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Research Article

Selecting the Optimal Green Supplier and Order Allocation under Linear Discount

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Selecting the right supplier can be one of the most critical decisions for manufacturing firms. Strategic issues often dictate whether a company thrives or fails. When making important decisions, certain people consider the importance of green-friendly criteria before selecting a supplier. Various companies prioritize green suppliers in their selection process. This work considers the grey method of choosing green suppliers by considering the excellence and weakness. In addition to the green suppliers, the allocation of orders is carried out. The green vendors are focused on utilizing grey, and the demand is assigned by utilizing linear discounts for multiple products and time periods. This work introduces an integrated model with multiple products and time periods for determining demand using green criteria. The outcome of this work is to assign orders to the best suppliers to increase total purchase value while reducing total purchase costs. Then, the method is depicted with a numerical model in a linear discount scenario. A sensitivity analysis was carried out. TVP and TCP differences in order quantity and optimum solution are illustrated in the sensitivity analysis. The numerical model is programmed and resolved by LINGO 18.

1. Introduction

To focus on environmental issues, manufacturers are introducing green supply chain concepts. The industry has to modify traditional supply chains to GSCMs through the initiation of green procurement strategies to develop supply chains that are environmentally sustainable [1]. Green supply chain management is becoming a more challenging task for businesses in the current environment [2]. As per the statement of Zhang et al. [3], the rise of competition, more government regulations, and a concern about environmental issues have spurred firms to pursue long-term sustainability in their supply chains and operations. Integrating environmental, social, and economic aspects into production processes and supply networks is required to achieve sustainability. GSCM has received attention from academics and businesses due to increased regulatory and environmental consciousness. Lo et al. reported that business circles are paying special attention to GSCM. A GSCM strategy can help companies meet their social responsibilities while responding to market changes. Selecting green suppliers, which includes qualitative and quantitative factors, is essential for managing a green supply chain [4]. An essential role for managers in managing supply chains is supplier selection. Organizations must address environmental concerns and implement a supplier evaluation strategy to maintain a competitive market position [5].

This study aimed to develop a complete green supplier selection model that considers economic and environmental issues. A green supplier selection model built on grey theory is therefore necessary. Many methods and approaches solve supplier selection and order allocation problems. To solve the order allocation problem, the decision-maker must make several decisions. Which product should be ordered? What quantity should be ordered and from which supplier? When should it be ordered?

A mathematical model for assessing multiple objectives is discussed. In this model, the TVP is maximized, while the TCP is minimized. To illustrate the model, we present a numerical example in a linear discount environment. Besides, the suppliers sometimes offer discounts, so price reductions are designed to induce large orders. Considering budget and demand constraints, a novel hybrid model is presented to assess green supplier selection and order allocation. An integration of grey and multi-period MOMINLP is suggested in this study for selecting the best green vendors and defining the optimal amounts among the chosen vendors. The author was able to identify the best suppliers with uncertain information using grey theory-based approaches. Grey is used for choosing and ranking green suppliers. The output of grey is applied to a mathematical model that determines order quantities from each supplier using a proposed goal programming model. This study proposes a multiobjective mixed-integer nonlinear programming (MIMONLP) model for selecting and allocating suppliers under linear discounts for multi-period, multiproduct, and multisourcing scenarios. In the following section, a mathematical model for allocating orders among selected suppliers is presented.

Current research proposes a manufacturing company and tends to choose the most appropriate suppliers to prove the integrated model and find a solution to the problem of supplier selection in grey environments. To accomplish this, the study is organized as follows. SSP-related environmental issues and literature reviews are discussed in Section 2. Section 3 discusses grey and goal programming models. The numerical example in Section 4 is designed to demonstrate the results, the efficiency, and the validity of the proposed model. Finally, the conclusion and practical implications of the model are included in Section 5.

2. Literature Review

According to Quan et al. [6], an improved grey incidence model with economic and environmental factors can be used to make green supplier selection decisions for the chemical industry. Durga et al. have proposed a methodology called VIKOR that integrates AHP with multi-criteria optimization and compromise solution techniques to resolve uncertainty when selecting the best alternative. The proposed method was implemented at a manufacturing facility to analyze the effect [7]. Oroojeni Mohammad et al. explain KSC's practice of selecting green suppliers using the best worst method and fuzzy TOPSIS. This research makes it possible to rank suppliers according to their green innovation capability [8]. Shi et al. presented an integrated approach based on IVIULS and GRA-TOPSIS for evaluating and selecting green suppliers. It was demonstrated by evaluating the green performance of suppliers under economic and environmental criteria using the proposed green supplier selection model. IVIULS and GRA-TOPSIS were utilized to rank alternative green suppliers [9]. According to Hamdan and Jarndal, the allocation of orders in GSCM is also a crucial decision-making process [10].

Govindan and Sivakumar [11] proposed a fuzzy TOPSIS and multi-objective linear programming model to select the best green supplier and allocate orders among the potential suppliers. Using recycled products, 26.2% fewer carbon emissions are produced. Hamdan and Cheaitou developed a similar model that considers all unit quantity discounts for the allocation of real-world orders. Using an integrated model, they proved that decision-makers could obtain practical reference information more easily [12]. Additionally, Hamdan and Cheaitou developed a model for assessing suppliers' purchasing volume based on weighted comprehensive criteria and an algorithm that includes branch-and-cut algorithms within fuzzy sets. This model was applied to a real-world business case to demonstrate its accuracy, effectiveness, and flexibility [13]. In this study, a multi-objective approach to supplier selection and demand allocation among candidates' suppliers was developed. There were two stages to tackling this problem: first, the ratings of suppliers were evaluated based on fuzzy TOPSIS. An integer programming model was developed in the second stage by considering PV and transportation and inventory costs, including full and low truckloads, based on supplier rating data acquired in the first stage [14].

