C_{2B}	C_3	C_{3A}	C_{3B}	C_4	C_{4A}	C_{4B}	C_5	C_{5A}	C_{5B}
DM_4	Company A (S_A)	MI	MMI	SMI	MMI	MI	LI	SMI	MI	LI	MLI	LI	EI	LI	SLI	LI	LI
	Company B (S_B)	MMI	MMI	MMI	MI	MMI	SLI	SLI	EI	SLI	SLI	SMI	MLI	SLI	EI	SLI	EI
	Company C (S_C)	SMI	MI	MMI	SMI	SLI	LI	MLI	MMI	EI	LI	EI	MLI	MLI	MI	EI	SLI
	Company D (S_D)	MI	SMI	SMI	MMI	MI	SLI	EI	SMI	LI	MLI	MLI	LI	EI	MLI	LI	MLI
	Company E (S_E)	MMI	MI	MI	MI	EI	SMI	SMI	LI	SLI	MLI	SLI	SLI	SMI	LI	SMI	SMI

7. Numerical Illustration and Discussion

The numerical calculations of this study are illustrated in this section. Two MCDM methodologies, namely, CRITIC and MULTIMOORA methods, were utilized here; mathematical steps are described in Section 3. A list of the data set referenced in Section 6 was used for further evaluation.

The CRITIC-based MCDM method determined the local weight of the criteria and sub-criteria and the theoretical techniques are explained in Section 3.1. All the weights are presented in Table 6.

Table 6. Different weights of the criteria and sub-criteria evaluated by CRITIC method.

Criteria and Sub-Criteria	Local Weight	Global Weight
Supply Chain Disruptions (C_1)	0.2361	0.2361
Pandemic Impact (C_{1A})	0.3636	0.0858
Geopolitical Tensions (C_{1B})	0.3304	0.0780
Natural Disasters (C_{1C})	0.3060	0.0723
Logistics Challenges (C_2)	0.2248	0.2248
Port Congestion (C_{2A})	0.4818	0.1083
Transportation Costs (C_{2B})	0.5182	0.1165
Demand and Supply Imbalances (C_3)	0.1554	0.1554
Fluctuating Demand (C_{3A})	0.5573	0.0866
Inventory Management (C_{3B})	0.4427	0.0688
Technological and Cybersecurity Issues (C_4)	0.1877	0.1877
Digital Transformation (C_{4A})	0.5430	0.1019
Cybersecurity Threats (C_{4B})	0.4570	0.0858
Sustainability and Ethical Sourcing (C_5)	0.1959	0.1959
Environmental Regulations (C_{5A})	0.5461	0.1070
Ethical Sourcing (C_{5B})	0.4539	0.0889

The CRITIC method is mathematically represented in Section 3.1 and the data set used in the numerical process is mentioned in Table 5. The decision matrices ($\mathscr{D}_d$ and $\mathscr{D}_d^{k_j}$) in linguistic terms are presented in Equations (1) and (2), which are data sets and were converted into crisp numbers ($\mathscr{D}_d^c$) by consulting Table 4 in Equation (3). Further, we aggregated the decision matrices ($\mathscr{D}_d^c$) from the DMs into one aggregated decision matrix ($\mathscr{D}^c$) by Equation (4), presented in Equation (5). Then, we normalized ($\mathscr{D}_n^c$) the aggregated decision matrix by Equation (6). After that, the standard deviation (σ_q) and linear correlation coefficient ($\mathscr{O}_{jj'}$) were evaluated by Equations (7) and (8), respectively. Next, the measure of the conflict ($\mathscr{E}_{jj'}$) was evaluated by Equation (9) and the quantity of the information (C_j) calculated by Equation (10). Finally, we determined the criteria and sub-criteria weight (C_j^{lw} and $C_{k_j}^{lw}$) using Equation (11), which is known as the local weight of the criteria and sub-criteria. Furthermore, we evaluated the global weights of criteria and sub-criteria (C_j^{gw} and $C_{k_j}^{gw}$) using Equation (13) and Equation (12), respectively.

All the weights of the criteria and sub-criteria are presented in Table 6. The Pi diagrams of the weight of the criteria and sub-criteria are depicted in Figure 2 and Figure 3, respectively.

Remark 1. *Table 6 and Figure 2 represent the weight of the criteria evaluated by the CRITIC method. We see that the most weighted criterion is Supply Chain Disruptions (C_1) with a weighted value of 0.2361; the second highest weighted criterion is Logistics Challenges (C_2), followed by Sustainability* *and Ethical Sourcing* (C_5), *Technological and Cybersecurity Issues* (C_4), *and Demand and Supply Imbalances* (C_3).

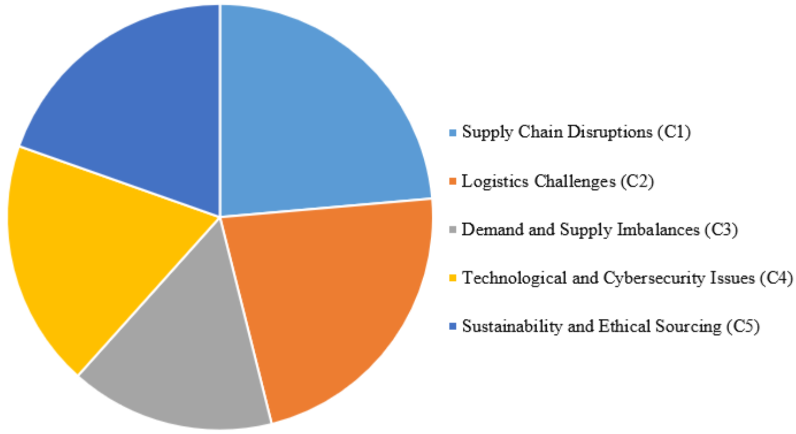

Figure 2. Pi diagram of the criteria weight evaluated by CRITIC method.

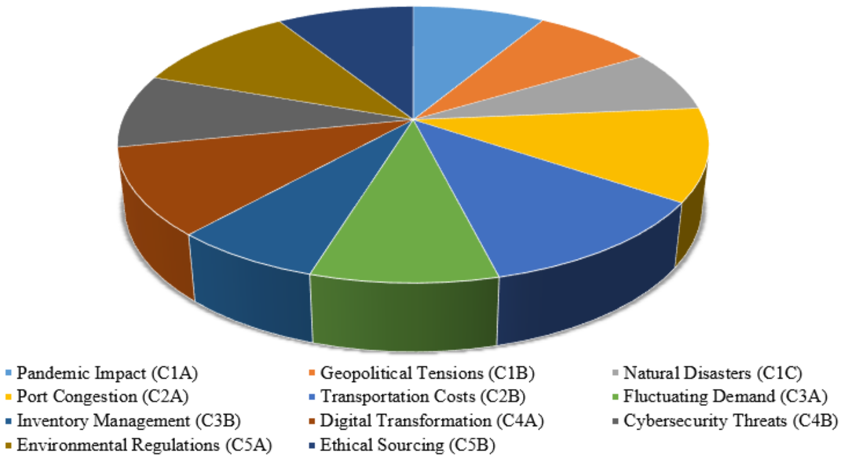

Figure 3. Pi structure of the sub-criteria weight determined by CRITIC technique.

