Chapter 5
Sustainable Supplier Selection and Order Allocation Considering Discount Schemes and Disruptions in Supply Chain

Akash Sontake, Naveen Jain, and A. R. Singh

Abstract Supplier evaluation and selection on economic, social, and environmental dimensions are crucial for sustaining the pressure of a competitive global supply chain. In this work, a mixed-integer linear programming for supplier selection and order allocation in a single period, multi-supplier, multi-item environment with a prime consideration to the selection of transportation alternatives while delivering items is developed. To capture the real-world situation, the proposed model incorporates no discount and all quantity discount situations considering the bad quality and late delivery disruptions in the supply chain. To reflect a wide variety of operational conditions, two scenarios with two cases have been developed to demonstrate the effect of disruptions and discounts over demand and procurement cost. A real-life case of the automotive sector in central India is studied to validate the proposed model. Also, sensitivity analysis has been performed to understand the trade-offs between different sustainability criteria and the total cost of purchase.

Keywords Sustainable supplier selection · Order allocation · Discount schemes · Disruptions · Sustainability

5.1 Introduction

Formulation and implementation of sound and robust strategies for production planning and management activities for inventory management is important for the industry to exist in the tough competitive global market. Specifically, the selection of a set of right suppliers is a vital decision for the industry to make, as suppliers being upstream supply chain partners help the industry to gain competitive advantage. Therefore, supplier evaluation and selection have become a strategic decision for the managers [11]. Often the supplier selection problem is considered as a Multi-Criteria

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Decision-Making (MCDM) problem in which both qualitative and quantitative evaluation criteria are considered for the formulation of a set of potential suppliers for making the final selections [22]. Carrying out the final selection of suppliers needs addressing of two crucial aspects (i) establishment of the degree of importance of selection criteria and (ii) evaluation of suppliers performance with regard to the selection criteria [38].

In recent years, integration order allocation model with supplier selection decision model has been extensively addressed by the researchers. Researchers have proposed various order allocation models with the objective of determining the optimal order quantity of items to be allocated to each supplier to meet the production plan considering the laid constraints [12, 41]. Earlier supply chain decisions of Supplier Selection and Order Allocation (SS&OA) considered only economic criteria. However, in the last two decades, there has been exponential growth in sustainability awareness among the various stakeholders of the industry. Customers, employees, government agencies, nonprofit organizations are very much vigilant about the sustainable actions and goals of the industry. The advent of sustainable development concept imposes new rules and regulations in the supply chain, forcing decision-makers to consider three pillars of sustainability or Triple Bottom Line (TBL) [5], i.e., environmental, economic, and social criteria in decision-making. According to the Brundtland report, “Sustainable development is to meet the needs of the present without compromising the need of future generation” [50]. In recent years, Sustainable Supply Chain Management (SSCM), where the inclusion of social and environmental dimensions along with the economic sustainability dimension is considered by decision-makers, has attracted the attention of persons from both industry and academia [6, 8]. Inclusion of sustainability objectives in the industry’s supply chain helps in achieving two-fold advantages. Firstly taking sustainability initiatives helps the industry to stay competitive in the global market and helps in timely fulfill of market demands. Secondly, sustainable and green methods help industry’s to build an image in the market and thus achieves higher sales [17]. Further, taking up sustainability activities in the supply chain helps industries to comply with the stringent government laws and improve their sustainability performance level [51]. Suppliers play a major role in facilitating the industries in meeting the sustainability objectives [30]. Working with the suppliers who take into account sustainability practices while manufacturing helps the company to enhance sustainability rank among their supply chain competitors. Thus, Sustainable Supplier Selection (SSS) is the evaluation and selection of suppliers on the basis of their performance relative to TBL [23]. However, the economic competition in the market is becoming severe each day. Therefore, selection of suppliers needs to be addressed not only on sustainability criteria but also to be investigated on the type of discount scheme offered by the supplier [24, 41]. In a real-world the situation, industry allocates orders for the same items to multiple suppliers so as to survive in a competitive market as various uncertainties exist which might cause the firm to lose its existing customers and has to see more time for the product to reach market. Further, suppliers offer various discount schemes when the order quantity is large in order to increase their chances of selection and also encourage the buyer to buy more. On the other hand or the industry the order quantity increases but the unit price of the item offered by the supplier decreases.

Most of the researchers have addressed the supplier selection and order allocation problem considering only the economic and environmental dimensions of sustainability [9, 25, 26]. With the growing awareness about social issues more recently, social dimension has also been considered with economic and environmental aspects of sustainability in researches pertexting to sustainable supplier selection and order allocation [1, 32, 42]. Further, most researchers have considered only single item while addressing order allocation problem. Researches considering social, environmental, and economic criteria for supplier selection and considering multi-item with quantity discounts and disruptions are very scarce. Further, consideration of different modes of transportation to reduce greenhouse gas emissions to lower the environmental impact is very less addressed.

Accordingly, for the above-mentioned problem, in this work SSS&OA problem of the strategic decision-maker in a single period, multi-item, multi-supplier environment considering quantity discount and disruptions in shipment such as bad quality and late deliveries has been considered. Further, multiple transportation modes problem is considered by the decision-maker to deliver allocated orders because the threat of climate change has been increasingly discussed at an international level, with greenhouse gas emissions from fossil energy sources being at the forefront of governmental concerns [40]. Transportation activities while delivering allocated order to companies' accounts a major portion in GHGs emission. Selection of proper transportation modes, improving vehicle fill and determining the number of trucks for delivery are crucial decisions to improve environmental sustainability.

The proposed SSS&OA model comprises of three phases: in the first stage, sustainability criteria and sub-criteria in economic, social, and environmental dimensions are established based on companies' competitive strategy, expert's opinions, government regulations and available literature and sustainable supplier evaluation and selection are performed. Further, Analytic Hierarchy Process (AHP) method is applied for assigning weights to criteria and sub-criteria for each sustainability dimensions and supplier's sustainability performance on these criteria is evaluated by applying Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and based on performance ranks are awarded to the suppliers. In the second stage, a mathematical model is developed to minimize total Purchasing cost, Ordering cost, Transportation cost, considering disruptions of defective items cost, late delivery cost and GHG emission penalty along with maximizing score of the supplier on basis of sustainability dimensions. In the third stage Order delivery (OD) by the suppliers is addressed by considering a truck routing problem to minimize transportation cost, GHGs emissions, and improving truck fill. A case study in automobile company producing car accessories situated in central India is applied to accumulate model parameters and to demonstrate the applicability of the proposed model.