The multi-objective mixed-integer nonlinear programming model developed by Jolai et al. was proposed for solving the supplier order allocation problem, where a buyer ordered multiple products in multiple time periods from several suppliers. Model results show that linear discounts from suppliers can significantly affect order values [15]. In addition, Gurel et al. prepared a literature review to express how different criteria affect decision environments. A criteria list for green supplier selection for the textile industry was also presented in a hierarchical structure that can be used for multi-criteria decision analysis. The proposed criteria list consists of eight significant criteria and thirty-one sub-criteria, including green criteria such as cost, delivery, quality, service, and strategic alliances, and nongreen criteria such as pollution control, environmental management, and green products [16].

Using a fuzzy TOPSIS and ELECTRE approach, Qu ranked and compared the green chain suppliers' performance using outranking degrees and incomparability among fuzzy ELECTRE actions. Then, sensitivity analyses were conducted to determine whether the best alternative was feasible [17]. To identify the most promising green suppliers who will meet a firm's demands consistently, Yao used the MMAHP. To demonstrate how the proposed method works, a numerical example is given. Based on the results, the MMAHP is an effective approach to the considered problem, which also helps to prevent rank reversals [18]. By focusing on the synergies involved in being green while emphasizing leanness, companies with large, extended SCs can achieve cost savings and improved profitability [19]. Green SCs are more effective and environmental friendly throughout their entire business operations. With government regulations and rules getting stricter to meet environmental standards and consumer demand for green products increasing, this concept has emerged [20].

According to this study, four levels of production rates are modelled under deteriorating inventory conditions, and the rebate value-based demand is derived from the product price under shortage conditions. It maximizes profit by optimizing replenishment time, ordering quantity, rebate value, and selling price [21].

The purpose of this study was to optimize a retailer's whole profit function, to find the optimal selling prices and replenishment cycles when the demand rate is dependent on cost and reduction in carbon emissions. An economic order quantity model is examined, which also positively impacts carbon emission reduction besides sales price. A supplier offers a discount for paying in advance on the purchased price while requesting payment in advance on the purchased price [22].

This study helps governments and decision-makers understand the implications of countries' consumption of products and services on carbon emission peaks and forms effective carbon mitigation plans. Based on the Monte Carlo simulation technique, a dynamic scenario simulation model was created to assess possible future peaks in countries' carbon emissions in the Asian and Pacific regions while considering the uncertainty of various factors [23].

Under a price-dependent demand and a discount facility, the paper simultaneously examines the optimal pricing and inventory decisions. It also introduces a time-dependent holding cost. To maximize the overall profit, the critical decision variables must be carefully balanced [24].

Based on previous studies of the banking industry that failed to identify the attributes, a smart product-service system model is developed using the diffusion of innovation theory. To design a valid hierarchical model and identify causal relationships among the attributes of smart product-service systems with high uncertainty, the hybrid method of fuzzy Delphi method and fuzzy decision-making trial and evaluation laboratory is used [25].

2.1. Research Gaps. A literature review reveals several methods and tools available for evaluating and selecting green suppliers. Based on reviews of various contributions to GSC paradigms, it was determined that additional work should be undertaken to identify specific practices that manufacturers could adopt. There has been plenty of research that has identified the enablers of GSC implementation, but we need more information on how they will be implemented at a manufacturing level. Various mathematical methods and techniques are described in the literature for selecting suppliers, and most of them involve the use of multi-criteria decision-makings such as AHP, fuzzy, DEA, VIKOR, DEMATEL, ANP, and TOPSIS. Numerous studies have been conducted on these methods. However, there is a lack of research focusing on the trade-off between grey and GP approaches in SC management. According to the authors, no previous work has considered allocating orders using a linear discount for multiple products and multiple time periods among green suppliers with the integration of grey and goal programming. A framework for green supplier selection is presented in this study, which emphasizes the importance of supplier selection.

2.2. Problem Statement. To evaluate green suppliers and plan order allocation, MCDM methods have been developed. Only a few studies have combined these two subjects. However, these subjects tend to be studied separately. This study is divided into two parts: supplier selection and order allocation. By properly allocating orders to qualified suppliers, a company can maximize profits and efficiency.

The company's managers are thus faced with critical challenges in identifying qualified suppliers and allocating orders to them, which significantly impact the company's market competitiveness. A combination of market competition and regulatory requirements is causing the company several difficulties. A significant problem with their current supplier evaluation procedure is that environmental factors are not considered, and they do not have a systematic way to assess their green suppliers. Additionally, department managers decide the weights of their evaluation criteria subjectively, and different managers prioritize the factors differently based on their preferences. Furthermore, their purchasing plans are not based on supplier evaluation results. Order allocation is often based on the subjective experience of purchasing department managers. Even though the case company has a supply chain management system, it is not fully integrated. It is urgently necessary for the company to develop an order allocation system capable of integrating outcomes of supplier audits and considering managerial judgments that are uncertain.

3. Methodology

This study examines the green supply chain management (GSCM) practices in Indian industries to identify and prioritize green suppliers. An updated version of the MCDM method was used in this paper for decision.

3.1. Research Design. Data collection and creating a sample are the first steps. Initially, reputable databases such as Elsevier, Springer, and Science Direct were utilized to assemble research papers. Keywords incorporated into the study included grey theory, goal programming, green supplier, MOMINLP model, and sensitivity analysis. These databases were used to tailor the search for peer-reviewed journals in GSC management. These key GSC operations were identified as a result of this process. In this study, the authors aimed to recruit Indian industrial experts with experience of four to eight years.

These experts were presented with the green criteria based on the literature survey. The opinions of a group of experts are always more reliable than those of a single expert. For this reason, the authors gathered the opinions of various experts. The researcher assembled an expert team, including academics and industry members, to identify green practices for this project. In the current scenario of a questionable data condition, the grey methodology is invaluable in choosing the best green vendor out of the options. GP is utilized to assign the interest to the appropriate vendors under linear discount with multiple products and multiple time periods for multiple suppliers.