Remark 2. *The local and global weights of the sub-criteria evaluated by the CRITIC methods are represented in Table 6 and the Pi diagram of the sub-criteria weights is graphically represented in Figure 3.*

The MULTIMOORA technique is an MCDM-based optimization method discussed in Section 3.2. This method was applied to the data set given in Section 6 and weights were determined in the previous section.

The MULTIMOORA method is theoretically described in Section 3.2 and the data set utilized in the mathematical computation is shown in Table 5. The aggregated decision matrix $(\mathscr{D}^c)$ determined in the CRITIC method by Equation (5) was processed using this method. Then, the normalized decision matrix $(\mathscr{D}_n^c)$ was evaluated using Equation (14) and the weighted normalized decision matrix $(C_j^{gw}$ and $C_{k_j}^{gw})$ was calculated by Equation (15). Further, we determined the ranking of alternatives by the MOORA ratio approach $(\mathscr{R}_i)$, MOORA significance coefficient approach $(\mathscr{S}_i)$, MOORA reference point approach $(\mathscr{P}_i)$, and MOORA full multiplication approach $(\mathscr{F}_i)$ by using Equations (16), (17), (18), and (20), respectively. Lastly, we calculated the alternatives by ranking by the MULTIMOORA approach method $(\mathscr{M}_i)$ using Equation (21).

Here, different MOORA method approaches are shown below. Table 7 represents the MOORA ratio approach of the alternatives and Table 8 shows the MOORA significance coefficient approach of the alternatives. Furthermore, Table 9 represents the MOORA reference point approach and Table 10 displays the r_j and r_{k_j} values for different criteria and sub-criteria. Additionally, the MOORA full multiplication approach of the alternatives is shown in Table 11. Finally, the rank of the alternatives by the MULTIMOORA method is presented in Table 12.

Table 7. MOORA ratio approach and associated data.

Alternative	$\sum_{j=1}^{q'} \mathscr{C}_{ij}^{w}$	$\sum_{j=q'+1}^{q} \mathscr{C}_{ij}^{w}$	$\mathscr{R}_i$	Ranking
Company A	0.6734	0.2233	0.4501	5
Company B	0.7059	0.2113	0.4946	2
Company C	0.6991	0.1626	0.5364	1
Company D	0.6796	0.2053	0.4744	4
Company E	0.6743	0.1899	0.4844	3

Table 8. MOORA significance coefficient approach and associated data.

Alternative	$\sum_{j=1}^{q'} \left(\mathcal{S}_j^c \times \mathscr{C}_{ij}^{w}\right)$	$\sum_{j=q'+1}^{q} \left(\mathcal{S}_j^c \times \mathscr{C}_{ij}^{w}\right)$	$\mathscr{S}_i$	Ranking
Company A	0.0949	0.0372	0.0577	5
Company B	0.1016	0.0349	0.0666	2
Company C	0.1031	0.0281	0.0750	1
Company D	0.0966	0.0355	0.0611	4
Company E	0.0947	0.0321	0.0625	3

Table 9. MOORA reference point approach and associated data.

Alternative	$\mathscr{P}_i = \sum_{j=1}^{q} \left\| r_j - \mathscr{C}_{ij}^{w} \right\|$	Ranking
Company A	0.1776	1
Company B	0.1331	4
Company C	0.0913	5
Company D	0.1534	2
Company E	0.1433	3

Table 10. The r_j and r_{k_j} values for different criteria and sub-criteria for MOORA reference point approach.

Criteria	r_j Value	Sub-Criteria	r_{k_j} Value
Supply Chain Disruptions (C_1)	0.1164	Pandemic Impact (C_{1A})	0.0404
		Geopolitical Tensions (C_{1B})	0.0392
		Natural Disasters (C_{1C})	0.0343
Logistics Challenges (C_2)	0.0871	Port Congestion (C_{2A})	0.0327
		Transportation Costs (C_{2B})	0.0393
Demand and Supply Imbalances (C_3)	0.0809	Fluctuating Demand (C_{3A})	0.0470
		Inventory Management (C_{3B})	0.0351
Technological and Cybersecurity Issues (C_4)	0.0898	Digital Transformation (C_{4A})	0.0521
		Cybersecurity Threats (C_{4B})	0.0446
Sustainability and Ethical Sourcing (C_5)	0.1015	Environmental Regulations (C_{5A})	0.0543
		Ethical Sourcing (C_{5B})	0.0513

Table 11. MOORA full multiplication approach and associated data.

Alternative	$\prod_{j=1}^{q'} \mathscr{C}_{ij}^{w}$	$\prod_{j=q'+1}^{q} \mathscr{C}_{ij}^{w}$	$\mathscr{F}_i$	Ranking
Company A	6.4254×10^{-15}	3.5863×10^{-4}	1.7916×10^{-4}	5
Company B	10.0959×10^{-15}	3.0157×10^{-4}	3.3478×10^{-4}	3
Company C	4.9364×10^{-15}	1.2399×10^{-4}	3.9814×10^{-4}	1
Company D	6.8000×10^{-15}	2.4700×10^{-4}	2.7531×10^{-4}	4
Company E	7.4116×10^{-15}	1.9329×10^{-4}	3.8345×10^{-4}	2

Table 12. Ranking of the alternatives by MULTIMOORA method.

Alternative	Different MOORA Methods				MULTIMOORA	
	Ratio Approach	Significance Coefficient Approach	Reference Point Approach	Full Multiplication Approach	$\mathscr{M}_i$	Ranking
Company A	5	5	1	5	−0.2667	5
Company B	2	2	4	3	0.0667	2
Company C	1	1	5	1	0.2667	1
Company D	4	4	2	4	−0.1333	4
Company E	3	3	3	2	0.0667	3

Remark 3. *From Table 12, we have Company C obtain the optimal alternative for SCM. Furthermore, Company B occupies the second optimal alternative, followed by Company E, Company D, and Company A. The graphical representation of the alternatives is represented in Figure 4.*

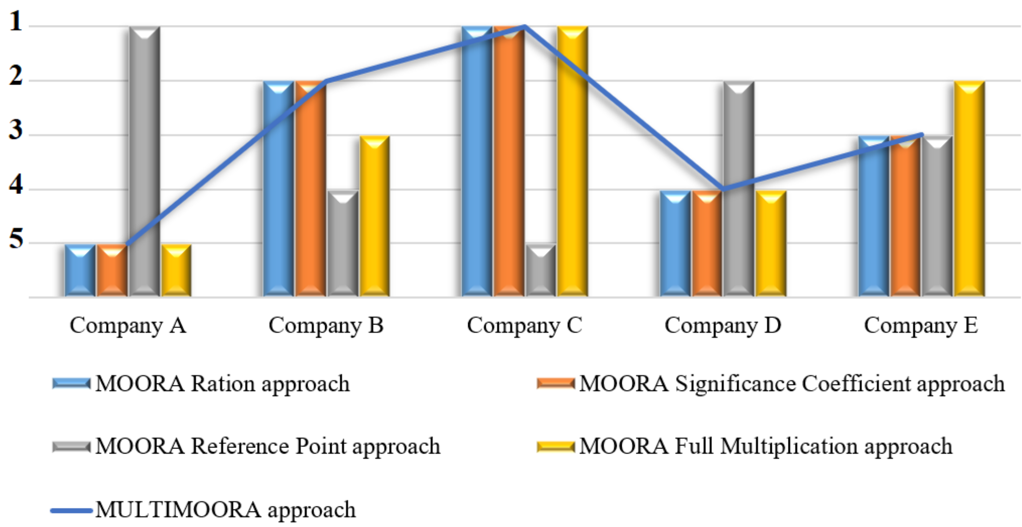

Figure 4. Comparative ranking analysis of MULTIMOORA method.

