Sustainable Supplier Evaluations and Order Allocation with Multiple Products using Machine Learning

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Abstract

This study is to propose a framework for sustainable supplier evaluation and optimal allocation of orders for multi-product and multi-period. In order to forecast demand, the study employed a machine learning algorithm. Concurrently, an integrated Mathematical programming model, encompassing four crucial sustainability factors, is formulated. This model effectively allocates purchase orders to suppliers based on the outcomes of the evaluation process. The model also accommodates the distribution of orders across various time frames and diverse product categories. Subsequently, the effectiveness and robustness of the proposed model are assessed through sensitivity analysis via a real-world case study implemented within an authentic supply chain setting.

Keywords
Sustainable Supplier Selection, Demand Forecasting, Order Allocation, Multi-Criteria Decision Making, Machine Learning.

1. Introduction
Supplier selection is the process of identifying, evaluating, and making decisions on selecting and contracting suppliers. As every order fulfilled starts with the decision on identifying the appropriate suppliers, the selection of suppliers has been recognized as one of the critical issues in organizations that determine the ability to successfully satisfy demands while maintaining a strategically competitive position in the market (Gupta et al. 2019). The decision made in supplier selection determines the results of other closely related problems, such as optimal order allocation. Order allocation is the process of determining the quantity and assigning orders to specific suppliers. The question of how to distribute orders to the appropriate suppliers is one that frequently comes up, especially in the case of multiple suppliers (Kawtummachai & Van Hop 2005). Proper supplier selection allows optimal order allocation by linking the evaluation scores of the suppliers with the corresponding quantity ordered. By selecting the most appropriate suppliers for each order, companies can minimize delays and disruptions, reduce costs, and improve customer satisfaction. All of this help to optimize the supply chain operations in a timely, cost-effective, and efficient manner.

The world has witnessed a growing awareness of environmental and social issues related to the operation of supply chains. Due to the increasingly important environmental and social considerations in supplier selection and supply chain operations, not only are economic factors taken into account but organizations are pressured to consider environmental and social aspects in their supply chain practices, forming the three pillars in the process of sustainable supplier selection.

The inter-relationship between supplier selection and order allocation has resulted in numerous research and studies on this topic. However, there is an insufficiency of supplier selection-order allocation models that focus on all three sustainable elements of economic, environmental, and social. Furthermore, not all of the proposed models have wide applicability due to the exclusion of factors such as multi-product and multi-period.

To address these challenges, there is a need for research that focuses on developing innovative approaches to supplier selection and order. Specifically, the economic, environmental, and social factors that impact supplier selection and order allocation must be considered.

1.1 Objectives

The main purpose of this study is to propose an integrated approach for sustainable supplier selection and order allocation. Specifically, this paper aims at three objectives. Firstly, relevant study is conducted to review and identify the gaps in the previous works on supplier selection – order allocation models. Secondly, an MCDM – Mathematical programming model that considers three sustainable factors to assign purchase orders to suppliers as efficiently as possible, depending on evaluation results. In this model, multiple products and order allocation over multiple time periods are taken into account. Finally, the proposed model is validated with a case study in real-world supply chain contexts and tested for level of sensitivity to changes in parameters.

2. Literature Review

Multi-criteria decision-making (MCDM) is a broad field of decision-making that involves evaluating and comparing multiple criteria or factors in a decision-making process. Some commonly used MCDM methods are Simple Additive Weighting (SAW), Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), and Grey Relational Analysis (GRA). These methods can be used in a variety of applications, such as the assessment of solar and wind farm locations using the AHP approach (Saraswat et al. 2021), the evaluation of coffee supplier selection using the Best-Worst method (Rahmawati & Salimi 2022), etc. Alongside the crisp models, there are proposed works that consider fuzzy logic. Memari, Dargi et al. (2019) applied the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (F-TOPSIS) in the evaluation of potential suppliers. There are many works that combine more than one MCDM method. Chi and Trinh (2016) proposed a supplier selection model using two crisp methods of AHP and TOPSIS. Ayhan (2013) applied both Fuzzy Analytic Hierarchy Process (F-AHP) and F-TOPSIS for a supplier selection problem. Yazdani (2014) combined the AHP and F-TOPSIS methods for green supplier selection.