3.2. Grey Theory. For selecting green suppliers, a new approach focused on the degree of grey is suggested. This technique is particularly well-tailored to solve the challenges of collective decision-making in an unpredictable situation. Suppose $S = \{\mathrm{Sl}_1, \mathrm{Sl}_2, \ldots \mathrm{Sl}_\mathrm{m}\}$ is a discrete collection of potential supplier alternatives. $A = \{\mathrm{Al}_1, \mathrm{Al}_2, \ldots, \mathrm{Al}_\mathrm{n}\}$ is a sequence of the supplier's n attributes. These attributes are additionally free. $\mathrm{w}_\mathrm{t} = \{\mathrm{wt}_1, \mathrm{wt}_2, \mathrm{wt}_3 \ldots \mathrm{wt}_\mathrm{n}\}$ is the weight of the vector attribute. In this research, the weight of the attribute weights and locations of vendors shall be known as linguistic variables.

According to Table 1, these grey numbers represent linguistic variables on a scale of 1–7. Table 2 also displays characteristics G on a scale of 1–7 in grey numbers. According to Li, the grey is composed of the following steps [26]:

Stage 1: DMs should describe the vendors' characteristics using a group of DMs. Considering K to be the number of individuals in the decision group, the characteristic weight of Wt_j can also be calculated as follows:

$$\otimes \mathrm{wt}_j = \frac{1}{K}\left[\otimes \mathrm{wt}_j^1 + \otimes \mathrm{wt}_j^2 + \cdots + + \otimes \mathrm{wt}_j^K\right], \tag{1}$$

where $\otimes \mathrm{wt}_j^K$ is the attribute weight of Kth DMs and could be represented by a grey number:

$$\otimes \mathrm{wt}_j^K = \left[\underline{w}\,t_j^K, \overline{w}t_j^K\right]. \tag{2}$$

Stage 2: linguistic variables for scores are used to measure the price of the score attribute. Then, the value of the ranking can be determined as follows:

$$\otimes \mathrm{GN}_\mathrm{ij} = \frac{1}{K}\left[\otimes \mathrm{GN}_\mathrm{ij}^1 + \otimes \mathrm{GN}_\mathrm{ij}^2 + \cdots + + \otimes \mathrm{GN}_\mathrm{ij}^K\right], \tag{3}$$

where $\otimes \mathrm{GN}_\mathrm{ij}^K$ is the attribute rating value of Kth *DMs* and could be represented by a grey number $\otimes \mathrm{GN}_\mathrm{ij}^K = [\underline{GN}_\mathrm{ij}^K, \overline{G}N_\mathrm{ij}^K]$.

Stage 3: the GDM is set.

$$D = \begin{bmatrix} \otimes \mathrm{GN}_{11} & \otimes \mathrm{GN}_{12} & \cdots & \otimes \mathrm{GN}_{1n} \\ \otimes \mathrm{GN}_{21} & \otimes \mathrm{GN}_{22} & \cdots & \otimes \mathrm{GN}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes \mathrm{GN}_{m1} & \otimes \mathrm{GN}_{m2} & \cdots & \otimes \mathrm{GN}_\mathrm{mn} \end{bmatrix}, \tag{4}$$

where $\otimes \mathrm{GN}_\mathrm{ij}$ is linguistic variables that depend on the grey number.

Stage 4: the GNDM is normalized.

$$D^* = \begin{bmatrix} \otimes \mathrm{GN}_{11}^* & \otimes GN_{12}^* & \cdots & \otimes \mathrm{GN}_{1n}^* \\ \otimes \mathrm{GN}_{21}^* & \otimes \mathrm{GN}_{22}^* & \cdots & \otimes \mathrm{GN}_{2n}^* \\ \vdots & \vdots & \ddots & \vdots \\ \otimes \mathrm{GN}_{m1}^* & \otimes \mathrm{GN}_{m2}^* & \cdots & \otimes \mathrm{GN}_{mn}^* \end{bmatrix}, \tag{5}$$

where for a benefit attribute, $\otimes \mathrm{GN}_\mathrm{ij}^*$ is conveyed as follows:

$$\begin{aligned} \otimes \mathrm{GN}_\mathrm{ij}^* &= \left[\frac{\underline{GN}_\mathrm{ij}}{\mathrm{GN}_j^\mathrm{max}}, \frac{\overline{GN}_\mathrm{ij}}{\mathrm{GN}_j^\mathrm{max}}\right], \\ \mathrm{GN}_j^\mathrm{max} &= \max_{1\le i\le m}\left(\overline{\mathrm{GN}}_\mathrm{ij}\right). \end{aligned} \tag{6}$$

For a cost attribute, $\otimes \mathrm{GN}_\mathrm{ij}^*$ is conveyed as follows:

$$\begin{aligned} \otimes \mathrm{GN}_\mathrm{ij}^* &= \left[\frac{\mathrm{GN}_j^\mathrm{min}}{\overline{GN}_\mathrm{ij}}, \frac{\mathrm{GN}_j^\mathrm{min}}{\underline{GN}_\mathrm{ij}}\right], \\ GN_j^\mathrm{min} &= \min_{1\le i\le m}\left(\underline{GN}_\mathrm{ij}\right). \end{aligned} \tag{7}$$

The standardization approach alluded to above is to keep the property that the degrees of the standardized grey quantity belong to $[0, 1]$.

Stage 5: the WNGM is constructed. The significance of every attribute, in the WNGM is as follows:

$$D^* = \begin{bmatrix} \otimes \mathrm{VCC}_{11} & \otimes \mathrm{VC}_{12} & \cdots & \otimes \mathrm{VC}_{1n} \\ \otimes \mathrm{VC}_{21} & \otimes \mathrm{VC}_{22} & \cdots & \otimes \mathrm{VC}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes \mathrm{VC}_{m1} & \otimes \mathrm{VC}_{m2} & \cdots & \otimes \mathrm{VC}_\mathrm{mn} \end{bmatrix}, \tag{8}$$

where $\otimes \mathrm{VC}_\mathrm{ij} = \otimes \mathrm{GN}_{ij}^* \times \otimes w_j$.