7.1. Managerial Insights Based on Numerical Results

Managerial insights for applying the above-mentioned approaches emphasize the value of structured models and clear decision processes that balance both quantitative and qualitative factors. Furthermore, by prioritizing criteria associated with planned goals, managers can justify the proper decisions, involve key investors, and increase resource allocation efficiency.

7.1.1. Managerial Insights Based on the Criterion Weight

A hierarchy can be derived for the weights of criteria involved in supply chain management. It is perceived that Supply Chain Disruptions (C_1) gain supremacy among the listed criteria in this article. The result can be decoded as "continuation of supply flow through diminishing operational hazards should be prioritized first". Then, Logistics Challenges (C_2) are ranked second in the hierarchical positions. This observation reflects the significance of smooth coherence between warehouses and distribution centers through an effective supply chain. Sustainability and Ethical Sourcing (C_5) have the third rank among the criteria in the list based on priorities. This can be interpreted through the significance of ethical sourcing and environmentally friendly economic advancements. Along with these primary concerns, Technological and Cybersecurity Issues (C_4) follow the list as secondary criteria. Finally, Demand and Supply Imbalances (C_3) occupy the bottom of the list. This can be explained by the fact that the concern regarding the discordance between consumption and supply gains less importance during supply chain management policy. In the following subsection, we will discuss the ordering for sub-criterion weights involved in different criteria.

(a). Managerial insights based on the sub-criterion weight for (C_1):
Pandemic Impact (C_{1A}) is perceived to be the most significant one with the highest weight among the sub-criteria under the Supply Chain Disruptions (C_1) criterion. It influences the supply chain networks rapidly with impulsive impacts. Geopolitical Tensions (C_{1B}), due to political volatility and conflicts among nation states, come in the second position among sub-criterion regarding the disruption of the supply network. Natural Disasters (C_{1C}) also impact the supply network with lower intensity and weaker measures. So, the manager of the supply chain must be concerned about the devastating impact of pandemics and the risk of conflict in international borders.

(b). Managerial insights based on the sub-criterion weight for (C_2):
Logistics Challenges (C_2) is one of the impactful criteria in supply chain phenomena, which includes several sub-criteria. Transportation Costs (C_{2B}) are the most fundamental concerns among the list of sub-criteria. The issue has direct impacts on controlling costs and optimizing the profitability goal. Port Congestion (C_{2A}) comes as a secondary issue within the list and corresponds to the negative impacts on the supply network due to delays and bottlenecks at ports. The managerial insights are perceived here to be that the decision-maker should go through the smart communication, bargaining, and economic transaction approach to reduce the transportational cost in an effective supply chain.

(c). Managerial insights based on the sub-criterion weight for (C_3):
The coherence between supply and demand may be disrupted due to either fluctuating demand or inappropriate inventory management. So, Fluctuating Demand (C_{3A}) is viewed as the fundamental sub-criterion included in the Demand and Supply Imbalances (C_3) criterion. Demand forecasting in unpredictable market situations is perceived the most crucial managerial job in this regard. Inventory Management (C_{3B}) emerges as the secondary concern in this category because supply and demand stability may be disrupted due to insufficient or excessive amounts of inventory in warehouses and showrooms.

(d). Managerial insights based on the sub-criterion weight for (C_4):
Digital Transformation (C_{4A}) and Cybersecurity Threats (C_{4B}) occupy the consecutive two places in the hierarchical list within the Technological and Cybersecurity Issues (C_4) criterion. It is evident that policy makers associated with the supply chain network should prioritize the digital transformation initiatives through the incorporation of artificial intelligence, data analytics, and other contemporary advancements. The secondary concern should be for Cybersecurity Threats (C4B) for encrypting digital transactions and communications.

(e). Managerial insights based on the sub-criterion weight for (C_5):
Environmental Regulations (C_{5A}) should be the most crucial issue under the Sustain-

ability and Ethical Sourcing (C_5) criterion because the economic advancements will be sustainable when managerial policies become concerned with the environment. Immediate priority is given to the Ethical Sourcing (C_{5B}) sub-criterion because maintenance of regulatory standard is an essential prerequisite for sustainable growth in a legal context.

7.1.2. Managerial Insights Based on the Alternative Ranking

By the proposed approaches, any decision-maker may conclude which company is best for supply chain management. Unlike the traditional ranking method, this proposed methodology can provide deeper viewpoints by taking many variables such as cost, time, quality, and risk, into account; as a result, by using the ideology, a manager has a greater ability to evaluate different companies.

7.2. Computational Complexity

This section describes the computational complexity (as in [84]) of the proposed CRITIC MULTIMOORA-based MCDM model. The concept of computational complexity is the number of numerical calculations conducted to get the final results. It is also known as Time Complexity (T^c) and is calculated in this study. Here, we consider q to be number of criteria, s_j the number of sub-criteria associated with a p number of alternatives to construct a decision matrix, and n to be the number of decision-makers giving the required data. Then, the computational complexity of this study was calculated as follows:

1. For the CRITIC technique, the decision matrix had $p \times q$ entries with an n number of decision-makers giving npq entries. To find the aggregated decision matrix, another $p \times q$ operation was performed. Further, we normalized the decision matrix by performing $p \times q + 2q$ operations. We found the standard deviation and correlation coefficient's total of $p \times q + q$ operation conducted. To determine the quantity of information, $p \times q + 2p$ operations were performed. Finally, we evaluated the criteria weight by conducting another $p + 1$ operation. Therefore, a total of $npq + pq + pq + 2q + pq + q + pq + 2p + p + 1 = (n+1)pq + 3(p+q) + 1$ operations were conducted to determine the criteria weight. Additionally, we evaluated the sub-criteria weight of the criteria j by performing $(n+1)ps_j + 3(p+s_j) + 1$ operations.
2. To determine the global weight, an $s_j + q$ number of mathematical operations were performed.
3. For the MULTIMOORA method, the decision matrix had $p \times s_j$ entries with an n number of decision-makers giving nps_j entries for the criteria j. To find the aggregated decision matrix, another $p \times s_j$ operation was performed. Further, we normalized the decision matrix by performing $p \times s_j + 2s_j$ operations. After that, we determine the weighted normalized decision matrix by another $p \times s_j$ operations. For the MOORA ratio approach, there were $4p$ operations performed and, in the MOORA significance coefficient approach, $s_j + 4p$ operations were also conducted. Further, in the MOORA reference point approach, there were $s_j + 2p$ operations conducted and, in the MOORA full multiplication approach, $4p$ operations were also performed. Finally, in the MULTIMOORA approach, there were $2p$ operations conducted. Therefore, a total of $nps_j + ps_j + ps_j + 2s_j + ps_j + 4p + s_j + 4p + s_j + 2p + 4p + 2p = (n+3)ps_j + 4s_j + 16p$ operations were performed.