The rest of this paper is organized as follows. Section 5.2 provides a brief literature review of related work. Section 5.3 provides details of the mathematical model. Sections 5.4 and 5.5 covers the AHP and TOPSIS MCDM techniques used in the study. Section 5.6 presents the application of the model in the case company and finally, Sect. 5.7 gives concluding remarks of the paper.

5.2 Literature Review

In this section, a literature review related to SSS&OA, Discount schemes, disruptions, and Transportation problems is given and finally, research gaps and proposed research contributions are presented.

5.2.1 Sustainable Supplier Selection

In recent years, a major shift is experienced by supply chain decision-maker with the advent of sustainability in the present world. Thus, the inclusion of environmental and social criteria is considered in research along with economic criteria [2, 6, 17, 15, 16, 25, 29]. Supplier selection is a multi-criteria decision-making process. So, managers always try to opt for the best approach to select and evaluate their suppliers in order to optimize their companies' benefits and to achieve higher sustainability ranks among its supply chain counterparts. In literature researchers have considered various MCDM approaches: AHP [6], TOPSIS [38], BWM [6], DEMATEL [17, 48], etc.

5.2.2 Order Allocation

In the traditional supply chain, only economic criteria were prevalent for supplier selection and evaluation. Hadian et al. [18] proposed a supplier selection and order allocation problem in which a Multi-Objective Linear Programing (MOLP) is converted to single-objective problem using Weighing method to develop a mathematical model for allocating orders to suppliers. The multiple objectives in their problem include Cost minimization, Maximizing Purchasing value, minimizing the number of defective and late delivered items. Tsai [52] stated that determining the suppliers and splitting orders between them has become a major challenge for buying firms. Keeping in mind the statement, SS&OA problem of MOMIP model considering imperfect shipment is presented by the author which is solved by the weighing method which is traditional, popular, and easy to implement. Basnet and Leung [3] presented a Multi-supplier, Multi-item, Multi-period inventory lot-sizing scenario aimed to minimize Procurement cost which includes purchasing cost, holding cost and ordering cost with constraints of capacity and demand. Songhori et al. [49] proposed a supplier and transportation alternatives selection problem. Data development analysis model is utilized to determine the relative efficiency of suppliers and transportation alternatives. In order allocation phase, Multi-objective mixed integer programming is considered with objectives of cost minimization and overall efficiency maximization. Razmi and Rafiei [44] proposed a Hybrid Analytic Network Process-mixed integer mathematical model in purchasing planning to select suppliers and allocate orders to them. Wang et al. [54] considered a *n*-capacity supplier inventory system with Suppliers having different lead times and purchase prices in linear integer programming model of SS&OA to select the best suppliers and to determine reorder level order splitting among suppliers. Meena and Sarmah [33] studied the problem of SS&OA under risk of supplier failure due to disruption events with objectives of minimizing expected total cost which includes purchasing cost, supplier management cost, and expected loss cost. Ruiz-Torres and Mahmoodi [45] presented a mathematical model that optimizes the allocation of demand across a set of selected suppliers with objectives of minimizing expected total cost which includes purchasing cost, supplier management cost, and expected loss cost. Fazlollahtabar and Mahdavi [7] proposed an integrated approach of AHP, TOPSIS, and multi-objective nonlinear programming to consider various factors in choosing the suppliers and splitting orders among selected suppliers to maximizing total purchasing value and minimizing the budget, total penalty due to tardiness and defect rate. Sawik [47] proposed a problem which deals with optimal supplier selection and order allocation in the presence of supply chain disruption risks. Table 5.1 presents a brief review of the SSS and OA literature.

5.2.3 Quantity Discounts

Quantity discount offerings in procurement play a major role in providing benefits to both the suppliers and buyers. Some discounts increases annual demand from customers, while others may only increase the order size [37]. Tsai [52] stated Price discount encourages buyers to make large purchases, and are a common and effective way for a supplier to promote their product. Thus, researchers have included quantity discounts in model formulation. Recently, Cheraghalipour and Farsad [6] proposed a multi-objective model for SS&OA where they utilized both all quantity and Incremental discount schemes for model formulation. Gupta et al. [16] employed a weighted possibilistic programming approach for sustainable vendor selection and order allocation in a fuzzy environment considering All quantity discount schemes to attract buyers. All quantity discount in multi-period green supplier selection problem is proposed by Hamdan and Cheaitou [19] where suppliers availability varies in each period. Jain et al. [21] utilized a chaotic bee colony approach for SS&OA problem considering all quantity and incremental discount. The author has reported that all quantity discount scheme is more preferable than an incremental discount scheme. However, in an overview for quantity discount by Munson and Jackson [37], the author has reported that all quantity discount represents by far the most popular form of quantity discount and is applied best in the purchase made at a single point of time or single period purchasing model. Further, the authors stated that incremental

Table 5.1 Literature review on SS&OA

Authors	Solution approach	Mathematical model	Economic	Environ mental	Social	OA	Item[a]
Basnet and Leung [3]	Enumerative search algorithm	✓	✓			✓	MI
Ruiz-Torres and Mahmoodi [45]	EXCEL solver	✓	✓			✓	SI
Razmi and Maghool [43]	MINLP, ANP	✓	✓			✓	SI
Wang et al. [54]	Genetic algorithm	✓	✓			✓	SI
Fazlollahtabar and Mahdavi [7]	AHP, TOPSIS, MINLP	✓	✓			✓	MI
Lee et al. [28]	ANP	✓	✓	✓			MI
Govindan et al. [14]	Fuzzy TOPSIS, MOLP	✓	✓	✓		✓	SI
Orji and Wei [39]	System dynamic simulation	✓	✓	✓	✓	✓	MI
Gupta et al. [16]	Fuzzy, Probabilistic programming	✓	✓	✓	✓	✓	MI
Tsai [52]	Weighing method	✓	✓			✓	MI
Nourmohamadi Shalke et al. [38]	RMCGP, TOPSIS	✓	✓	✓	✓	✓	MI
Cheraghalipour and Farsad [6]	RMCGP, BWM	✓	✓	✓	✓	✓	MI
Mohammed et al. [36]	Fuzzy AHP, MOP	✓	✓	✓	✓	✓	SI
Mirzaee et al. [34]	Fuzzy goal programming	✓	✓			✓	MI
Vahidi et al. [53]	Hybrid SWOT QFD	✓	✓	✓	✓	✓	MI
Hamdan and Cheaitou [19]	Branch and cut algorithm	✓	✓	✓		✓	MI
Govindan et al. [13]	MOP	✓	✓	✓	✓	✓	SI