Stage 6: perfect options are created as referential options. For "m" conceivable vendor opportunity set $\mathrm{Sl} = (\mathrm{Sl}_1, \mathrm{Sl}_2, \ldots\ldots, \mathrm{Sl}_n)$ and impeccable referential supplier opportunity:

$$S^\mathrm{max} = \left\{ \begin{array}{c} \left[\min\limits_{1\le n\le m} \underline{V}_{i1}, \min\limits_{1\le n\le m} \overline{V}_{i1}\right], \left[\max\limits_{1\le n\le m} \underline{V}_{i2}, \max\limits_{1\le n\le m} \overline{V}_{i2}\right], \ldots \\ \left[\max\limits_{1\le n\le m} \underline{V}_{in}, \max\limits_{1\le n\le m} \overline{V}_{in}\right] \end{array} \right\}. \tag{9}$$

Stage 7: the grey possibility degree between compared supplier alternative set $S = (\mathrm{Sl}_1, \mathrm{Sl}_2, \ldots\ldots, \mathrm{Sl}_m)$ and ideal referential supplier alternative Sl^max is ascertained:

$$P\{\mathrm{Sl}_i \le \mathrm{Sl}^\mathrm{max}\} = \frac{1}{n}\sum_{j=1}^{n} P\left\{\otimes \mathrm{VC}_\mathrm{ij} \le \otimes \mathrm{GN}_j^\mathrm{max}\right\}. \tag{10}$$

Stage 8: suppliers are to be ranked in order. While ranking, if the order is $P\{\mathrm{Sl}_i \le \mathrm{Sl}^\mathrm{max}\}$ smaller, then Sl_i is better. In any case, the ranking order is awful. In this methodology, the ranking sequence among all the supplier's alternatives can be chosen and picked the finest from a set of possible suppliers ($\sum_{i=1}^{m}\sum_{j=1}^{n} w_{\mathrm{itX_{jit}}}$).

3.3. MOMINLP Model. In this a MOMINLP model, customer is expected to purchase *j* commodity from vendors at different times. The following are several hypotheses that were used in the display of the problem [15].

3.4. Suspicions

(i) There is a deterministic demand for every product for each period
(ii) When allocating orders, linear discounts are considered
(iii) A buyer's order can be supplied by multiple suppliers
(iv) Different periods of time are involved in the buyer's purchase of the goods

3.5. Parameters

D_{jt}: requirement regarding *j* item in time *t*

h_{jt}: holding cost for *j* item in time *t*

O_{it}: order prices of vendor *i* in time *t*

q_{ijt}: in period *t*, supplier *i* had a defect rate of product *j*

L: minimal order volume if the contract is to be put with each vendor for each commodity for each span of time

VC_{ijt}: vendor capability *i* for commodity *j* over the period *t*

$Cmax_{ijt}$: max procurement of product *j* from vendor *i* during the *t* span if X_{ijt} is equal to L

$Cmin_{ijt}$: min procurement of product *j* from vendor *i* during the *t* span if X_{ijt} is equal to VC

DT_{ijt}: commodity *j* being delivered on time by vendor *i* over the span *t*.

DTB_j: minimum delivery rate that the buyer is willing to accept for product *j*

W_{it}: score the vendor earned from applying the grey principle in time *t*

Q_j: the absolute minimum error rate for product *j*

B_t: purchaser's target for the duration *t*

P_t: potential maximum bound of the TVP duration t

Here, i = 1, 2, . . ., m index of suppliers j = 1, 2, . . . n index of products t = 1, 2, . . . T index of time periods k = 1, 2, . . . K index of goals.

3.6. Variables

X_{ijt}: in the time *t* obtained from vendor *i*, the volume of product *j*

Y_{it}: in time *t*, this should be equal to 1 if the order was placed with supplier *i*, otherwise zero

I_{jt}: stocks of material *j* brought over from time *t* to time t_1

Z_1: fractional undesirable deviation from Goal 1

Z_2: fractional undesirable deviation from Goal 2

Z: total fractional unwanted deviation

$d^{+}{}_{kt}$: in period *t*, the deviation from the target value for kth goal was positive

$d^{-}{}_{kt}$: in period *t*, the deviation from the target value for kth goal was negative

$$Z_1 = \frac{\sum_{t=1}^{T} d_{1t}^{+}}{\sum_{t=1}^{T} B_t},$$
$$Z_2 = \frac{\sum_{t=1}^{T} d_{2t}^{-}}{\sum_{t=1}^{T} P_t}. \tag{11}$$

So, now we can develop the model on the basis:

$$\mathrm{Min}\, z = w_1 z_1 + w_2 z_2. \tag{12}$$

The parameters w1 and w2 in the goal function become the essential weights of the targets and are decided by the decision-makers in a certain way that $w_1 + w_2 = 1$.

Subject to the following:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\mathrm{AE}_{\mathrm{ijt}} - \mathrm{BE}_{\mathrm{ijt}}X_{\mathrm{ijt}}\right)X_{\mathrm{ijt}} + \sum_{i=1}^{m} O_{\mathrm{it}}Y_{\mathrm{it}} + \sum_{j=1}^{n} h_{\mathrm{jt}}I_{\mathrm{jt}} + d_{1t}^{-} - d_{1t}^{+} = B_t, \quad \forall_t, \tag{13}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} W_{\mathrm{it}}X_{\mathrm{ijt}} + d_{2t}^{-} - d_{2t}^{+} = P_t \quad \forall t, \tag{14}$$

$$\mathrm{AE}_{\mathrm{ijt}} = \left(\frac{\mathrm{Cmax}_{\mathrm{ijt}} - \mathrm{Cmin}_{\mathrm{ijt}}}{V_{\mathrm{ijt}} - L}\right) \quad \forall i, j, t, \tag{15}$$

$$\mathrm{BE}_{\mathrm{ijt}} = \mathrm{Cmax}_{\mathrm{ijt}} + L\left(\frac{\mathrm{Cmin}_{\mathrm{ijt}} - \mathrm{Cmax}_{\mathrm{ijt}}}{V_{\mathrm{ijt}} - L}\right) \quad \forall i, j, t, \tag{16}$$

$$\sum_{i=1}^{m} q_{\mathrm{ijt}}X_{\mathrm{ijt}} \le Q_j D_{j^{\cdot}t} \quad \forall j, t, \tag{17}$$

$$I_{j(t-1)} + \sum_{i=1}^{m}\left(1 - q_{\mathrm{ijt}}\right)X_{\mathrm{ijt}} \ge D_{\mathrm{jt}} \quad \forall j, t, \tag{18}$$

$$I_{\mathrm{jt}} = 1_{j(t-1)} + \sum_{i=1}^{m}\left(1 - q_{\mathrm{ijt}}\right)X_{\mathrm{ijt}} - D_{\mathrm{jt}} \quad \forall i, j, t, \tag{19}$$

$$X_{\mathrm{ijt}} \le V_{\mathrm{ijt}}Y_{\mathrm{it}} \quad \forall j, t, \tag{20}$$

Table 1: Range for weights of attributes $\otimes w$.