The Time Complexity (T^c) of this research is calculated for criteria $q = 5$, sub-criteria $s_j = 11$, alternatives $p = 5$ and decision-makers $n = 4$ for the present problem as follows:

a. For the CRITIC method, the number of calculations conducted for criteria is $(4+1) \times 5 \times 5 + 3 \times (5+5) + 1 = 156$, and for sub-criteria is $(4+1) \times 5 \times 11 + 3 \times (5+11) + 1 = 324$. The total mathematical calculation performed for CRITIC techniques is 480.

b. For global weights of the criteria and sub-criteria, total $11 + 5 = 16$ operations were conducted.

c. For the MULTIMOORA method, the total number of numerical operations conducted is $(5+3) \times 5 \times 11 + 4 \times 11 + 16 \times 5 = 564$

Then, the Time Complexity (T^c) of this study is $480 + 16 + 564 = 1060$.

8. Sensitivity Analysis and Comparative Analysis

This section describes the sensitivity analysis and comparative analysis in detail. First, the sensitivity analysis (as in [9]) was conducted, followed by a comparative analysis (as in [10]) with graphical representations.

8.1. Sensitivity Analysis

The sensitivity analysis of this study was performed to check the stability and flexibility of the results. There were five cases conducted by removing criteria-changing weights, interchanging criteria weights, or interchanging beneficial and non-beneficial criteria themselves. Different sensitivity cases are described as follows.

8.1.1. Case 1: Remove Criterion Technological and Cybersecurity Issues (C_4)

In this section, we conducted a sensitivity analysis by removing the fourth criterion and associated sub-criteria of Technological and Cybersecurity Issues (C_4). The alternatives' ranking by removing criteria is represented in Table 13.

8.1.2. Case 2: Removing Criterion Sustainability and Ethical Sourcing (C_5)

This section describes a sensitivity analysis by removing the fifth criterion and its sub-criteria of Sustainability and Ethical Sourcing (C_5). The ranking of the alternatives in the new system is shown in Table 13.

Table 13. Ranking of the alternatives by different sensitivity analysis cases.

Alternative	Case 1	Case 2	Proposed Method
Company A	5	5	5
Company B	1	2	2
Company C	2	1	1
Company D	4	4	4
Company E	3	2	2

8.1.3. Case 3: Consider Criteria Supply Chain Disruptions (C_1) as Non-Beneficial Criteria

This section conducts a sensitivity analysis by changing the first criterion Supply Chain Disruptions (C_1) to non-beneficial criteria from beneficial criteria. The alternatives' ranking by the updated model are depicted in Table 14.

Table 14. Alternative ranking by different sensitivity analysis cases.

Alternative	Case 3	Case 4	Case 5	Proposed Method
Company A	4	2	5	5
Company B	5	1	2	2
Company C	2	5	1	1
Company D	1	3	4	4
Company E	3	4	3	2

8.1.4. Case 4: Consider Criteria Logistics Challenges (C_2) as Beneficial Criteria

In this section, we carried out a sensitivity analysis by exchanging the second criterion Logistics Challenges (C_2) as beneficial criteria for non-beneficial criteria. The results of alternatives' ranking are listed in Table 14.

8.1.5. Case 5: Interchange Criteria Weight between Demand and Supply Imbalances (C_3) and Sustainability and Ethical Sourcing (C_5)

In this section, a sensitivity analysis was conducted by interchanging the weight of the criteria and sub-criteria, respectively, between the two criteria Demand and Supply Imbalances (C_3) and Sustainability and Ethical Sourcing (C_5). The alternative ranking by the modified model is shown in Table 14.

Remark 4. *There were five cases that were conducted for sensitivity analysis and the results are shown in Tables 13 and 14. From the above cases, Case 2 is the most stable case. The graphical representation of the alternative rankings with the proposed model is pictured in Figure 5.*

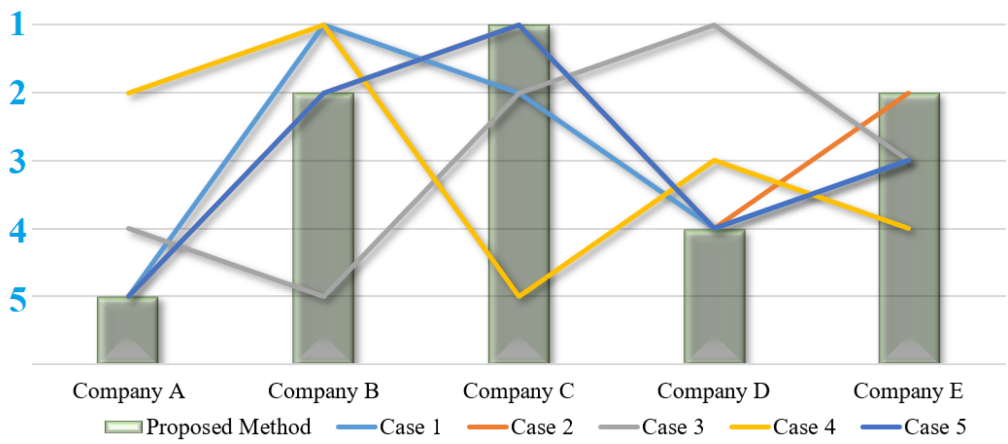

Figure 5. Sensitivity analysis of MULTIMOORA method.

8.2. Comparative Analysis

This section conducted a comparative analysis of different MCDM methods and an analysis of the alternatives ranking. There were two MCDM methods utilized here, namely the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [24] and Complex Proportional Assessment (COPRAS) [61] methods. All alternative ranks are identical to the proposed model shown in Table 15.

Table 15. Comparative ranking of the alternatives by different MCDM methods.

Alternative	TOPSIS	COPRAS	MULTIMOORA
Company A	5	5	5
Company B	2	2	2
Company C	1	1	1
Company D	4	4	4
Company E	3	3	3

Remark 5. *The comparative ranking of the alternatives by different MCDM methods is shown in Table 15. The results are the same as the proposed MULTIMOORA method, which is also depicted graphically in Figure 6.*

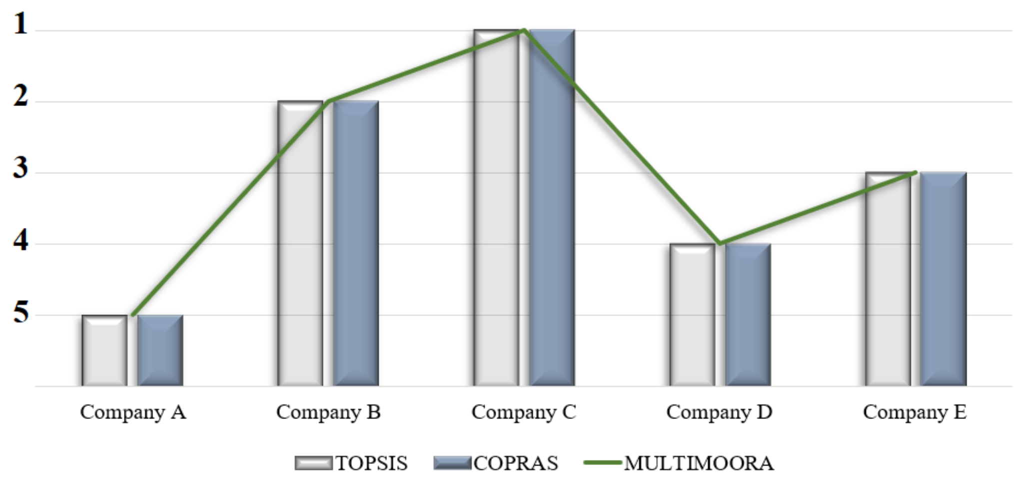

Figure 6. Comparative analysis by various MCDM-based optimization techniques.