In MCDM for supplier selection, organizations typically consider a range of criteria or factors to evaluate potential suppliers. The types and number of criteria, or in some cases, sub-criteria, vary depending on the objectives. In economic-focused supplier selection, the proposed criteria are the price of materials, delivery time, payment method, financial stability, etc. (Chatterjee et al 2019). For green supplier selection, criteria such as Environmental management system, Green Image, Eco-design, Resource consumption, etc. (Gupta et al. 2019). Depending on the organization's objectives, top priorities, and industry, different criteria might be applied. In MCDM, each criterion is typically assigned a weight or importance, and suppliers are evaluated based on how well they fulfil each criterion. Organizations can choose vendors with greater objectivity and expertise by using MCDM.

In supplier selection-order allocation problems, one of the most common approaches is applying suitable MCDM methods to evaluate suppliers and implementing the generated MCDM scores into mathematical programming to determine the quantity ordered from each supplier. Hamdan and Cheaitou (2017) built a bi-objective integer linear programming model to allocate orders after evaluating green suppliers by F-TOPSIS and AHP. Kazemi, Ehsani, and Glock (2014) combined fuzzy preference programming and interval-based TOPSIS and used the scores obtained to develop a fuzzy multi-objective linear programming model.

The findings of earlier studies on supplier evaluation and order distribution issues are compiled in Table 1. It is evident that there are limited research works that focus on all three sustainable elements, in which the social factors are often omitted. Moreover, the majority of proposed models did not consider the case in which there is more than one product, which is more accurate to real-life supply chains. Multi-period is another issue that needs to be addressed, especially with supplier selection and order allocation in a long-term context. Hence, more work and evaluations on sustainable supplier selection and order allocation with multi-product and multi-period are urgently needed.

Table 1. Reviewing previous works

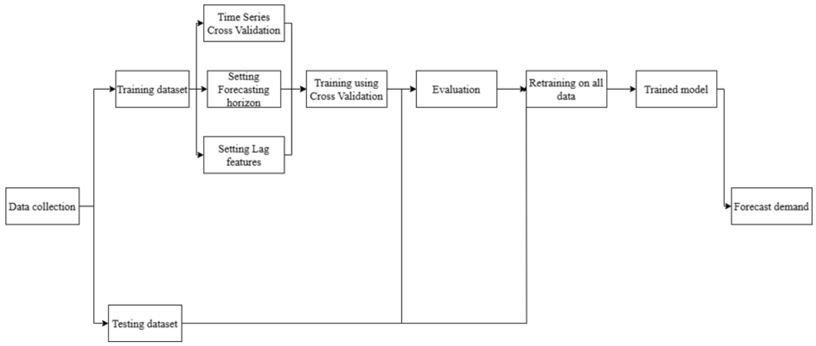
Proposed work	Environmental /Green	Social	Economic	Supplier Selction	Order Allocation	Forecasting	Single-Objective	Multi-Objective	Multi-product	Multi-period	Classical	Fuzzy	Hybrid	Method
Özgen, D., Önüt, S., Gülsün, B., Tuzkaya, U. R., & Tuzkaya, G. (2008)	x		x	x	x			x	x	x	x			AHP, MOPLP
Lin, R.-H. (2009)			x	x	x			x				x		FANP, MOLP
Büyüközkan, G., & Çifçi, G. (2012)	x		x	x								x	x	Fuzzy DEMATEL, Fuzzy ANP, Fuzzy TOPSIS
Yazdani, M. (2014)	x		x	x							x	x	x	AHP, F-TOPSIS
Bakeshlou, E. A., Khamseh, A. A., Asl, M. A. G., Sadeghi, J., & Abbaszadeh, M. (2014)	x		x	x	x			x				x	x	Fuzzy DEMATEL, Fuzzy ANP, Fuzzy MOLP
Govindan, K., & Sivakumar, R. (2015)	x		x	x	x			x				x		Fuzzy TOPSIS, Multi-objective linear programming
Hamdan, S., & Cheaitou, A. (2017)	x		x	x	x			x		x	x	x	x	Fuzzy TOPSIS, AHP, Multi-period bi-objective and multi-objective optimization
Torğul, B., & Paksoy, T. (2018)	x			x								x	x	FAHP, FTOPSIS, MOLP, FMOLP
Chatterjee, P., & Stević, Ž. (2019)			x	x								x	x	Fuzzy AHP, Fuzzy TOPSIS
Ortiz-Barrios, M., Cabarcas-Reyes, J., Ishizaka, A., Barbati, M., Jaramillo-Rueda, N., & de Jesús Carrascal-Zambrano, G. (2020)	x		x	x							x	x	x	Fuzzy AHP, Fuzzy DEMATEL, TOPSIS
Çalık, A. (2021)	x			x								x	x	Pythagorean Fuzzy AHP, Pythagorean Fuzzy TOPSIS
Nguyen, N.B.T., Lin, G.-H., & Dang, T.-T. (2021)	x		x	x							x	x	x	FAHP, VIKOR
Puška, A., Božanić, D., Nedeljković, M., & Janošević, M. (2022)	x		x	x								x	x	Z-numbers, fuzzy LMAW method, CRADIS method modified
Islam, S., Amin, S. H., & Wardley, L. J. (2021)	x		x	x	x	x		x	x	x	x			Holt's Linear Trend, Relational Regressor Chain, Stochastic MILP
Rouyendegh, B.D., & Savalan, Ş. (2022)	x		x	x								x	x	Fuzzy numbers, B-FAHP, Fuzzy TOPSIS
Sriklab, S., & Yenradee, P. (2022)	x	x	x	x	x		x	x	x		x			TOPSIS, MOLP, ESLP, SOLP
Lin, C.-T., Chen, C.-B., & Ting, Y.-C. (2010)			x	x	x		x				x			ANP, LP
Chi, H. T. X., & Trinh, D. H. N. (2016)			x	x	x		x		x	x	x		x	AHP, TOPSIS, Goal Programming
Micheli, G.J.L., Rezaei, J., Vitrano, G., & Masi, D.(2022)			x	x	x		x				x			Linear BWM, Two-staged LP: allocate orders
Azadnia, A., Saman, M. Z. M., & Wong, K.Y. (2015)	x	x	x	x	x			x	x	x		x		Rule-based weighted fuzzy method, Fuzzy AHP, MOPP
Çalık, A., Paksoy, T., & Huber, S. (2018)	x	x	x	x	x			x				x		FAHP, MOLP
Memari, A., Dargi, A., Akbari Jokar, M. R., Ahmad, R., & Abdul Rahim, A. R. (2019)	x	x	x	x								x		Intuitionistic Fuzzy TOPSIS, Fuzzy TOPSIS
Ecer, F., & Pamucar, D. (2020)	x	x	x	x							x	x	x	Fuzzy best worst method, Fuzzy CoCoSo with Bonferroni
Rouyendegh, B. D., Yildizbasi, A., & Üstünyer, P. (2019)	x	x	x	x								x		Intuitionistic Fuzzy TOPSIS (IFTOPSIS)
Thanh, N.V., & Lan, N.T.K. (2022)	x	x	x	x							x	x	x	Triple Bottom Line (TBL), FAHP, CoCoSo
Rahmawati, D., & Salimi, N. (2022)	x	x	x	x							x			Best-Worse method
This study	x	x	x	x	x	x	x		x	x	x			XGBoost, TOPSIS, Linear Programming