Range	VLO	LO	MLO	ME	MHI	HI	VHI
$\otimes w$	[0, 0.1]	[0.1, 0.3]	[0.3, 0.4]	[0.4, 0.5]	[0.5, 0.6]	[0.6, 0.9]	[0.9, 1]

Table 2: Range for rankings of attributes $\otimes$GN.

Range	VLO	LO	MLO	ME	MHI	HI	VHI
$\otimes w$	[0, 1]	[1, 3]	[3, 4]	[4, 5]	[5, 6]	[6, 9]	[9, 10]

$$X_{\text{ijt}} \geq \text{LY}_{\text{it}} \forall i, j, t, \tag{21}$$

$$\sum_{i=1}^{m} \left(1 - \text{DT}_{\text{ijt}}\right) X_{\text{ijt}} \leq D_{\text{jt}} \left(1 - \text{DTB}_j\right) \quad \forall i, j, t, \tag{22}$$

$$X_{\text{ijt}} \geq 0 \quad \forall i, j, t, \tag{23}$$

$$I_{\text{jt}} \geq 0 \quad \forall j, t, \tag{24}$$

$$Y_{\text{it}} \in \{0, 1\} \quad \forall i, t, \tag{25}$$

$$\text{AE}_{\text{ijt}}, \text{BE}_{\text{ijt}} \geq 0 \quad \forall i, j, t. \tag{26}$$

Since the price varies with the number of units purchased, (13) is a nonlinear function. Prices were assumed to be constant, independent of the number of products purchased. In this concept, assumptions are changed and used linear discounts to determine the quantity of order to be placed by each supplier; weights (or priority values) are used as coefficients in (14), whose goal is to maximize the total value of the purchasing TVP. Limitations (15) and (16) for linear discounts require suppliers i to disclose a linearly declining per unit price for each product j in each period t for the quantity X_{ijt}. Settling these constraints leads to an increase in prices between $C_{\min}$ and $C_{\max}$. In addition, the buyer's maximum acceptable defective items of product j must be less than the expected range of defective items of product j in period t.

Constraint (18) shows demand limitation; under this constraint, the sum of the acceptable products of type j received from all suppliers in each period t, plus carried quantities from the preceding period, should satisfy the buyer's demand for that product in that period. Material balance equations are shown in constraint (19) for product j for each period t. Constraint (20) indicates capacity hindrance since supplier i can produce up to V_{ijt} units of product j in period t, and its order quantity for product j in period t, X_{ijt}, should be less than its capacity. This constraint shows the minimum order quantities ordered from a supplier and ensures that the orders are greater than or equal to a specified value L under this constraint. The next constraint (22) shows delivery rate limitations. Finally, constraints (23) to (26) show the restriction of the decision variables. A flow chart for the proposed model is shown in Figure 1.

4. Numerical Illustrations

4.1. Computing the Weights of the Aspects and Their Criteria Using Grey. A manufacturing company determines the distribution of demand among the eight candidate suppliers, namely Sl_1, Sl_2, Sl_3, Sl_4 … Sl_8. The four decision-makers DMK_1 to DMK_4 engaged in the selection procedure.

Step 1. A group of four top and middle management personnel assembled as a decision-making team. The team members have been chosen from materials management, finance, store management, and quality control. In addition, personnel with extensive experience in their field and a thorough understanding of the industry's supplier selection process have been selected.

Step 2. A comprehensive literature review would lead to formulating the decision-maker's criteria for selecting green suppliers. The literature review was followed by a meeting with industry decision-makers to discuss their views on green criteria for supplier selection. A final set of eight attributes was determined.

Each decision-maker assigns its evaluation to every vendor according to the linguistic terms shown in Tables 3 and 4. Eight Sli ($i = 1, 2, \ldots, 8$) vendors are chosen as alternatives to eight attributes Aj ($j = 1, 2, \ldots, 8$). The eight attributes are quality, service, price, delivery time, recycling, communication, green purchasing, and consistency.

Step 3. The values of the A_1 to A_8 attributes are fixed. Four DM_1 to DM_4 decision-making committees have been set up to express their priorities, and the right vendors are chosen. As for (1), it was possible to compute evaluations of each of the four attribute weights as shown in Table 3. Table 1 describes linguistic variables in grey numbers between 0 and 1. As shown in Table 2, grey numbers are used to describe attribute scores of GN.

Step 4. The attribute to rank eight alternative suppliers is used, as per (3). The implications of the ranking values have been provided to the attributes, as seen in Table 4.

Step 5. A grey decision-making model was created. As for (4), the grey decision matrix of vendors can be accessed.

Step 6. The grey normalized decision matrix is set according to (5).

Step 7. The grey-weighted normalized decision matrix emerged using (8).

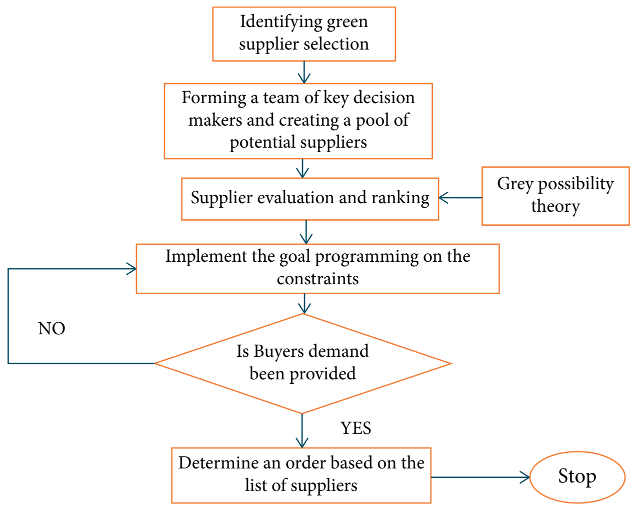

Figure 1: Flow chart for the proposed model.