9. Conclusions and Future Research Scope

In this paper, we have contributed a ranking-based analysis on the performances and challenges associated with supply chains. Several challenges like disruptions in supply chains, logistics constraints, lack of coherence between asking consumption rate and availability of the products, and technological, ethical sourcing-based challenges are present in supply chain phenomena. We accumulated the challenges as criteria in a mathematical analysis using the multi-criteria decision-making (MCDM) approach. The CRITIC method was used for manipulating both the local and global weights for such criteria and some significant sub-criteria. Some well-known e-commerce companies were considered as alternatives in MCDM phenomena. The ranking of the alternatives was conducted through the MULTIMOORA method.

The CRITIC-based numerical approach in the MCDM scenario obtained a decreasing order of weights among the criteria as follows: supply chain disruptions (C_1) > logistics challenges (C_2) > sustainability and ethical sourcing (C_5) > technological and cybersecurity issues (C_4) > demand and supply imbalances (C_3). The global weights of the criteria and sub-criteria were derived using the local weights. Furthermore, the MULTIMOORA-based numerical simulation obtained the ranking of the alternatives as follows: Company C > Company B > Company E > Company D > Company A. Additionally, we performed a sensitivity analysis and comparative analysis to check the system's stability and vagueness.

There are several scopes for extending the research work in the future. Further advancements can be done in the following directions:

1. The present research work has been carried out in a deterministic environment, which is not the case for real business phenomena. A real business management scenario contains several types of uncertainties regarding data manipulation and decision-making. So, fuzzy and other types of uncertain environments may be considered in such a ranking-based analysis for reliable outcomes.
2. Here, we have used the CRITIC method for obtaining weights regarding criteria and sub-criteria and the MULTIMOORA method for ranking the alternatives. However, similar kinds of problems can be analyzed using MCDM methods like AHP, entropy, and Stepwise Weight Assessment Ratio Analysis (SWARA) for criterion and sub-criterion weights and WASPAS, CoCoSo, VIKOR, and ELECTRE methods for ranking alternatives.
3. This paper has a specific focus on challenges and performances of e-commerce-based communications. Other supply chain models regarding retail and manufacturing organization, health care systems, and so on can be formulated using the proposed approach.
4. The performance of the supply chain networks may be evaluated with sustainable development goals (SDGs) as fundamental concerns in the future.

5. One of the limitations of this present study is that we have only addressed a few criteria and sub-criteria in the MCDM model, which have many impacts. However, there are several less impacting challenges in supply chain scenarios, which have been ignored for the sake of simplicity in this initial work. These challenges should be addressed for increased insights into business phenomena in future research works.

Author Contributions: Conceptualization, A.F.M., K.H.G., M.R. and S.S.; Methodology, A.F.M., K.H.G., M.R. and A.S.; Formal analysis, A.F.M., K.H.G. and S.P.M.; Resources, A.F.M., M.R. and A.G.; Software, K.H.G., M.R. and S.S.; Investigation, A.F.M., K.H.G., A.S., S.S. and S.P.M.; Validation, A.F.M., K.H.G. and M.R.; Writing—original draft preparation, K.H.G., M.R. and S.P.M.; Writing—review and editing, A.F.M., A.S., S.S., S.P.M. and A.G.; Supervision, K.H.G., S.S., S.P.M. and A.G.; Funding acquisition, A.F.M. These authors contributed equally to this work. All authors have read and agreed to the published version of the manuscript.

Funding: This study is supported via funding from Prince Sattam Bin Abdulaziz University project number (PSAU/2024/R/1445).

Data Availability Statement: All the necessary data are cited in the article.

Conflicts of Interest: The authors declare that they have no known conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper. There are no conflicts of interest between authors.

Abbreviations

The following acronyms or abbreviations were used in this study:

Acronyms	Full Name
3D	Three Dimensions
3PL	Third-Party Logistics
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
ARAS	Additive Ratio Assessment
BCauotSCF	Blockchain auto Supply Chain Finance
BDS	Blockchain-based Data Storage Scheme
BOMILP	Bi-Objective Mixed Integer Linear Programming
BWM	Best–Worst Method
CCSD	Correlation Coefficient and Standard Deviation
CEO	Chief executive officer
CEP	Corporate environmental performance
CNC	Computer numerical control
CoCoSo	Combined Compromise Solution
CODAS	Combinative Distance-based ASsesment
COPRAS	Complex Proportional Assessment
COVID-19	Coronavirus disease 2019
CRITIC	Criteria importance through inter-criteria correlation
CV	Crisp value
DEMATEL	Decision-making Trial and Evaluation Laboratory
DHL	Dalsey, Hillblom, and Lynn
DM	Decision-maker
DMASR	Discrete multi-arc shaped ribs
DMIO	Data-driven Multi-Index Overlay Method
DSS	Decision support system
E-commerce	Electronic Commerce
EDAS	Enterprise Distributed Application Service
ELECTRE	ELimination and Choice Expressing REality
EVCS	Electric Vehicle Charging Stations
FCEM	Fuzzy Comprehensive Evaluation Model
FDM	Fused Deposition Modeling

Acronyms	Full Name
FG	For group decision-making
FMEA	Failure Mode and Effect Analysis
FWTM	Food waste treatment method
GM	General manager
GRP	Grey Relational Projection
GSS	Green supplier selection
IFS	Intuitionistic fuzzy set
IT	Information technology
MARCOS	Measurement of Alternatives and Ranking according to COmpromise Solution
MCDM	Multi-criteria decision-making
MOORA	Multi-Objective Optimization on the basis of Ratio Analysis
MULTIMOORA	Multiple objective optimization on the basis of ratio analysis plus full multiplicative form
NA	Not applicable
PFS	Pythagorean fuzzy set
PUL-MAGDM	Probabilistic uncertain linguistic multiple attribute group decision-making
R134a	(Chemical Designation: 1,1,1,2-tetrafluoroethane) A hydrofluorocarbon
REGIME	Row Geometric Mean Method
RFID	Radio Frequency Identification
S3PRLP	Sustainable Third-Party Reverse Logistics Providers
SAHS	Solar Air Heating System
SC	Supply chain
SCCs	Supply chain companies
SCM	Supply chain management
SCOR	Supply Chain Operations Reference
SD	Standard deviation
SDGs	Sustainable development goals
SSCRM	Sustainable supply chain risk management
SWARA	Stepwise Weight Assessment Ratio Analysis
SWD	Solid waste disposal
TOPSIS	Technique for Order Preference by Similarity to the Ideal Solution
VIKOR	VIekriterijumsko KOmpromisno Rangiranje
WAAM	Wire Arc Additive Manufacturing
WASPAS	Weighted Aggregated Sum Product Assessment
WHT	Wearable health technology