3. Proposed Method

3.1 XGBoost

XGBoost (eXtreme Gradient Boosting) is a popular machine learning technique that has demonstrated great performance in demand forecasting problems. XGBoost is a form of gradient boosting method that adds decision trees to a model iteratively, with each new tree fixing errors of the preceding ones. The complicated correlations between several demand drivers, such as past sales data, price changes, promotions, and weather conditions, can be learned using XGBoost in demand forecasting. Both numerical and categorical data may be handled using XGBoost, which also automatically deals with missing values and outliers.

The process of demand forecasting with XGBoost is described in Figure 1. The process starts with the demand dataset from 2015 to 2022 being split into two sets: training dataset and testing dataset. The training dataset is trained using cross-validation. Then, all data from both datasets are trained again together, resulting in a trained model. This model is used to forecast demand in 2023. The forecasted demands are used to assign order allocation.



Able 1. The Process of Forecasting Demand with XGBoost

3.2. Supplier Selection with TOPSIS

The supplier selection process is solved using the MCDM method of Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) proposed by Hwang and Yoon (1981). Five suppliers, S1 to S5, are evaluated based on their scores of ten products on five criteria: unit cost, transportation distance, defective ratios, on-time delivery fractions, and environmental scores. The five criteria are chosen because they can reflect the suppliers' performance on crucial aspects of not only the costs but also the environmental impacts (transportation distance, environmental scores), customer's satisfaction (on-time delivery fractions), and the quality of the products (defective ratios). The levels of importance of the criteria are equal, meaning that each criterion is assigned with the weight of 0.2. The purpose of this phase is to rank the suppliers in accordance with the preferences of the buyer and select the best supplier for the case based on how closely they have come to the ideal and anti-ideal criteria. This process also results in the alternative's closeness coefficients, which are later implemented into the mathematical model for order allocation.