5. Results and Discussion

5.1. Evaluating and Ranking the Suppliers. The ideal provider Sl^{max}, a comparison option, is rendered. So, it is consistent with (9), and below is shown the ideal provider Sl^{max}:

$Sl^{max} = \{[0.58,\ 0.85],\ [0.45,\ 0.75],\ [0.41,\ 0.75],\ [0.42,\ 0.725],\ [0.48,\ .77],\ [0.45,\ 0.75],\ [0.43,\ 0.72],\ [0.49,\ 0.75]\}$.

The grey probability is determined between the contrasts of the eight green suppliers Sli I = (1, 2, . . ., 8) and the ideal reference vendor choice Sl^{max}. Then, as per (10), the outcome of the grey probability is displayed as follows:

$P(Sl_1 \leq Sl^{max}) = 0.603$ $P(Sl_2 \leq Sl^{max}) = 0.635$ $P(Sl_3 \leq Sl^{max}) = 0.77$

$P(Sl_4 \leq Sl^{max}) = 0.683$ $P(Sl_5 \leq Sl^{max}) = 0.82$ $P(Sl_6 \leq Sl^{max}) = 0.70$

$P(Sl_7 \leq Sl^{max}) = 0.703$ $P(Sl_8 \leq Sl^{max}) = 0.687$.

Phase 6 is as follows: the sequence of eight Sl_i suppliers is selected. Finally, in the grey principle, the right provider is Sl_1, and then, Sl_2, Sl_4, Sl_8, Sl_6, Sl_7, Sl_3, and Sl_5 are used for the chosen set of criteria.

5.2. Order Allocation Using Goal Programming. During three different buying cycles, the model shown here provides a qualitative representation of discount scenarios to reflect that decision-makers are likely to acquire raw materials from four vendors. The vendor score and the incidence of defects were the same for all three periods. The criteria for the issues are indiscriminate and are drawn from a uniform allocation as shown in Table 5, and in the same way, it is common for the score to be given to each supplier and the incidence of the product defect. The following parameters have been utilized in the model issue.

The demand matrix D_{jt}, holding cost h_{jt}, ordering cost O_{it}, and defect rate matrix q_{it} for all three periods are as follows:

$$D_{jt}\begin{pmatrix} 10400 & 14000 & 10000 \\ 15000 & 18000 & 18800 \\ 14000 & 17900 & 19000 \end{pmatrix}, h_{jt}\begin{pmatrix} 1 & 1.5 & 1.9 \\ 4 & 2.5 & 2.2 \\ 3.1 & 3.5 & 4.1 \end{pmatrix},$$

$$O_{jt}\begin{pmatrix} 140 & 115 & 145 \\ 200 & 190 & 195 \\ 170 & 165 & 165 \\ 160 & 150 & 155 \end{pmatrix} q_{jt}\begin{pmatrix} 0.0020 & 0.0030 & 0.0025 \\ 0.0025 & 0.0035 & 0.0055 \\ 0.0045 & 0.0050 & 0.0045 \\ 0.0040 & 0.0035 & 0.0020 \end{pmatrix}. \tag{27}$$

The buyers' max acceptable defect level for every commodity is (0.035, 0.004, 0.0045) Q_j.

$$\mathrm{Cmax}_{ij1} = \begin{pmatrix} 26 & 28 & 30 \\ 31 & 28 & 32 \\ 26 & 30 & 27 \\ 28 & 31 & 20 \end{pmatrix} \quad \mathrm{Cmax}_{ij2} = \begin{pmatrix} 20 & 22 & 30 \\ 23 & 20 & 22 \\ 27 & 28 & 23 \\ 20 & 24 & 29 \end{pmatrix}$$

$$\mathrm{Cmax}_{ij3} = \begin{pmatrix} 25 & 24 & 30 \\ 27 & 23 & 28 \\ 24 & 26 & 30 \\ 27 & 20 & 25 \end{pmatrix} \mathrm{Cmin}_{ij1} = \begin{pmatrix} 22.1 & 23.8 & 25.5 \\ 26.3 & 23.8 & 27.2 \\ 22.1 & 25.5 & 22.9 \\ 23.8 & 26.3 & 17 \end{pmatrix}$$

$$\mathrm{Cmin}_{ij2} = \begin{pmatrix} 17 & 18.7 & 25.5 \\ 19.5 & 17 & 18.7 \\ 22.9 & 23.8 & 19.5 \\ 17 & 20.4 & 24.6 \end{pmatrix} \mathrm{Cmin}_{ij3} =$$

$$\begin{pmatrix} 21.2 & 20.4 & 25.5 \\ 22.9 & 19.5 & 23.8 \\ 20.4 & 22.1 & 25.5 \\ 22.9 & 17 & 21.2 \end{pmatrix} V_{ij1} = \begin{pmatrix} 8800 & 5800 & 7200 \\ 5600 & 3600 & 6800 \\ 4900 & 5500 & 5700 \\ 5500 & 6500 & 7200 \end{pmatrix}$$

$$V_{ij2} = \begin{pmatrix} 5300 & 6500 & 7600 \\ 5900 & 7100 & 6500 \\ 5700 & 5700 & 6100 \\ 8500 & 8500 & 7000 \end{pmatrix}$$

TABLE 3: Attribute weight for 8 suppliers.

A_J	DMK_1	DMK_2	DMK_3	DMK_4
A_1	H	VH	MH	H
A_2	M	H	MH	VH
A_3	H	H	MH	MH
A_4	M	MH	H	H
A_5	MH	VH	MH	H
A_6	VH	MH	H	M
A_7	M	VH	M	H
A_8	H	VH	M	MH

TABLE 4: Attribute rating values for suppliers.