References

1. Riahi, Y.; Saikouk, T.; Gunasekaran, A.; Badraoui, I. Artificial intelligence applications in supply chain: A descriptive bibliometric analysis and future research directions. *Expert Syst. Appl.* **2021**, *173*, 114702. [CrossRef]
2. Kim, J.S.; Shin, N. The Impact of Blockchain Technology Application on Supply Chain Partnership and Performance. *Sustainability* **2019**, *11*, 6181. [CrossRef]
3. Soheilirad, S.; Govindan, K.; Mardani, A.; Zavadskas, E.K.; Nilashi, M.; Zakuan, N. Application of data envelopment analysis models in supply chain management: A systematic review and meta-analysis. *Ann. Oper. Res.* **2018**, *271*, 915–969. [CrossRef]
4. Erceg, Ž.; Mularifović, F. Integrated MCDM model for processes optimization in the supply chain management in the wood company. *Oper. Res. Eng. Sci. Theory Appl.* **2019**, *2*, 37–50. [CrossRef]
5. Büyüközkan, G.; Güler, M. A combined hesitant fuzzy MCDM approach for supply chain analytics tool evaluation. *Appl. Soft Comput.* **2021**, *112*, 107812. [CrossRef]
6. Parthiban, P.; Mathiyalagan, P.; Punniyamoorthy, M.; Dominic, P. Optimisation of supply chain performance using MCDM tool—A case study. *Int. J. Value Chain Manag.* **2010**, *4*, 240–255. [CrossRef]
7. Sufiyan, M.; Haleem, A.; Khan, S.; Khan, M.I. Evaluating food supply chain performance using hybrid fuzzy MCDM technique. *Sustain. Prod. Consum.* **2019**, *20*, 40–57. [CrossRef]
8. Khan, S.; Khan, M.I.; Haleem, A.; Jami, A.R. Prioritising the risks in Halal food supply chain: An MCDM approach. *J. Islam. Mark.* **2022**, *13*, 45–65. [CrossRef]
9. Momena, A.F.; Gazi, K.H.; Mukherjee, A.K.; Salahshour, S.; Ghosh, A.; Mondal, S.P. Adaptation Challenges of Edge Computing Model in Educational Institute. *J. Intell. Fuzzy Syst.* **2024**, 1–18. [CrossRef]
10. Gazi, K.H.; Momena, A.F.; Salahshour, S.; Mondal, S.P.; Ghosh, A. Synergistic Strategy of Sustainable Hospital Site Selection in Saudi Arabia Using Spherical Fuzzy MCDM Methodology. *J. Uncertain Syst.* **2024**, *17*, 2450004. [CrossRef]

11. Dutta, P.; Choi, T.M.; Somani, S.; Butala, R. Blockchain technology in supply chain operations: Applications, challenges and research opportunities. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *142*, 102067. [CrossRef]
12. Min, H. Artificial intelligence in supply chain management: Theory and applications. *Int. J. Logist. Res. Appl.* **2010**, *13*, 13–39. [CrossRef]
13. Ivanov, D.; Sethi, S.; Dolgui, A.; Sokolov, B. A survey on control theory applications to operational systems, supply chain management, and Industry 4.0. *Annu. Rev. Control* **2018**, *46*, 134–147. [CrossRef]
14. Blossey, G.; Eisenhardt, J.; Hahn, G.J. Blockchain Technology in Supply Chain Management: An Application Perspective. *AIS Affil. Conf.* **2019**, *52*, 6885–6893.
15. Leung, J.; Cheung, W.; Chu, S.C. Aligning RFID applications with supply chain strategies. *Inf. Manag.* **2014**, *51*, 260–269. [CrossRef]
16. Sellitto, M.A.; Pereira, G.M.; Borchardt, M.; da Silva, R.I.; Viegas, C.V. A SCOR-based model for supply chain performance measurement: Application in the footwear industry. *Int. J. Prod. Res.* **2015**, *53*, 4917–4926. [CrossRef]
17. Ahmadi, A.; Mousazadeh, M.; Torabi, S.A.; Pishvaee, M.S. OR Applications in Pharmaceutical Supply Chain Management. *Oper. Res. Appl. Health Care Manag.* **2017**, *262*, 461–491. [CrossRef]
18. Chen, J.; Cai, T.; He, W.; Chen, L.; Zhao, G.; Zou, W.; Guo, L. A Blockchain-Driven Supply Chain Finance Application for Auto Retail Industry. *Entropy* **2020**, *22*, 95. [CrossRef]
19. Genovese, A.; Acquaye, A.A.; Figueroa, A.; Koh, S.L. Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega* **2017**, *66*, 344–357. [CrossRef]
20. Raoui, H.E.; Oudani, M.; Alaoui, A.E.H. Coupling Soft Computing, Simulation and Optimization in Supply Chain Applications: Review and Taxonomy. *IEEE Access* **2020**, *8*, 31710–31732. [CrossRef]
21. Diakoulaki, D.; Mavrotas, G.; Papayannakis, L. Determining objective weights in multiple criteria problems: The CRITIC method. *Comput. Oper. Res.* **1995**, *22*, 763–770. [CrossRef]
22. Peng, X.; Zhang, X.; Luo, Z. Pythagorean fuzzy MCDM method based on CoCoSo and CRITIC with score function for 5G industry evaluation. *Artif. Intell. Rev.* **2019**, *53*, 3813–3847. [CrossRef]
23. Ghorabaee, M.K.; Amiri, M.; Zavadskas, E.K.; Antuchevičienė, J. Assessment of third-party logistics providers using a CRITIC–WASPAS approach with interval type-2 fuzzy sets. *Transport* **2017**, *32*, 66–78. [CrossRef]
24. Rostamzadeh, R.; Ghorabaee, M.K.; Govindan, K.; Esmaeili, A.; Nobar, H.B.K. Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS- CRITIC approach. *J. Clean. Prod.* **2018**, *175*, 651–669. [CrossRef]
25. Ali, J. A novel score function based CRITIC-MARCOS method with spherical fuzzy information. *Comput. Appl. Math.* **2021**, *40*, 280. [CrossRef]
26. Mohamadghasemi, A.; Hadi-Vencheh, A.; Lotfi, F.H. The multiobjective stochastic CRITIC–TOPSIS approach for solving the shipboard crane selection problem. *Int. J. Intell. Syst.* **2020**, *35*, 1570–1598. [CrossRef]
27. Wang, S.; Wei, G.; Lu, J.; Wu, J.; Wei, C.; Chen, X. GRP and CRITIC method for probabilistic uncertain linguistic MAGDM and its application to site selection of hospital constructions. *Soft Comput.* **2022**, *26*, 237–251. [CrossRef]
28. Haktanır, E.; Kahraman, C. A novel picture fuzzy CRITIC & REGIME methodology: Wearable health technology application. *Eng. Appl. Artif. Intell.* **2022**, *113*, 104942. [CrossRef]
29. Ertemel, A.V.; Menekse, A.; Akdag, H.C. Smartphone Addiction Assessment Using Pythagorean Fuzzy CRITIC-TOPSIS. *Sustainability* **2023**, *15*, 3955. [CrossRef]
30. Kaur, G.; Dhara, A.; Majumder, A.; Sandhu, B.S.; Puhan, A.; Adhikari, M.S. A CRITIC-TOPSIS MCDM Technique under the Neutrosophic Environment with Application on Aircraft Selection. *Contemp. Math.* **2023**, *4*, 1180–1203. [CrossRef]
31. Chaurasiya, R.; Jain, D. Hybrid MCDM method on pythagorean fuzzy set and its application. *Decis. Mak. Appl. Manag. Eng.* **2023**, *6*, 379–398. [CrossRef]
32. Menekse, A.; Ertemel, A.V.; Akdag, H.C.; Gorener, A. Additive manufacturing process selection for automotive industry using Pythagorean fuzzy CRITIC EDAS. *PLoS ONE* **2023**, *18*, e0282676. [CrossRef] [PubMed]
33. Krishnan, A.R.; Kasim, M.M.; Hamid, R.; Ghazali, M.F. A Modified CRITIC Method to Estimate the Objective Weights of Decision Criteria. *Symmetry* **2021**, *13*, 973. [CrossRef]
34. Rani, P.; Mishra, A.R.; Krishankumar, R.; Ravichandran, K.; Kar, S. Multi-criteria food waste treatment method selection using single-valued neutrosophic-CRITIC-MULTIMOORA framework. *Appl. Soft Comput.* **2021**, *111*, 107657. [CrossRef]
35. Alrababah, S.A.A.; Gan, K.H. Effects of the Hybrid CRITIC–VIKOR Method on Product Aspect Ranking in Customer Reviews. *Appl. Sci.* **2023**, *13*, 9176. [CrossRef]
36. Shanthi, S.A.; Umamakeswari, T.; Saranya, M. MCDM method on complex picture fuzzy soft environment. *Mater. Proc.* **2022**, *51*, 2375–2379. [CrossRef]
37. Liu, Q. TOPSIS Model for evaluating the corporate environmental performance under intuitionistic fuzzy environment. *Int. J. Knowl.-Based Intell. Eng. Syst.* **2022**, *26*, 149–157. [CrossRef]
38. Liu, P.; Saha, A.; Mishra, A.R.; Rani, P.; Dutta, D.; Baidya, J. A BCF–CRITIC–WASPAS method for green supplier selection with cross-entropy and Archimedean aggregation operators. *J. Ambient Intell. Humaniz. Comput.* **2022**, *14*, 11909–11933. [CrossRef]
39. Mishra, A.R.; Rani, P.; Pandey, K. Fermatean fuzzy CRITIC-EDAS approach for the selection of sustainable third-party reverse logistics providers using improved generalized score function. *J. Ambient Intell. Humaniz. Comput.* **2021**, *13*, 295–311. [CrossRef]