3.3. Order Allocation with ESLP

As the primary method for solving the order allocation problem, an evaluation score-based linear programming (ESLP) mathematical model is created. The ESLP has one objective: to maximize the sum of the TOPSIS-evaluated supplier scores and the volume of goods purchased. Accordingly, greater quantities are placed from provider in with the higher the evaluation score. The aim of this stage is to determine whether the buyer should place orders from that supplier for the product and the quantity ordered.

Table 2. Notations in the Mathematical Model

Notation	Meaning
i	Supplier
j	Product
m	Month
TS_{ij}	TOPSIS score of product j from supplier i
Dm_j	Demand of product j in month m
F_{ij}	1 if supplier i supply product j, 0 otherwise
A_j	Minimum order fraction of product j
M	Big positive number
Variables	
X_{ij}	Purchased quantity of product j from supplier i in month m
Y_{ij}	1: if product j is purchased from supplier i 0: otherwise

Objective function:

$$max \sum_{i} \sum_{i} TS_{ij} X_{ijm}$$

Subject to:

(1) $\sum_i X_{ijm} = D_{jm}, \forall j$ (The ordered quantity must be sufficient to satisfy the demand)
(2) $\sum_i Y_{ij} \geq 2, \forall j$ (At least two suppliers must be chosen to supply each product. This is to ensure one of the sustainability issues: disruption of the supply chain)
(3) $Y_{ij} \leq F_{ij}, \forall i, j$ (Products are only ordered from suppliers who can supply them)
(4) $X_{ijm} \geq A_j D_{jm} Y_{ij}, \forall i, j$ (The ordered quantity must comply with the minimum order policy. This is for the social aspect of sustainability and survival of the suppliers)
(5) $X_{ijm} \leq M\, Y_{ij}, \forall i, j$ (If a supplier is not chosen, no order is placed from that supplier)
(6) $X_{ijm} \geq 0$ (Non-negative constraint for order quantity)

4. Data Collection

The demand data used in this paper are collected from a company in Vietnam that is a producer and exporter of in spices. Found in 2006, the company's strength are red chili products, along with the other spices such as pepper, cinnamon, ginger powder, etc., processed and manufactured into jars and bags that are ready-use for end-consumers. The company's core value is to supply consumers with clean, sustainable, and high-quality spices. As the company provide products both domestically and internationally with the quantity of over 4,000 tons annually, it is important that they have reliable suppliers that can provide raw materials for their products. The raw materials that are considered are Shallot, Red Chili, Green Chili, Black Pepper, Galanga, Turmeric, Ginger, Cinnamon, Anise, and Garlic. These products are referred as Product 1 (P1), Product 2 (P2), Product 3 (P3), Product 4 (P4), Product 5 (P5), Product 6 (P6), Product 7 (P7), Product 8 (P8), Product 9 (P9), and Product 10 (P10), correspondingly.

The monthly demand data for each product are collected from 2015 to 2022. The data collected are checked to make sure there are no missing points and all data are continuous in the considered time period. The suppliers' scores of ten products on five criteria - unit cost, transportation distance, defective ratios, on-time delivery fractions, and environmental scores, are also collected.

Table 3. The Suppliers' Scores on Five Criteria

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
Unit cost (millions VND/ton)										
S1	22	21.5	23.5	67.5	15.5	n/a	14.5	n/a	34	24
S2	n/a	22	27	69	13.5	11	n/a	22.5	35	23.5
S3	n/a	23.5	26	68	15	11.5	12	23	35.5	25
S4	20	n/a	24	70	15	12.5	13	23	36	26
S5	19	n/a	23	68.5	n/a	11	13	23.5	37	n/a
Transportation distance (km)										
S1	515	81	81	11.1	515	n/a	515	n/a	1028	515
S2	n/a	80.9	80.9	235	14.8	952	n/a	952	952	14.8
S3	n/a	1548	1548	11.9	607	232	607	232	232	607
S4	558	n/a	1207	106	558	255	558	255	255	558
S5	536	n/a	41.7	503	n/a	271	536	271	271	n/a
Defective fractions										
S1	0.0122	0.0213	0.0299	0.0156	0.0148	n/a	0.0289	n/a	0.0124	0.0300
S2	n/a	0.0169	0.0147	0.0103	0.0100	0.0158	n/a	0.0236	0.0158	0.0248
S3	n/a	0.0245	0.0277	0.0300	0.0148	0.0138	0.0147	0.0101	0.0224	0.0278
S4	0.0131	n/a	0.0107	0.0164	0.0122	0.0192	0.0184	0.0147	0.0168	0.0101
S5	0.0224	n/a	0.0235	0.0246	n/a	0.0300	0.0147	0.0139	0.0265	n/a
On-time delivery fractions										
S1	1.000	0.901	0.988	0.916	0.904	n/a	0.989	n/a	0.925	0.999
S2	n/a	0.945	0.989	0.993	0.916	0.935	n/a	0.966	0.975	0.902