(continued)

Table 5.1 (continued)

Authors	Solution approach	Mathematical model	Economic	Environ mental	Social	OA	Item[a]
Ghadimi et al. [10]	A multi-system agent approach	✓	✓	✓	✓	✓	SI
Lo et al. [29]	FMOLP	✓	✓	✓		✓	MI
Babbar and Amin [2]	Fuzzy QFD	✓	✓	✓		✓	MI
Lee and Chien [27]	Stochastic programming	✓	✓			✓	MI

[a] *MI* multi-item; *SI* single item

Table 5.2 Literature review on discounts and disruptions

Authors	Discount			Disruptions
	All quantity	Incremental	Volume	
Basnet and Leung [3]			✓	✓
Ruiz-Torres and Mahmoodi [45]	✓			✓
Shalke et al. [38]	✓	✓		
Cheraghalipour and Farsad [6]	✓	✓		✓
Lee and Chien [27]	✓			
Gören [17]				✓
Hamdan and Cheaitou [19]	✓			
Meena and Sarmah [33]	✓			✓
Gupta et al. [16]	✓			
Moghaddam [35]				✓

discount works well when the order covers a period of time or when a multi-period model is considered. Table 5.2 addresses some literature on quantity discounts and disruptions.

5.2.4 *Disruptions*

Suppliers while supplying allocated orders to buyers, sometimes are subjected to disruption which in any form, late delivery, bad quality due to lack in inspection, lost sales, equipment failure, workers strike disturb's supply chain working. This motivates researchers to consider disruptions while developing models. Tsai [52] extended the traditional EOQ model including disruption in shipment, defective items, and late delivery, and formulated an NLP model of SS&OA in multi-item, multi-supplier environments. Similarly, Hadian et al. [18] presented a multi-objective supplier selection and order allocation model that tries to optimize the single buyer and multiple-supplier problem by minimizing the total purchasing cost, the total number of late delivered items and the total number of defective items. However, neither of these two papers imposed penalty over suppliers for such disruptions. The concept of lost sales in which suppliers are not able to meet buyers' demand is introduced in SS&OA model presented by Gören [17]. Thus, in order to make suppliers more resilient and to smoothen up the supply chain's performance considering disruptions and imposing a penalty is much-needed action.

5.2.5 Transportation Alternatives

Growing environmental pollution is a major concern in this era of sustainability where items delivery through transportation modes contributes a major portion by the release of GHG's emissions. To tackle this environmental issue many researches have been done. Bazan et al. [4] informed that GHGs emission from both production and transportation has to be considered in supply chain modeling which allow decision-makers to approach supply chain designing problem with the perspective of sustainable development. Gang, et al. [9] provided a review on OA problem with transportation alternatives, in which authors have concluded that only the buyer decides both order allocation and transportation alternatives. In contrast, he stated that in practice only the price and ordered quantity decisions are taken by the buyer while transportation alternative decisions are taken by Suppliers. Magiera [31] proposed a model to plan deliveries of food products by considering SS and transportation alternatives problems. Bazan et al. [4] in their research concluded that truck capacity, unfilled spaces, have a major impact on GHGs emissions and transportation costs. This has motivated the inclusion of transportation alternative problem with SS&OA in this proposed work.

5.3 Mathematical Model

In this work, a situation is considered where a buyer firm buys its requirements from various available suppliers. A multi-objective mathematical model is developed considering multiple items multiple suppliers' single periods taking into account quantity discount. Each supplier has a limited capacity and is subjected to disruption due to bad quality and late deliveries. The mathematical model is aimed to minimize total Purchasing cost, Ordering cost, Transportation cost, Defective items cost, Late Delivery cost, and GHG emission penalty along with maximizing the score of the supplier on basis of economic, environmental and social dimensions.

5.3.1 Subscripts

i Index of items ($i = 1, 2, \ldots, I$)
j Index of suppliers ($j = 1, 2, \ldots, J$)
k_{ij} Index of discount range from supplier i for item i ($k_{ij} = 1, 2, \ldots, K_{ij}$).

5.3.2 Parameters

C_{ij} Purchase price of item i from supplier j (w/o discount)
$C^{A}_{ijk_{ij}}$ Price of item i for the purchase in discount range k_{ij} of supplier j
D_i Demand of item i in planning horizon
O_j Ordering cost from supplier j
T_j Fixed transportation cost per shipment from supplier j
Cap_{ij} Capacity of supplier j for item i
δ_{ij} Defect rate (in percent) of item i from supplier j
δmax Maximum acceptable defect rate of item i
$\bar{d}$ On time delivery that supplier maintains for item i which is measured as percentage of late delivered items
M A sufficiently large number
$\text{LB}_{ijk_{ij}}$ Lower bound of the quantity discount range k_{ij} of supplier j for item i
$\text{UB}_{ijk_{ij}}$ Upper bound of the quantity discount range k_{ij} of supplier j for item i
G Penalty cost per surplus GHG emission (Rs.)
EF^s Green house Emission factor(kg/ton-km) by using transportation alternatives
N_j^s Number of unit supplied by supplier j using transportation alternatives H, M and L per shipment
ϕ_j Distance between supplier j and buyer organization (km)
W_i Weight of item i
DC_i Unit defective cost for item i
DD_i Unit delivery delay cost for item i
d_{ij} =1 if supplier j does not consider any discount for item i
=0 otherwise
d^A_{ij} =1 if supplier suggests all quantity discount for item i
=0 otherwise.

5.3.3 Decision Variables

$C'^{A}_{ijk_{ij}}$ =1 if supplier j selects discount range k_{ij} for item i
=0 otherwise
X_{ij} Number of item i bought from supplier j in planning horizon

Y_j =1 if an order is allocated to supplier j
=0 otherwise.

It should be noted that UB_{ij0} and LB_{ij0} are set to zero; $\text{UB}_{ijk_{ij-1}} = \text{LB}_{ijk_{ij}}$ $\forall i, j, k_{ij}$; $\text{UB}_{ijk_{ij}} = \infty \, \forall i, j$. To be more precise, each supplier is free to choose between quantity discount and no discount policy, i.e., $d_{ij} + d_{ij}^{A} = 1$, if $d_{ij} = 1$; quantity discount is not considered in a proposed order allocation model.