40. Mete, S. Assessing occupational risks in pipeline construction using FMEA-based AHP-MOORA integrated approach under Pythagorean fuzzy environment. *Hum. Ecol. Risk Assess. Int. J.* **2019**, *25*, 1645–1660. [CrossRef]
41. Maity, M.; Mondal, J.K.; Das, S.; Das, S. ANP–MOORA-Based Approach for Selection of FDM 3D Printer Filament. In *Advances in Additive Manufacturing and Metal Joining*; Springer: Singapore, 2023; pp. 29–42. [CrossRef]
42. Yagmahan, B.; Yılmaz, H. An integrated ranking approach based on group multi-criteria decision making and sensitivity analysis to evaluate charging stations under sustainability. *Environ. Dev. Sustain.* **2023**, *25*, 96–121. [CrossRef]
43. Miç, P.; Antmen, Z.F. A Decision-Making Model Based on TOPSIS, WASPAS, and MULTIMOORA Methods for University Location Selection Problem. *Sage Open* **2021**, *11*, 1–18. [CrossRef]
44. Poongavanam, G.; Sivalingam, V.; Prabakaran, R.; Salman, M.; Kim, S.C. Selection of the best refrigerant for replacing R134a in automobile air conditioning system using different MCDM methods: A comparative study. *Case Stud. Therm. Eng.* **2021**, *27*, 101344. [CrossRef]
45. Brauers, W.K.M.; Zavadskas, E.K. Project management by MULTIMOORA as an instrument for transition economies. *Technol. Econ. Dev. Econ.* **2010**, *16*, 5–24. [CrossRef]
46. Brauers, W.K.M.; Zavadskas, E.K. Multimoora Optimization Used to Decide on a Bank Loan to Buy Property. *Technol. Econ. Dev. Econ.* **2011**, *17*, 174–188. [CrossRef]
47. Brauers, W.K.M.; Zavadskas, E.K. Robustness of MULTIMOORA: A Method for Multi-Objective Optimization. *Informatica* **2012**, *23*, 1–25. [CrossRef]
48. Dahooie, J.H.; Zavadskas, E.; Firoozfar, H.; Vanaki, A.; Mohammadi, N.; Brauers, W. An improved fuzzy MULTIMOORA approach for multi-criteria decision making based on objective weighting method (CCSD) and its application to technological forecasting method selection. *Eng. Appl. Artif. Intell.* **2019**, *79*, 114–128. [CrossRef]
49. Hafezalkotob, A.; Hafezalkotob, A. Comprehensive MULTIMOORA method with target-based attributes and integrated significant coefficients for materials selection in biomedical applications. *Mater. Des.* **2015**, *87*, 949–959. [CrossRef]
50. Mandal, U.K.; Sarkar, B. Selection of Best Intelligent Manufacturing System (IMS) Under Fuzzy Moora Conflicting MCDM Environment. *Int. J. Emerg. Technol. Adv. Eng.* **2012**, *2*, 301–310.
51. Zhang, C.; Chen, C.; Streimikiene, D.; Balezentis, T. Intuitionistic fuzzy MULTIMOORA approach for multi-criteria assessment of the energy storage technologies. *Appl. Soft Comput.* **2019**, *79*, 410–423. [CrossRef]
52. Lin, M.; Huang, C.; Xu, Z. MULTIMOORA based MCDM model for site selection of car sharing station under picture fuzzy environment. *Sustain. Cities Soc.* **2020**, *53*, 101873. [CrossRef]
53. Chen, Y.; Ran, Y.; Huang, G.; Xiao, L.; Zhang, G. A new integrated MCDM approach for improving QFD based on DEMATEL and extended MULTIMOORA under uncertainty environment. *Appl. Soft Comput.* **2021**, *105*, 107222. [CrossRef]
54. Liu, P.; Gao, H.; Fujita, H. The new extension of the MULTIMOORA method for sustainable supplier selection with intuitionistic linguistic rough numbers. *Appl. Soft Comput.* **2021**, *99*, 106893. [CrossRef]
55. Zhao, H.; You, J.X.; Liu, H.C. Failure mode and effect analysis using MULTIMOORA method with continuous weighted entropy under interval-valued intuitionistic fuzzy environment. *Soft Comput.* **2016**, *21*, 5355–5367. [CrossRef]
56. Mishra, A.R.; Rani, P.; Pamucar, D.; Hezam, I.M.; Saha, A. Entropy and discrimination measures based q-rung orthopair fuzzy MULTIMOORA framework for selecting solid waste disposal method. *Environ. Sci. Pollut. Res.* **2022**, *30*, 12988–13011. [CrossRef] [PubMed]
57. Tian, C.; Peng, J.-j.; Long, Q.-q.; Wang, J.-q.; Goh, M. Extended Picture Fuzzy MULTIMOORA Method Based on Prospect Theory for Medical Institution Selection. *Cogn. Comput.* **2022**, *14*, 1446–1463. [CrossRef]
58. Arslankaya, S.; Çelik, M.T. Green supplier selection in steel door industry using fuzzy AHP and fuzzy Moora methods. *Emerg. Mater. Res.* **2021**, *10*, 357–369. [CrossRef]
59. Ramezanzade, M.; Karimi, H.; Almutairi, K.; Xuan, H.A.; Saebi, J.; Mostafaeipour, A.; Techato, K. Implementing MCDM Techniques for Ranking Renewable Energy Projects under Fuzzy Environment: A Case Study. *Sustainability* **2021**, *13*, 12858. [CrossRef]
60. Fattahi, R.; Khalilzadeh, M. Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment. *Saf. Sci.* **2018**, *102*, 290–300. [CrossRef]
61. Alkan, Ö.; Albayrak, Ö.K. Ranking of renewable energy sources for regions in Turkey by fuzzy entropy based fuzzy COPRAS and fuzzy MULTIMOORA. *Renew. Energy* **2020**, *162*, 712–726. [CrossRef]
62. Bera, A.K.; Jana, D.K.; Banerjee, D.; Nandy, T. Supplier selection using extended IT2 fuzzy TOPSIS and IT2 fuzzy MOORA considering subjective and objective factors. *Soft Comput.* **2019**, *24*, 8899–8915. [CrossRef]
63. Khorshidi, M.; Erkayman, B.; Albayrak, Ö.; Kılıça, R.; Demir, H.İ. Solar power plant location selection using integrated fuzzy DEMATEL and fuzzy MOORA method. *Int. J. Ambient Energy* **2022**, *43*, 7400–7409. [CrossRef]
64. Gupta, K.; Roy, S.; Poonia, R.C.; Kumar, R.; Nayak, S.R.; Altameem, A.; Saudagar, A.K.J. Multi-Criteria Usability Evaluation of mHealth Applications on Type 2 Diabetes Mellitus Using Two Hybrid MCDM Models: CODAS-FAHP and MOORA-FAHP. *Appl. Sci.* **2022**, *12*, 4156. [CrossRef]
65. Saraji, M.K.; Mardani, A.; Köppen, M.; Mishra, A.R.; Rani, P. An extended hesitant fuzzy set using SWARA-MULTIMOORA approach to adapt online education for the control of the pandemic spread of COVID-19 in higher education institutions. *Artif. Intell. Rev.* **2021**, *55*, 181–206. [CrossRef]