A_J	Sl_i	DMK_1	DMK_2	DMK_3	DMK_4
A_1	Sl_1	F	G	MG	MP
	Sl_2	G	VG	MG	F
	Sl_3	MP	F	G	MG
	Sl_4	MG	G	VG	F
	Sl_5	F	MP	MG	G
	Sl_6	F	MG	F	G
	Sl_7	G	MP	VG	MP
	Sl_8	VG	G	MG	F
A_2	Sl_1	MP	VG	G	MG
	Sl_2	G	F	VG	G
	Sl_3	F	MG	F	F
	Sl_4	MG	VG	G	MP
	Sl_5	P	F	G	F
	Sl_6	F	G	M	G
	Sl_7	VG	G	F	MG
	Sl_8	MP	VG	MG	G
A_3	Sl_1	P	VG	G	MG
	Sl_2	VG	G	F	P
	Sl_3	G	MO	MG	F
	Sl_4	F	F	F	G
	Sl_5	MG	P	G	VG
	Sl_6	G	MG	MP	G
	Sl_7	F	G	P	VG
	Sl_8	MP	F	G	P
A_4	Sl_1	G	VG	P	MG
	Sl_2	F	MG	MG	G
	Sl_3	VG	F	MG	G
	Sl_4	VP	G	MG	F
	Sl_5	MG	MP	F	MP
	Sl_6	F	MG	G	VG
	Sl_7	G	F	F	G
	Sl_8	MP	G	MG	P
A_5	Sl_1	MG	MG	F	G
	Sl_2	F	G	G	F
	Sl_3	MP	F	G	MG
	Sl_4	VG	G	VG	G
	Sl_5	MG	MG	MG	F
	Sl_6	VG	F	F	MP
	Sl_7	F	MP	G	F
	Sl_8	G	F	F	MG

Table 4: Continued.

A_J	Sl_i	DMK_1	DMK_2	DMK_3	DMK_4
A_6	Sl_1	MG	G	F	P
	Sl_2	VG	F	MP	G
	Sl_3	F	G	G	VG
	Sl_4	G	MG	VG	MP
	Sl_5	F	VG	G	F
	Sl_6	MP	MG	G	G
	Sl_7	G	F	MG	MG
	Sl_8	VG	VG	F	F
A_7	Sl_1	G	G	VG	F
	Sl_2	F	VG	MG	VP
	Sl_3	MG	MP	VG	F
	Sl_4	G	VG	F	MG
	Sl_5	MG	F	VG	VP
	Sl_6	F	G	VG	VP
	Sl_7	G	MP	MG	F
	Sl_8	G	F	G	G
A_8	Sl_1	VG	G	VG	MG
	Sl_2	F	VG	F	G
	Sl_3	MG	F	VG	MG
	Sl_4	VP	MG	F	MP
	Sl_5	P	F	MG	VG
	Sl_6	MG	MG	G	F
	Sl_7	G	MP	MG	VG
	Sl_8	VG	F	VG	MG

Table 5: Distribution of parameters for numerical examples.

Parameters	Distribution values
D_{jt}	[10,000–20,000]
H_{jt}	[1–4.5]
O_{it}	[110–200]
Q_{ijt}	[0.0020–0.0055]
Q_j	[0.0035–0.0045]
$Cmax_{ijt}$	[20–35]
$Cmin_{ijt}$	It is set as original price – (original price * (discount/100))
V_{ijt}	[4000–9000]
DT_{ijt}	[0.85–0.97]
DTB_j	[0.90–0.95]
B_t	[870000–1100000]
w_{it}	[0.589–0.660]
DTB_j	It is calculated as (0.95, 0.92, 0.93)
B_t	It is calculated as (960000, 108000, 880000)
L	Value is 100
w_{it}	Complete rating for each supplier i over three phases (0.603, 0.635, 0.683, 0.687)
P_t	It is calculated as (47492, 52521, 53984)
w_1, w_2	Are set as (0.5, 0.5)

Table 6: Periodic order allocation for product 1.

	TP_1	TP_2	TP_3
S_1	2577.325	2975.347	2510.871
S_2	2621.705	2730.205	2509.652
S_3	2616.866	5700	2505.006
S_4	2618.061	2643.449	2507.068

Table 7: Periodic order allocation for product 2.

	TP_1	TP_2	TP_3
S_1	3041.072	5488.329	4483.857
S_2	3039.628	4517.791	4474.752
S_3	3035.256	4511.051	4468.196
S_4	3039.553	4517.698	4474.817

Table 8: Periodic order allocation for product 3.

	TP_1	TP_2	TP_3
S_1	2841.225	7038.865	4526.596
S_2	2832.923	5101.017	4513.708
S_3	2835.909	5105.962	4517.695
S_4	2842.766	1419.374	4813.087

Table 9: SA for TCP.

Demand D_jt	Z_1	Z_2	Min z
$K = 3$	0	0.442	0.221
$K = 2$	0	0.442	0.221
$K = 1$	0	0.442	0.221
$K = 0$	0	0.442	0.221

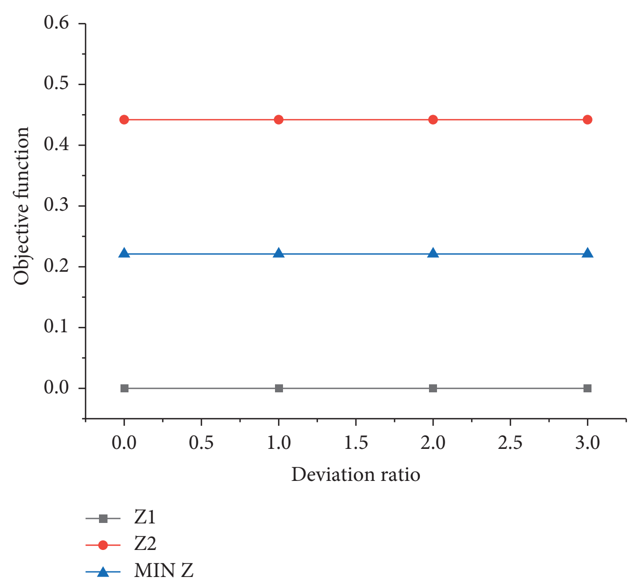

Figure 2: Result of sensitivity analysis for TCP.

Table 10: SA for TVP.