5.3.4 Objective Functions

$$\begin{aligned}\text{Obj}_1 = {} & (\text{Purchasing cost} + \text{Ordering cost} + \text{Transportation cost} \\ & + \text{Greenhouse emission cost} + \text{Bad quality cost} + \text{Late delivery cost})\end{aligned} \tag{5.1}$$

$$\text{Purchasing cost} = \sum_i \sum_j X_{ij} \times C_{ij} \times d_{ij} + d_{ij}^{A} \sum_i \sum_j \sum_k X_{ijk_{ij}} \times C_{ijk_{ij}}^{A} \times C_{ijk_{ij}}^{\prime A} \tag{5.2}$$

$$\text{Ordering cost} = \sum_j O_j \times Y_j \tag{5.3}$$

$$\text{Transportation cost} = \sum_j N_j^{H} \times \text{TC}_j + \sum_j N_j^{M} \times \text{TC}_j + \sum_j N_j^{L} \times \text{TC}_j \tag{5.4}$$

$$\text{Greenhouse emission cost} = G\left[\sum_i \sum_j \text{EF}^{s} W_i \phi_j N_j^{s} - \text{Limit}\right] \tag{5.5}$$

$$\text{Bad quality cost} = \sum_i \sum_j \delta_{ij} \times X_{ij} \times \text{DC}_{ij} \tag{5.6}$$

$$\text{Late delivery cost} = \sum_i \sum_j \bar{d}_{ij} \times X_{ij} \times \text{DD}_{ij} \tag{5.7}$$

$$\begin{aligned}\text{Obj}_2 = {} & W_{\text{eco}} \sum_i \sum_j X_{ij} \times \text{Eco}_{ij} + W_{\text{env}} \sum_i \sum_j X_{ij} \times \text{Env}_{ij} \\ & + W_{\text{soc}} \sum_i \sum_j X_{ij} \times \text{Soc}_{ij}\end{aligned} \tag{5.8}$$

Subjected to:

$$\sum_i X_{ij} \leq \text{Cap}_{ij} \times Y_j \, \forall i, j \tag{5.9}$$

$$\sum_i X_{ij} = D_i\left(1 + \delta_{ij}\right) \tag{5.10}$$

$$\delta_{ij} \le \delta\text{max} \tag{5.11}$$

$$\bar{d} \le \bar{d}\text{max} \tag{5.12}$$

$$X_{ij} \le M \times Y_j \tag{5.13}$$

$$\sum_i \sum_j X_{ij} \le \text{UB}_{ijk_{ij}} + M\left(1 - C'^A_{ijk_{ij}} d^A_{ij}\right) \forall i, j, k_{ij} \tag{5.14}$$

$$\sum_i \sum_j X_{ij} \ge \text{LB}_{ijk_{ij}} - M\left(1 - C'^A_{ijk_{ij}} d^A_{ij}\right) \forall i, j, k_{ij} \tag{5.15}$$

$$\sum_{k_{ij}} C'^A_{ijk_{ij}} = 1 \,\forall i, j \tag{5.16}$$

$$\sum N^S_j = \sum \left[N^H_j + N^M_j + N^L_j\right] \quad S \in H, M, L \tag{5.17}$$

$$\sum_i \sum_j X_{ij} \le \sum_j \sum_s N^s_j \tag{5.18}$$

$$\sum_i \sum_j \sum_s V_i \times N^s_j \le \sum_s V^s \tag{5.19}$$

$$\sum_i \sum_j \sum_s M_i \times N^s_j \le \sum_s M^s \tag{5.20}$$

$$\begin{aligned} &C'^A_{ijk_{ij}}, Y_j \in \{0, 1\} \\ &d^A_{ij}, d_{ij} \in \{0, 1\} \,\forall i, j, k_{ij} \\ &N^H_j, N^M_j, N^L_j \ge 0 \end{aligned} \tag{5.21}$$

Equation (5.1) calculates the first objective function and attempts to minimize total cost, which includes purchasing cost, ordering cost, transportation cost, greenhouse emission penalty, late delivery, and bad quality penalty. These costs are presented in Eqs. (5.2)–(5.7) separately. The first part of Eq. (5.2) calculates purchasing cost without discount while second part attempts to minimize purchasing cost with all quantity discounts. Equation (5.3) calculates ordering cost if a supplier is selected. Transportation cost is shown by Eq. (5.4) which is incurred while delivering items to the buyer. Three types of trucks are available with suppliers for items delivery. Equation (5.5) minimizes GHGs emission from transportation activities. If the Government implements regulation on GHGs emission (specifying limit) three conditions occur. The first condition is that, if the limit set by Government is less than the total GHGs emission from supplier j while transporting item i to a buyer than penalty cost G (Rs./ton) is incurred to supplier j for every surplus GHG's emission (ton). For the second condition, if the limit set by the government is more than the total GHG's emission from supplier j while transporting item i to a buyer than the supplier is not penalized, but he can use the remaining carbon emission for emission trading to other firms or suppliers. This model is limited to the first case and for the second case no emission trading is considered, i.e., the total cost due to GHG's emission will set to "0" if the second condition exists. Equation (5.6) and (5.7) attempts to minimize total rejected items and late delivered items. Quality and Late delivery in our case are measured in terms of percentage. The second objective function shown in Eq. (5.8) aims to maximize the weighted sum of total sustainability score of suppliers which includes the economic, environmental and social score. Supplier's scores with respect to criteria are calculated by AHP and TOPSIS. Equation (5.9) assures that the number of items i ordered from supplier j is equal to or less than the supplier's capacity in that time. Equation (5.10) assures that ordered quantity for each item from suppliers should be greater than demand during the planning horizon because defective pieces always remain in purchased quantity. Equations (5.11) and (5.12) puts a limitation on the defect rate of item i from supplier j. Equation (5.13) indicates that if the decision is to purchase item i from supplier j firstly the supplier should be selected. Constraints (5.14)–(5.16) utilize the proper discount range for suppliers who offer incremental discounts. Constraint (5.17) and (5.18) explains that a total number of units transported by using all available vehicles must be equal to the number of units supplied by all available supplier j. Constraint (5.19) and (5.20) are used to show the space and weight limitations on a particular transportation alternative. Constraint (5.21) imposes binary and positive integer constraints.