66. Siddiqui, Z.A.; Haroon, M. Research on significant factors affecting adoption of blockchain technology for enterprise distributed applications based on integrated MCDM FCEM-MULTIMOORA-FG method. *Eng. Appl. Artif. Intell.* **2023**, *118*, 105699. [CrossRef]
67. Saluja, R.S.; Singh, V. An Improved Fuzzy MULTIMOORA Approach and Its Application in Welding Process Selection. *Int. J. Fuzzy Syst.* **2023**, *25*, 1707–1726. [CrossRef]
68. Xie, K.; Liang, B.; Dulebenets, M.A.; Mei, Y. The Impact of Risk Perception on Social Distancing during the COVID-19 Pandemic in China. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6256. [CrossRef] [PubMed]
69. Khorram-Manesh, A.; Dulebenets, M.A.; Goniewicz, K. Implementing Public Health Strategies—The Need for Educational Initiatives: A Systematic Review. *Int. J. Environ. Res. Public Health* **2021**, *18*, 5888. [CrossRef]
70. Guan, D.; Wang, D.; Hallegatte, S.; Davis, S.J.; Huo, J.; Li, S.; Bai, Y.; Lei, T.; Xue, Q.; Coffman, D.; et al. Global supply-chain effects of COVID-19 control measures. *Nat. Hum. Behav.* **2020**, *4*, 577–587. [CrossRef]
71. Husain, A.; Greb, F.; Meyer, S. *Projected Increase in Acute Food Insecurity Due to War in Ukraine*; World Food Program: Rome, Italy, 2022; pp. 1–11.
72. Cavallo, A.; Cavallo, E.; Rigobon, R. Prices and Supply Disruptions during Natural Disasters. *Rev. Income Wealth* **2014**, *60*, 449–471. [CrossRef]
73. Kgare, T.; Raballand, G.; Ittmann, H.W. *Cargo Dwell Time in Durban: Lessons for Sub-Saharan African Ports*; World Bank Policy Research Working Paper No. 5794; The World Bank Group: Washington, DC, USA, 2011; pp. 1–35.
74. Albertzeth, G.; Pujawan, N.; Hilletofth, P.; Tjahjono, B. Mitigating transportation disruptions in a supply chain: A cost-effective strategy. *Int. J. Logist. Res. Appl.* **2020**, *23*, 139–158. [CrossRef]
75. Xiao, T.; Jin, J. Coordination of a fashion apparel supply chain under lead-time-dependent demand uncertainty. *Prod. Plan. Control* **2011**, *22*, 257–268. [CrossRef]
76. Chen, X.; Li, L.; Zhou, M. Manufacturer's pricing strategy for supply chain with warranty period-dependent demand. *Omega* **2012**, *40*, 807–816. [CrossRef]
77. Giri, B.C.; Roy, B. Modelling supply chain inventory system with controllable lead time under price-dependent demand. *Int. J. Adv. Manuf. Technol.* **2016**, *84*, 1861–1871. [CrossRef]
78. Wei, Y.; Wang, H.; Qi, C. The impact of stock-dependent demand on supply chain dynamics. *Appl. Math. Model.* **2013**, *37*, 8348–8362. [CrossRef]
79. Ramaa, A.; Subramanya, K.N.; Rangaswamy, T.M. Impact Of Warehouse Management System in a Supply Chain. *Int. J. Comput. Appl.* **2012**, *54*, 14–20. [CrossRef]
80. Dong, Y.; Ahmad, S.F.; Irshad, M.; Al-Razgan, M.; Ali, Y.A.; Awwad, E.M. The Digitalization Paradigm: Impacts on Agri-Food Supply Chain Profitability and Sustainability. *Sustainability* **2023**, *15*, 15627. [CrossRef]
81. Solfa, F.D.G. Impacts of Cyber Security and Supply Chain Risk on Digital Operations: Evidence from the Pharmaceutical Industry. *Int. J. Technol. Innov. Manag.* **2022**, *2*, 18–32. [CrossRef]
82. Turken, N.; Carrillo, J.; Verter, V. Strategic supply chain decisions under environmental regulations: When to invest in end-of-pipe and green technology. *Eur. J. Oper. Res.* **2020**, *283*, 601–613. [CrossRef]
83. Chen, J.Y.; Slotnick, S.A. Supply chain disclosure and ethical sourcing. *Int. J. Prod. Econ.* **2015**, *161*, 17–30. [CrossRef]
84. Ghaleb, A.M.; Kaid, H.; Alsamhan, A.; Mian, S.H.; Hidri, L. Assessment and Comparison of Various MCDM Approaches in the Selection of Manufacturing Process. *Adv. Mater. Sci. Eng.* **2020**, *2020*, 4039253. [CrossRef]