D_jt	Z_1	Z_2	Min z
$K = -3$	0	0.106	0.533–01
$K = -2$	0	0.253	0.126
$K = -1$	0	0.361	0.180
$K = 0$	0	0.442	0.221

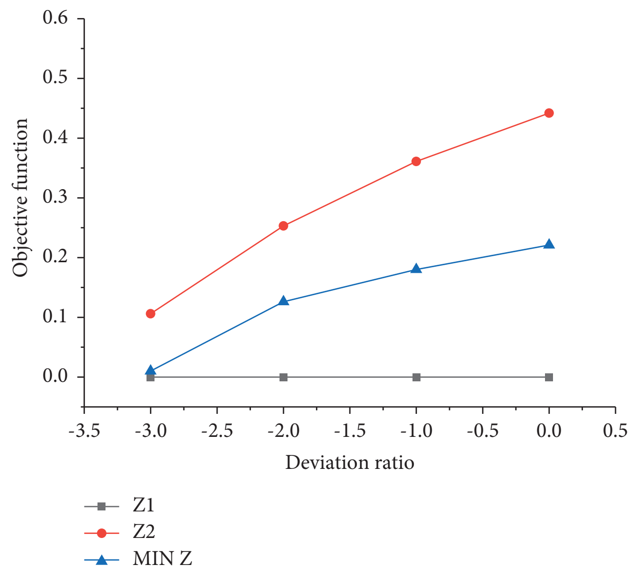

FIGURE 3: Result of sensitivity analysis for TVP.

$$V_{ij3} = \begin{pmatrix} 7500 & 6900 & 7700 \\ 7600 & 7200 & 8800 \\ 6300 & 5000 & 7200 \\ 7300 & 8300 & 7000 \end{pmatrix} \mathrm{DT}_{ij1} = \begin{pmatrix} 0.86 & 0.92 & 0.87 \\ 0.92 & 0.95 & 0.91 \\ 0.95 & 0.98 & 0.95 \\ 0.88 & 0.91 & 0.91 \end{pmatrix}$$

$$\mathrm{DT}_{ij2} = \begin{pmatrix} 0.99 & 0.86 & 0.92 \\ 0.95 & 0.92 & 0.92 \\ 0.95 & 0.96 & 0.98 \\ 0.89 & 0.91 & 0.93 \end{pmatrix} \mathrm{DT}_{ij3} = \begin{pmatrix} 0.87 & 0.94 & 0.89 \\ 0.94 & 0.95 & 0.90 \\ 0.96 & 0.97 & 0.95 \\ 0.96 & 0.94 & 0.97 \end{pmatrix}.$$

The numerical model is programmed and resolved by LINGO 18 optimization kit. The quantity of orders put with each vendor for each commodity within each time is shown in Tables 6–8.

5.3. Sensitivity Analysis. Sensitivity analysis refers to analyzing how exogenous variables' values affect a specific dependent variable behind a set of assumptions. Simulations are one of the primary applications of sensitivity analysis among administrators and decision-makers. Sensitivity analysis illustrates how differences in TCP and TVP affect the optimal solution and order quantity. The design was done by taking B' jt = Bjt + $K\nabla B$, where $\nabla B = 25000$, $t = 1, 2, 3$, and $K = 0, 1, 2, 3$. The descriptions are outlined in Table 9 and Figure 2, where Z1, Z2, and Z are the undesired fractional deviations from targets 1 and 2 and the overall fractional undesired deviation.

Figure 2 indicates that by reducing TCP Goal 1, Goal 2 and total unwanted deviation were constant for overall K values. For the vendor delivery rate, we describe P'jt = Pjt + $K\nabla P$ $\nabla P = 6500$, $t = 1, 2, 3$, and $K = -3, -2, -1, 0$. Table 10 and Figure 3 describe the details. When TVP is increased, Goal 2 and total unwanted deviation rise, but the undesirable deviation from Goal 1 remains constant for all K values.

5.4. Managerial Implications. A decision-making framework that has been proposed here has several implications for decision-makers in the manufacturing industry. First, models developed for the manufacturing industry have high efficiency. Firms can use this model to assess green suppliers and choose the best ones. It is intended to be used by allied business managers to evaluate their suppliers. In this manner, the results obtained can establish guidelines for an organization's SC to prevent insignificant vendors from entering the chain. Integrated methods can also be used for several other management decision-making issues. Due to the firm's focus on green strategies, a vendor that achieves high results can benchmark other vendors. Moreover, the following contributions were made in this study: (1) this paper revealed a limited number of research studies for grey systems to solve the supplier selection problem. (2) Furthermore, this study presented a novel grey integrated goal approach that can potentially be applied to any other future studies relating to the application of several criteria.

6. Conclusion

A few steps and operations are required to complete supplier selection and evaluation. Accordingly, this study presents an academic model for selecting suppliers and allocation of orders. Manufacturers in developing countries must implement comprehensive green supplier selection models to reduce negative environmental impacts and improve economic performance. A vital aspect of the organization's GSCM process is evaluating suppliers and selecting the best green suppliers. The concept of this model is to incorporate linear discounts to select green suppliers and allocate orders. There will be multiple suppliers to fulfil the total requirements known during various periods, and we will be considering a situation where there are multiple products to be purchased.

This work aims to develop a group decision-making model for evaluating green suppliers and allocating orders to suppliers. It is a relatively new approach to supplier selection that considers the relative importance of DMs. The concept was not widely known during the early days of supplier selection. MCDM and MOMINLP techniques are combined to offer a solution to evaluate suppliers and order allocation issues. As part of the integrated approach, the criteria weights and best green supplier are determined through the grey.

Based on the buyer's optimum objectives, the MOMINLP model allocates order quantities to suppliers. Based on this approach, the firm is supported to select the most prominent green supplier and assign optimum orders among the suppliers to satisfy its goals. It is possible to apply this methodology to specific supply chain cases in the oil and gas, textile, and electronics industries for further research to check their general validity. VIKOR, PROMETHEE, GRA, and ELECTRE are some decision-making tools that could be used in future research. Further, the proposed method can evaluate and rank sustainable suppliers using social, economic, and environmental criteria.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

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