5.4 AHP

In order to determine the criteria weights, A MCDM technique AHP is employed. The main steps of this technique to obtain the weight of criteria and alternatives (suppliers) are presented below:

Step 1. Develop a pairwise comparison matrix for sub-criteria by giving scores on the basis of relative importance in the scale of 1–9 given by Satty [46], given in Table 5.3.
Step 2. Add elements in each column to find the sum of each column.
Step 3. Divide each element of the pairwise comparison matrix by the sum of each column obtained in step 2.
Step 4. Add each row and find out average to obtain Principle vectors or Eigenvectors which represents weights of sub-criteria.

Table 5.3 Measurement scale [46]

Verbal judgment or preference	Numerical rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Intermediate values between two adjacent judgments (when compromise is needed)	2, 4, 6 and 8

5.5 TOPSIS

TOPSIS is one of the simplest, strongest, and fastest techniques in MCDM which determines the distance of selected alternatives from a positive ideal solution and the negative ideal solution [20]. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal. To obtain the supplier's score TOPSIS is utilized. The steps used in TOPSIS are:

Consider $m \times n$ matrix having m criteria and n alternatives. Let J the set of benefit attribute and J' set of negative attributes.

Step 1. Build the normalized decision matrix which can be described as

$$R_{ij} = \frac{x_{ij}}{\sum x_{ij}^2} \tag{5.22}$$

where R_{ij} is a normalized form of x_{ij}, where x_{ij} is the score of each alternative regarding each criterion.

Step 2. Construct the weighted normalized decision matrix which can be written as

$$V_{ij} = W_j \times R_{ij} \tag{5.23}$$

where W_j is the weight of the criterion.

Step 3. Determine positive ideal solution A^* and negative ideal solution A'

$$A^* = \{V_j^*, \ldots, V_n^*\} \tag{5.24}$$

where $V_j^* = \{\max(V_{ij}) \text{ if } j \in J;\ \min(V_{ij}) \text{ if } j \in J'\}$

$$A' = \{V_j', \ldots, V_n'\} \tag{5.25}$$

where $V_j' = \{\min(V_{ij}) \text{ if } j \in J,\ \max(V_{ij}) \text{ if } j \in J'\}$.

Step 4. Calculate distance measures of each alternative.

The distance from the ideal alternative is:

$$S_i^* = \left[\sum_j (V^* - V_{ij})^2)^{1/2} \right] \quad i = 1, \ldots, m \tag{5.26}$$

Similarly, the distance from the negative ideal alternative is:

$$S_i' = \left[\sum_j (V_j' - V_{ij})^2)^{1/2} \right] \quad i = 1, \ldots, m \tag{5.27}$$

Step 5. Calculate the relative closeness coefficient to an ideal solution C_i^*

$$C_i^* = S_i'/(S_i^* + S_i') \quad 0 < C_i^* < 1 \tag{5.28}$$

A supplier with higher value of relative closeness coefficient has a higher rank among the alternatives.

5.6 Computation Results

5.6.1 Case Study

To demonstrate the applicability of the proposed model, an automobile company situated in central India has been examined. The companies' CEO wants to consider sustainability aspects in its supply network activities in order to achieve higher ranks among its supply chain counterparts. So, the managers and experts concluded to consider the sustainability elements in their supplier evaluation. The company is involved in the production of 4 wheelers and to focus on its core functions, it outsources various accessories from local suppliers which include AC compressor, A/V system, and Navigation units. Buying these raw materials (items) is done from suppliers that considered sustainability requirements in their manufacturing procedures. The model has been used on a network of a supply chain consisting of five suppliers and a single buyer. However, the company wants to select at most three suppliers among the five candidate suppliers. Each supplier can supply multiple items to the buyer and are subjected to disruptions in demand due to the bad quality of manufactured items. Also, items can be purchased once a year. Suppliers are allowed to offer different pricing policies for each item, such as all quantity discounts, or no discount policies. The supplier is available with three types of trucks for items delivery, i.e., Heavy drive truck (Capacity up to 3.5 ton), Medium drive truck (capacity

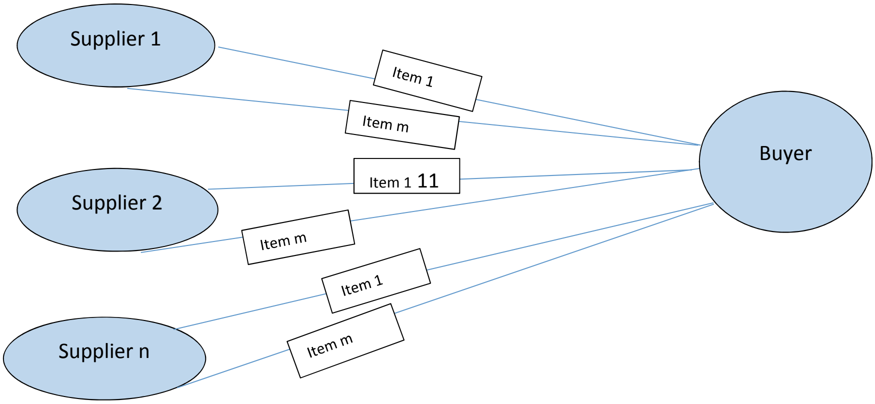

Fig. 5.1 Network configuration

3.5–8 ton), and Low drive truck (capacity > 8 ton). The network configuration is shown in Fig. 5.1.

5.6.2 Problem Description

This section describes the data required by the model to set values for the parameters. The supplier selection and order allocation consists of five suppliers who supply three kinds of items and a single buyer. The items are delivered from suppliers to buyers in three kinds of trucks. To study the behavior of the proposed model, data from the buying firm has been collected which is depicted in Tables 5.4, 5.5, 5.6, 5.7, 5.8, 5.9,

Table 5.4 Data related to capacity, purchase cost without discount of items from suppliers, a distance of suppliers and transportation cost from suppliers

Suppliers	AC compressors		A/V system		Navigation units		The distance of suppliers from the buyer	Transportation cost (Rs./km)
	Capacity	Unit cost	Capacity	Unit cost	Capacity	Unit cost		
S1	700	15,000	1700	16,000	900	16,000	150	150
S2	900	14,500	1800	18,000	1100	17,000	50	100
S3	800	17,000	1600	20,000	700	15,000	100	150
S4	1000	15,000	1500	30,000	1200	12,000	50	100
S5	600	19,000	1500	24,000	800	10,000	100	80
Demand for items	1100		2200		1100			