S3	n/a	0.972	0.985	0.947	0.981	0.945	0.905	0.987	0.925	0.955
S4	0.981	n/a	0.976	0.983	0.985	0.943	0.975	0.935	0.988	1.000
S5	0.929	n/a	0.961	0.981	n/a	0.915	0.936	0.985	1.000	n/a
Environmental score										
S1	4	0	1	1	4	n/a	1	n/a	1	2
S2	n/a	1	1	4	3	2	n/a	1	3	1
S3	n/a	3	1	2	2	3	1	3	2	2
S4	3	n/a	2	2	4	3	2	1	3	4
S5	2	n/a	2	4	n/a	1	1	4	4	n/a

5. Results and Discussion

5.1 Numerical Results

Demand Forecasting Results

The demands of the nine other products are forecasted, displayed in the table below:

Table 4. Forecast Demand of Ten Products in 2023

Year	Month	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
		Demand (tons)									
2023	1	1.7	378.3	1.3	3.9	0.3	0.2	25.6	7.2	0.5	0.8
	2	5.2	104.4	3.2	12.2	0.8	0.3	25.6	1.7	0.4	2.7
	3	26.3	341.4	5.4	7.8	7.0	1.7	4.1	14.0	0.5	3.5
	4	5.6	68.7	5.6	2.2	0.8	0.3	2.9	12.6	1.0	1.7
	5	73.0	1109.0	13.4	30.9	0.7	0.3	25.9	62.0	0.4	43.8
	6	6.1	101.7	4.0	3.1	0.7	0.4	3.3	7.6	0.4	1.9
	7	9.7	57.0	2.7	3.2	0.7	0.4	2.9	9.7	1.1	1.9
	8	72.2	795.4	30.3	30.6	11.4	0.3	55.1	70.4	15.7	3.4
	9	2.0	75.7	6.3	1.6	0.8	0.2	4.8	4.5	0.8	1.9
	10	2.1	58.4	3.0	1.8	0.8	0.4	5.0	5.3	1.8	1.0
	11	3.2	121.7	4.5	1.6	2.3	0.3	3.8	2.5	0.7	1.9
	12	23.2	216.7	3.0	8.5	0.7	0.2	24.2	4.8	1.7	2.5

With the total predicted demand of 4358.3 tons in 2023, the growth rate is 6%/year compared to 2022. Table 5 shows the growth rate in demand after the disrupted time of COVID-19. As the company is aiming to reach 5000 tons/year in 2025, they are expected to achieve this goal with the growth rate of 6-7%/year as forecasted.

Table 5. The Growth Rate of Demand

Year	Total Demand	Annual Growth Rate
2022	4107.8	9%
2023	4358.3	6%
2024 *(expected)*	4619.8	6%
2025 *(expected)*	4943.2	7%

TOPSIS Results

The TOPSIS results are shown as follows:

Table 6. The TOPSIS Score of Suppliers Based on Five Products

TOPSIS Score	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
S1	0.859	0.498	0.606	0.656	0.362	n/a	0.151	n/a	0.310	0.231
S2	n/a	0.617	0.715	0.667	0.811	0.361	n/a	0.027	0.439	0.480
S3	n/a	0.495	0.052	0.625	0.059	0.976	0.485	0.822	0.591	0.203
S4	0.659	n/a	0.467	0.673	0.362	0.849	0.813	0.547	0.774	0.565

The results of the TOPSIS Score of the suppliers for each product are used in the Evaluation Score based Model for order allocation.

Order Allocation Results

The results suggest that each product is supplied by two suppliers that have the highest TOPSIS scores. For instance, Supplier 1 and 4 have the highest TOPSIS score in terms of Product 1, so they are chosen to supply Product 1. Similarly with the other products, this result ensure that the products are assigned to the suppliers that have the highest rating.