Table 5.5 Expected defect rate of suppliers for different items and penalty

Suppliers	AC compressors	A/V system	Navigation units
S1	0.01	0.02	0.01
S2	0.03	0.02	0.02
S3	0.01	0.01	0.02
S4	0.02	0.02	0.04
S5	0.02	0.02	0.01
δmax	0.05	0.05	0.05
DC_i	2000	3000	2000

Table 5.6 Percentage of late deliveries from each supplier and penalty

Suppliers	AC compressor	A/V system	Navigation units
S1	0.02	0.02	0.01
S2	0.03	0.03	0.02
S3	0.01	0.02	0.02
S4	0.02	0.01	0.04
S5	0.02	0.03	0.01
Max lead time allowed	0.05	0.05	0.05
DD_I	1000	1000	1500

5.10, and 5.11. Table 5.4 depicts the maximum capacity of all types of items, unit purchasing cost of each item from each supplier, and distance of suppliers from the buyer's organization. Expected defect rate of each item from suppliers, maximum allowable defect rate, and penalty associated are given in Table 5.5. Table 5.6 depicts expected late deliveries, allowable late delivery, and associated cost. Discount ranges offered by suppliers for each item are shown in Table 5.7. Table 5.8 gives information related to the weights of items and their dimensions. The capacity of each truck used by suppliers to deliver the items and emission factor of each truck is given in Table 5.9. A maximum number of units that trucks can carry while delivering is depicted in Table 5.10. Each type of truck can deliver multiple items in a single shipment. Table 5.11 depicts the penalty associated with the GHG emission exceeding the permissible limit values.

5.6.3 Solution Procedure

The proposed problem is solved in three phases. In the first, evaluation of suppliers, according to the economic, environmental, and social aspects is studied. For the computation of the criteria's weights along with suppliers' scores, AHP and TOPSIS approach is applied. In the second phase, MS excel solver is utilized to solve the

Table 5.7 Discount range from each supplier

Items	S1		S2		S3		S4		S5	
	Range	Unit price	Range	Unit price	Range	Unit price	Range	Unit price	Range	Unit price
AC compressor	0–200	15,000	0–300	14,500	0–200	17,000	0–300	15,000	0–400	19,000
	200–400	14,000	300–600	14,000	200–400	16,000	300–600	14,500	400–600	18,000
	400–∞	13,000	600–∞	13,000	400–∞	14,500	600–∞	14,000	600–∞	17,000
A/V system	0–300	16,000	0–400	18,000	0–500	20,000	0–300	30,000	0–500	24,000
	300–900	15,500	400–900	17,500	500–1100	19,000	300–800	29,000	500–1500	23,000
	900–∞	15,000	900–∞	17,000	1100–∞	18,500	800–∞	25,000	1500–∞	21,000
Navigation unit	0–200	16,000	0–300	17,000	0–200	15,000	0–300	12,000	0–400	10,000
	200–400	15,500	300–600	16,000	200–400	14,500	300–600	11,500	400–600	9500
	400–∞	15,000	600–∞	15,500	400–∞	14,000	600–∞	11,000	600–∞	9000

Table 5.8 Weight (kg) and dimensions (mm^3) of items

	AC compressor	A/V system	Navigation units
Weight	5	5	3
Dimensions	250 × 250 × 250 mm	457 × 406 × 305 mm	250 × 200 × 130 mm

Table 5.9 Emission factors for trucks and capacity of each truck

Type	Capacity (ton)	Emission factor (kg CO_2/km)
LDV	<3.5	0.3070
DV	3.5–12	0.5928
HDV	>12	0.7375

Table 5.10 Maximum no. of units of each item in each truck

Truck type	AC compressor	A/V system	Navigation unit
LDV	62.9376	17	151.29
MDV	552.512	152.55	1328.15
HDV	2623.26	724.32	6306.15

Table 5.11 Emission penalty data

Emission		Penalty
0	50	100
50	100	200
100	150	300
150	200	400
200	250	500
250	300	600
300	350	700
350	400	800
400	450	900
450	∞	1000

proposed bi-objective model for sustainable supplier selection and order allocation problems. To deliver the allocated order to a buyer, the knapsack problem is utilized which is presented in the third phase.

Table 5.12 Sustainability criteria and sub-criteria

Dimension	Criteria	References
Environmental	Green packaging, emission, and waste disposal, pollution	[16, 38]
Social	Worker safety and health, wages. Child and bonded labor, information disclosure	[6]
Economic	Cost, quality certification, late delivery, performance history	[38]

Table 5.13 Sustainability criteria weights in three dimensions

Economic dimension		Environment dimension		Social dimension	
Criteria	Weight	Criteria	Weight	Criteria	Weight
Cost	0.3109	Pollution	0.5389	Wages	0.4894
Quality	0.4915	Emission and waste disposal	0.2972	Worker safety and health	0.2878
Late delivery	0.1260	Green packaging	0.1637	Child and bonded labor	0.1623
Performance history	0.0714			Information disclosure	0.0603

5.6.3.1 Sustainable Supplier Selection

A team of Decision-Makers (DM) comprising of experts from various departments of the company such as purchasing, production, quality control is formed. All experts are experienced and have significant knowledge of supplier selection process in the organization. Discussion with team members was held and the sustainability criteria for supplier selection were finalized (Table 5.12). Further, steps of AHP are applied and the comparison matrix is established. The CI values were checked and the weights to the sustainability criteria in all three dimensions are established (Table 5.13). Each supplier is assessed for sustainability performance with respect to four economic, three environmental, and five social criteria for every item supplied by them by applying the TOPSIS method. All the steps of TOPSIS, were applied and closeness coefficient of suppliers was established and weighted suppliers score for each item with respect to economic, environmental, and social criteria is established as presented in Tables 5.14 and 5.15, respectively. Based on the values of the final scores, ranks are awarded to the suppliers. The final ranks of suppliers are the following order S1 > S6 > S2 > S3 > S7 > S8 > S4 > S5.