Once it is identified which suppliers are responsible for which products, the order quantities for each month are also determined. The table below shows the quantity of each product purchased from their suppliers monthly.

Table 7. The Order Allocation of Products

Month	P1		P2		P3		P4		P5	
	Supplied quantity (tons)									
	S1	S4	S1	S2	S2	S5	S2	S4	S2	S4
1	1.19	0.51	113.49	264.81	0.39	0.91	1.17	2.73	0.21	0.09
2	3.64	1.56	31.32	73.08	0.96	2.24	3.66	8.54	0.56	0.24
3	18.41	7.89	102.42	238.98	1.62	3.78	2.34	5.46	4.9	2.1
4	3.92	1.68	20.61	48.09	1.68	3.92	0.66	1.54	0.56	0.24
5	51.1	21.9	332.7	776.3	4.02	9.38	9.27	21.63	0.49	0.21
6	4.27	1.83	30.51	71.19	1.2	2.8	0.93	2.17	0.49	0.21
7	6.79	2.91	17.1	39.9	0.81	1.89	0.96	2.24	0.49	0.21
8	50.54	21.66	238.62	556.78	9.09	21.21	9.18	21.42	7.98	3.42
9	1.4	0.6	22.71	52.99	1.89	4.41	0.48	1.12	0.56	0.24
10	1.47	0.63	17.52	40.88	0.9	2.1	0.54	1.26	0.56	0.24
11	2.24	0.96	36.51	85.19	1.35	3.15	0.48	1.12	1.61	0.69
12	16.24	6.96	65.01	151.69	0.9	2.1	2.55	5.95	0.49	0.21
Month	P6		P7		P8		P9		P10	
	Supplied quantity (tons)									
	S3	S4	S4	S5	S3	S5	S4	S5	S2	S4
1	0.14	0.06	17.92	7.68	2.16	5.04	0.35	0.15	0.24	0.56
2	0.21	0.09	17.92	7.68	0.51	1.19	0.28	0.12	0.81	1.89
3	1.19	0.51	2.87	1.23	4.2	9.8	0.35	0.15	1.05	2.45
4	0.21	0.09	2.03	0.87	3.78	8.82	0.7	0.3	0.51	1.19
5	0.21	0.09	18.13	7.77	18.6	43.4	0.28	0.12	13.1	30.7
6	0.28	0.12	2.31	0.99	2.28	5.32	0.28	0.12	0.57	1.33
7	0.28	0.12	2.03	0.87	2.91	6.79	0.77	0.33	0.57	1.33
8	0.21	0.09	38.57	16.53	21.1	49.28	11	4.71	1.02	2.38

9	0.14	0.06	3.36	1.44	1.35	3.15	0.56	0.24	0.57	1.33
10	0.28	0.12	3.5	1.5	1.59	3.71	1.26	0.54	0.3	0.7
11	0.21	0.09	2.66	1.14	0.75	1.75	0.49	0.21	0.57	1.33
12	0.14	0.06	16.94	7.26	1.44	3.36	1.19	0.51	0.75	1.75

The monthly quantities ordered for each product from each suppliers ensure that each supplier can earn a sale of at least 30% of the demand. The orders placed comply with the demand, ensuring that all demands are met.
The total purchasing cost calculated from this model is 99,466,285,000.00 VND. The total transportation distance is 5454.1 km. The average defective fractions, timely delivery rates, and environmental scores are 0.015945, 0.96575, and 2.6, correspondingly.

5.2 Sensitivity Analysis

Changing the Weights of the Criteria

The five criteria of unit cost, transportation distance, defective fractions, timely delivery rates, and environmental scores are considered to be equally significant, with each criterion assigned with the weight of 0.2. However, if the company chooses to emphasize the importance of a specific aspect, for instance, the costs, the weights of the criteria are altered correspondingly. In this case, the company targets at achieving the lowest cost; hence, the criteria of unit cost and transportation distance, which is greatly linked with transportation cost, will be given greater weights. Assume that the weights of the two cost-related criteria are now 0.35 each, and the rest share the same level of importance of 0.1 each. This results in some changes in Supplier evaluation, as shown in the TOPSIS results below:

Table 8. The TOPSIS Score of Suppliers Based on Five Products after Changing the Weights of the Criteria

TOPSIS Score	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
S1	0.645	0.776	0.842	0.864	0.196	n/a	0.323	n/a	0.152	0.180
S2	n/a	0.840	0.866	0.562	0.934	0.161	n/a	0.030	0.207	0.761
S3	n/a	0.222	0.028	0.852	0.032	0.970	0.504	0.926	0.826	0.090
S4	0.613	n/a	0.278	0.785	0.158	0.897	0.713	0.796	0.897	0.276
S5	0.372	n/a	0.914	0.137	n/a	0.796	0.533	0.925	0.838	n/a

Compared to the previous TOPSIS results, it can be inferred that the values of the TOPSIS scores are greatly different. Although the orders of preference are not significantly changed, this leads to some modifications in the Order allocation. Firstly, there are some changes in assigning products to suppliers, specifically for Product 4 and 5. Product 4, which is initially assigned to Supplier 2 and 4, is now assigned to Supplier 1 and 3. Similarly, Product 5 changes from Supplier 2 and 4 to Supplier 1 and 2.

Table 9. The Order Allocation of Products after changing the weights of the criteria (red-coded indicates changes compared to the previous results.

Month	P1		P2		P3		P4		P5	
	Supplied quantity (tons)									
	S1	S4	S1	S2	S2	S5	S1	S3	S1	S2
1	1.19	0.51	113.49	264.81	0.39	0.91	2.73	1.17	0.09	0.21
2	3.64	1.56	31.32	73.08	0.96	2.24	8.54	3.66	0.24	0.56
3	18.41	7.89	102.42	238.98	1.62	3.78	5.46	2.34	2.1	4.9
4	3.92	1.68	20.61	48.09	1.68	3.92	1.54	0.66	0.24	0.56
5	51.1	21.9	332.7	776.3	4.02	9.38	21.63	9.27	0.21	0.49
6	4.27	1.83	30.51	71.19	1.2	2.8	2.17	0.93	0.21	0.49
7	6.79	2.91	17.1	39.9	0.81	1.89	2.24	0.96	0.21	0.49

8	50.54	21.66	238.62	556.78	9.09	21.21	21.42	9.18	3.42	7.98
9	1.4	0.6	22.71	52.99	1.89	4.41	1.12	0.48	0.24	0.56
10	1.47	0.63	17.52	40.88	0.9	2.1	1.26	0.54	0.24	0.56
11	2.24	0.96	36.51	85.19	1.35	3.15	1.12	0.48	0.69	1.61
12	16.24	6.96	65.01	151.69	0.9	2.1	5.95	2.55	0.21	0.49
Month	**P6**		**P7**		**P8**		**P9**		**P10**	
	Supplied quantity (tons)									
	S3	**S4**	**S4**	**S5**	**S3**	**S5**	**S4**	**S5**	**S2**	**S4**
1	0.14	0.06	17.92	7.68	5.04	2.16	0.35	0.15	0.56	0.24
2	0.21	0.09	17.92	7.68	1.19	0.51	0.28	0.12	1.89	0.81
3	1.19	0.51	2.87	1.23	9.8	4.2	0.35	0.15	2.45	1.05
4	0.21	0.09	2.03	0.87	8.82	3.78	0.7	0.3	1.19	0.51
5	0.21	0.09	18.13	7.77	43.4	18.6	0.28	0.12	30.66	13.14
6	0.28	0.12	2.31	0.99	5.32	2.28	0.28	0.12	1.33	0.57
7	0.28	0.12	2.03	0.87	6.79	2.91	0.77	0.33	1.33	0.57
8	0.21	0.09	38.57	16.53	49.28	21.12	10.99	4.71	2.38	1.02
9	0.14	0.06	3.36	1.44	3.15	1.35	0.56	0.24	1.33	0.57
10	0.28	0.12	3.5	1.5	3.71	1.59	1.26	0.54	0.7	0.3
11	0.21	0.09	2.66	1.14	1.75	0.75	0.49	0.21	1.33	0.57
12	0.14	0.06	16.94	7.26	3.36	1.44	1.19	0.51	1.75	0.75

It can be inferred that not only do the order allocation of Product 4 and 5 alter but also Product 8 and 10 despite no changes in the chosen suppliers.