5.6.3.2 Order Allocation

Another round of discussions was held with the DM's and it was decided to examine and test the model in three different scenarios. In the first scenario, optimal order allocation to suppliers is determined without disruption risks like defective items

Table 5.14 Closeness coefficients of suppliers for each item for sustainability criteria

Closeness coefficients									
	Environmental criteria			Social criteria			Economic criteria		
	AC compressor	A/V system	Navigation unit	AC compressor	A/V system	Navigation unit	AC compressor	A/V system	Navigation unit
S1	0.3489	0.3226	0.7065	0.7835	0.7325	0.6513	0.8978	0.8978	0.8978
S2	0.5249	0.4590	0.6816	0.6347	0.7803	0.4616	0.7208	0.7208	0.7208
S4	0.5249	0.4372	0.3620	0.6347	0.6334	0.6194	0.5523	0.5523	0.5523
S5	0.5770	0.4785	0.6648	0.1845	0.1781	0.4311	0.3287	0.3287	0.3287
S6	0.7818	0.7038	0.6743	0.4436	0.3942	0.7863	0.6654	0.6654	0.6654
S7	0.1194	0.8536	0.5139	0.2942	0.8469	0.2149	0.1513	0.1513	0.1513
S8	0.5670	0.1474	0.1516	0.8289	0.4630	0.5122	0.5930	0.5930	0.5930
S9	0.5172	0.3626	0.6724	0.2863	0.4859	0.5789	0.5043	0.5043	0.5043

Table 5.15 Weighted supplier score

	Economic	Environmental	Social	Final scores
S1	0.8978	0.4594	0.7224	0.6932
S2	0.7208	0.5552	0.6255	0.6338
S4	0.5523	0.4414	0.6292	0.5409
S5	0.3287	0.5735	0.2646	0.3889
S6	0.6654	0.7200	0.5413	0.6423
S7	0.1513	0.4957	0.4520	0.3663
S8	0.5930	0.2887	0.6013	0.4943
S9	0.5043	0.5174	0.4504	0.4907

and late delivery. In the second scenario order allocation is optimized by considering disruption risk in the same problem environment. Finally, the results of the said scenarios have been compared. Also, order allocation with discount and without discount is compared in both the scenarios. The third scenario compares the order allocated to suppliers and costs associated when the allowable defect rate by buyer varies.

Scenario 1: Order Allocation—Without Disruptions

In this case, the mathematical model is allowed to determine the allocated quantities to available suppliers without considering the constraints of late delivery and bad quality, i.e., it is assumed that reliability of the quality of items which is supplied by the supplies is 100% in the first scenario. Therefore, it converts the inequality constraints of late delivery and defective rates into equality. The only objective is to optimize the purchasing cost while considering a discount in one case and no discount on another one.

Case 1: No Discount is Offered by the Supplier

In this case, available suppliers do not offer any form of quantity discount schemes to the buyer. It means, supplier having least unit cost has more chances of selection. The results of the order allocated to selected suppliers are shown in Table 5.16. It is seen that order is split among suppliers 1, 2, 3, and 4. The total purchasing cost to the buyer, in this case, is Rs. 63,956,000. The optimal order allocation to suppliers for each item is shown in Table 5.16.

Case 2: All Quantity Discounts is Offered by the Supplier

In this case, it is assumed that all quantity discounts is offered by the suppliers. The unit cost decreases after certain ranges which encourages the buyer to order more quantities with less price. The results of the order allocated to suppliers are shown in Table 5.16. It is seen that order is split among suppliers 1, 2, and 5. The total purchasing cost to the buyer, in this case, is Rs. 60,880,000. Selected suppliers

Table 5.16 Quantity allocation with disruptions

Quantity allocation					
X_{ij}	Without a discount	With discount	X_{ij}	Without a discount	With discount
X11	200	700	X24	0	0
X12	900	400	X25	0	0
X13	0	0	X31	0	300
X14	0	0	X32	0	0
X15	0	0	X33	0	0
X21	1700	1700	X34	300	0
X22	500	500	X35	800	80
X23	0	0			
The total cost to the buyer					
Without a discount INR 63,956,000/-			With discount INR 60,880,000/-		

decrease as more orders are allocated to selected suppliers in higher discount ranges. The total decrease in purchasing cost due to the discount offered is 4.8%.

Scenario 2: Order Allocation—With Disruptions

In this scenario, inequality constraints of late delivery and defective items are introduced while allocating orders to available suppliers. The maximum defect rate and late delivery, the buyer can sustain is 5%. To deal with such uncertainties buyers order more quantities from the suppliers. Two cases are considered for order allocation: (1) Order allocation without quantity discount (2) Order allocation with a quantity discount.

Case 1: No Discount is Offered by Suppliers
In this case, available suppliers do not offer any form of quantity discount schemes to the buyer. It means, supplier having the least unit cost has more chances of selection. Supplier's chances of selection also depend on items quality and delivery time offered by them. The results of the order allocated to selected suppliers are shown in Table 5.17. It is seen that order is split between suppliers 1 and 2 only since they are most eligible to deliver items with allowable defective quality and in the allowable time. The total purchasing cost to the buyer, in this case, is Rs. 72,910,405 which is more than 14% of the purchasing cost in case 1 of Sect. 5.6.3.2.1.

Case 2: When all Quantity Discounts is Offered by the Suppliers
In this case, it is assumed that all quantity discounts are offered by the suppliers. This is the most realistic case where the uncertainties as well as quantity discount scheme offered by the suppliers is considered. The unit cost decreases after certain ranges which encourages the buyer to order more quantities with less price. The results of

Table 5.17 Quantity allocation with disruptions

Quantity allocation					
X_{ij}	Without a discount	With discount	X_{ij}	Without a discount	With discount
X11	244	700	X24	0	0
X12	900	0	X25	0	0
X13	0	422	X31	900	582
X14	0	0	X32	233	0
X15	0	0	X33	0	573
X21	1700	1166	X34	0	0
X22	588	0	X35	0	0
X23		1100			
The total cost to the buyer					
Without a discount INR 72,910,405/-			With discount INR 69,871,462/-		

the order allocated to suppliers are shown in Table 5.17. It is seen that the order is split among supplier 1 and supplier 3. The total purchasing cost to the buyer, in this case, is Rs. 69,871,462. The total decrease in purchasing cost due to the discount offered is 4.16%. Also purchasing cost, in this case, is more than 12.68% of the cost in case 2 of Sect. 5.6.3.2.1.

Order Allocation—A Variation of Purchasing Cost with Allowable Defective Rate

In this scenario mathematical model is allowed to determine the optimal order allocation, purchasing cost, and change in demand when the allowable defective rate by buyer increase from 5 to 7%. Such cases arise when a buyer organization doesn't have strict quality control.