The total purchasing cost calculated from this model is 99,142,705,000.00 VND, which is 323,580,000.00 less than the previous results, and the total travel distance drops to 5093.1 km. Although this shift in criteria's weights helps to reduce the cost significantly, it also results in less desirable values in other criteria of defective fractions, timely delivery rates, and environmental scores. The average defective fractions, timely delivery rates and scores of environments are 0.01678 (increases by 0.0835%), 0.95665 (decreases by 0.91%), and 2.4 (decreases by 0.2 points), correspondingly. As the less desirable values in these criteria are not too significant, the company can consider to focus on reducing costs. This is a good example of trade-offs that decision makers must take into consideration.

Changing the Minimum Value of Number of Suppliers

The sustainability issues mentioned in this study consider the disruption of the supply chain, which requires at least two suppliers must be chosen to supply each product. Despite the major benefit of ensuring supplies at all time, in reality, cooperate with multiple suppliers for each product can be inconvenient, as more paper work and negotiations must be made. Therefore, in the case where the company chooses to work with the minimum value of one supplier per product, the order allocation definitely changes. In this case, the model chooses the suppliers with the highest TOPSIS score as the sole suppliers for each product. The order allocation is shown in Table 10.

Table 10. The Order Allocation of Products after Changing the Minimum Number of Suppliers

Month	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
	Supplied quantity (tons)									
	S1	**S2**	**S5**	**S4**	**S2**	**S3**	**S4**	**S5**	**S4**	**S4**
1	1.7	378.3	1.3	3.9	0.3	0.2	25.6	7.2	0.5	0.8
2	5.2	104.4	3.2	12.2	0.8	0.3	25.6	1.7	0.4	2.7
3	26.3	341.4	5.4	7.8	7	1.7	4.1	14	0.5	3.5

4	5.6	68.7	5.6	2.2	0.8	0.3	2.9	12.6	1	1.7
5	73	1109	13.4	30.9	0.7	0.3	25.9	62	0.4	43.8
6	6.1	101.7	4	3.1	0.7	0.4	3.3	7.6	0.4	1.9
7	9.7	57	2.7	3.2	0.7	0.4	2.9	9.7	1.1	1.9
8	72.2	795.4	30.3	30.6	11.4	0.3	55.1	70.4	15.7	3.4
9	2	75.7	6.3	1.6	0.8	0.2	4.8	4.5	0.8	1.9
10	2.1	58.4	3	1.8	0.8	0.4	5	5.3	1.8	1
11	3.2	121.7	4.5	1.6	2.3	0.3	3.8	2.5	0.7	1.9
12	23.2	216.7	3	8.5	0.7	0.2	24.2	4.8	1.7	2.5

The total purchasing cost calculated from this model is 100,111,150,000.00 VND, which is 644,865,000.00 more than the initial results. However, the total transportation distance is cut down by half, which is now 2,632.4 km. The average defective fractions, timely delivery rates, and environmental scores are better: 0.0152 (decreases by 0.0745%), 0.9698 (increases by 0.405%), and 2.8 (increases by 0.2 points), correspondingly. This means that although choosing one supplier per product can increase the purchasing cost, the values of the other metrics are improved. However, if this is applied in reality, the risk of supply disruption can be high.

6. Conclusion

This study proposes an framework for sustainable supplier evaluation and allocating orders for a multi-product spice company. The findings demonstrate that each product is supplied by two different providers, with orders aligned to meet demand, ensuring all requirements are fulfilled. When changing the weights of the criteria so that cost-related criteria are more emphasized, the model gives out a much lower total purchasing cost, but also values that are less desirable in other criteria. It is also observed that changing the minimum value number of suppliers results in better average defective fractions, timely delivery rates, and environmental scores at the expense of increased purchasing costs and higher risk of supply disruption. The model proposed in this study covers the fundamental aspects in sustainable supplier selection and order allocation, and can be applied in not only the spice industry but also other fields as well. This paper, however, does have some limitations. First, all parameters are considered to be constant, and data uncertainty is omitted, which can be inaccurate in practice. Second, the sustainable issue of supply chain interruption is only dealt with by requiring at least two suppliers for each product, while the social issues focus solely on the supplier element rather than all stakeholders of the supply chain. Hence, additional techniques for dealing with this problem should be developed.

For future research, the forecasting methods should be compared to other algorithms and techniques for more accurate forecasting. Fuzzy numbers should be used to estimate uncertain input parameters, meaning that some constraints and objective functions could also be fuzzy. Lastly, since the sustainable issues in supplier selection and order allocation comprise various aspects and hence can be complicated, it is recommended that the model consider these aspects more deeply to further emphasize the importance of sustainability in the supply chain.

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