The total items allocated by the buyer to suppliers in each discount ranges are shown in Table 5.18. Almost all the allocated quantities fall in a third discount range which has a minimum unit cost of items. Weak quality control leads to more defective parts in the received orders and thus lower customer satisfaction. When the expected defective rate of 7% is allowed buyer has to order extra 229 units resulting in an increase in purchasing cost from Rs. 69,871,462 to 71,435,659, i.e., 2.23% increase. Similarly ordering cost increases from Rs. 60,000 to Rs. 85,000 which means selected supplier varies with buyer's allowable quality level. To control defects in delivered quantity and hence to satisfy its customers, buying firms should impose a penalty on a number of defective items and late deliveries items which is depicted in Table 5.18. The total defective cost increases from Rs. 230 to Rs. 370 when allowable defect rate changes from 5 to 7%.

Table 5.18 Order allocation variation with allowable defective rate

When the allowable defect rate is 5%						When the allowable defect rate is 7%					
X111	0	X211	0	X311	0	X111	0	X211	0	X311	0
X112	0	X212	0	X312	0	X112	0	X212	0	X312	0
X113	700	X213	1166	X313	582	X113	600	X213	1210	X313	679
X121	0	X221	0	X321	0	X121	4	X221	0	X321	0
X122	0	X222	0	X322	0	X122	0	X222	0	X322	0
X123	0	X223	0	X323	0	X123	0	X223	0	X323	0
X131	0	X231	0	X331	0	X131	0	X231	0	X331	0
X132	0	X232	0	X332	0	X132	0	X232	0	X332	0
X133	422	X233	1100	X333	573	X133	553	X233	1100	X333	487
X141	0	X241	0	X341	0	X141	0	X241	0	X341	0
X142	0	X242	0	X342	0	X142	0	X242	0	X342	0
X143	0	X243	0	X343	0	X143	0	X243	0	X343	0
X151	0	X251	0	X351	0	X151	0	X251	0	X351	0
X152	0	X252	0	X352	0	X152	0	X252	0	X352	0
X153	0	X253	0	X353	0	X153	0	X253	0	X353	0
Costs											
Purchasing cost			INR 69,871,462			Purchasing cost			INR 71,435,659		
Ordering cost			INR 60,000			Ordering cost			INR 85,000		
Defective penalty			INR 230			Defective penalty			INR 370		
Late delivery penalty			INR 115			Late delivery penalty			INR 205		
Increase in demand			143 units			Increase in demand			229 units		

5.6.3.3 Implementation of Knapsack Problem for Planning Items Delivery

Supplier plans the delivery of items after receiving orders from the buyer. In this model, each supplier is available with three types of trucks (HDV, MDV, and LDV). Each truck can carry multiple items in a single shipment. The primary objective in this scenario is to select such truck combination which maximizes the number of items in each truck shipment while minimizing the transportation cost and Greenhouse gas penalty which is shown by Eq. (5.4) which is subjected to constraints shown in Eqs. (5.17)–(5.20). In truck selection, problem two scenarios are considered. In the first scenario, the order has been allocated to suppliers considering no discount. In the second scenario, orders have been allocated considering the quantity discount. In both cases, the allowable defective rate is 5%.

Scenario 1: Items Delivery—Without Discount

In this scenario, the buyer allocates the whole demand to supplier 1 and supplier 2. The results of suitable truck combinations by S1 and S2 are shown in Table 5.19. In solution 1, a number of shipments increase when supplier 1 selects more light drive trucks which results in more distance traveled by the trucks. The trucks release a total of 1234.33 kg of GHGs due to which penalty of Rs. 1,234,325 is incurred by the supplier. In solution 2, when more HDVs and MDVs are used by suppliers for items delivery, GHGs emission reduced to 222.29 kg due to which penalty incurred is Rs. 111,146. Similarly when supplier 2 delivers allocated quantity to the buyer using higher LDVs 339. 03 kg GHGs emitted and the incurred penalty is Rs. 237,321. Emitted GHGS reduces to 59. 84 kg when more HDVs and MDvs are utilized.

Scenario 2: Items Delivery-With Discount

Buyer allocates whole demand to supplier 1 and supplier 3 when a discount is offered by suppliers. The results of suitable truck combinations by S1 and S3 are shown in Table 5.20. GHGS emission and penalty decreases when the supplier uses a number of HDVs and LDVs. For delivering the same number of items to buyer GHGs emission decreases from 1091 to 168.98 kg. GHGS emission and penalty decreases when the supplier 3 uses a number of HDVs and LDVs. For delivering the same number of items to buyer GHGs emission decreases from 94.21 to 57.97 kg while going from solution 1 to solution 3 in Table 5.20.

Effect of a Number of Trucks on GHGs Emission

Truck capacity can play a major role in determining the amount of CO_2 emissions from transport [4]. From Table 5.21 it is clear that as the number of higher capacity trucks increases or lower capacity trucks decreases for delivering the same number of items, transportation cost reduces. Also, GHG emission decreases as more quantities are transported in fewer shipments using more number of HDVs and MDVs (Figs. 5.2 and 5.3).

5.6.3.4 Weight Sensitivity Analysis

To demonstrate the analytical capability of the approach and to analyze trade-offs between criteria, the model is solved by varying weights of sustainability criteria in the range (0, 1) in Eq. (5.8). For example, the first three solutions Sol. 1, 2, and 3 in Table 5.22 considers only one of the criteria, which maximizes economic, environmental, and social scores, respectively. In the rest of the solutions weights are varied in the range (0, 1).

Table 5.19 Truck combinations by supplier 1 and supplier 2

Items delivery in trucks by supplier 1						Items delivery in trucks by supplier 2					
HDV	MDV	LDV	Transportation cost	GHGs emission	Penalty	HDV	MDV	LDV	Transportation cost	GHGs emission	Penalty
1	6	15	503,600	1234.33	1,234,325	0	5	10	224,600	339.03	237,321
2	3	0	450,100	222.29	111,146	2	3	0	195,600	59.84	11,968

Table 5.20 Truck combinations by supplier 1 and supplier 3

Items delivery in trucks by supplier 1						Items delivery in trucks by supplier 3					
HDV	MDV	LDV	Transportation cost (INR)	GHGs emission	Penalty	HDV	MDV	LDV	Transportation cost (INR)	GHGs emission	Penalty
1	3	15	430,700	1091	1,096,101	1	3	6	246,000	94.218	18,843.7
1	4	6	408,200	437.98	394,182	1	4	0	232,500	71.19	14,238.1
1	5	0	394,700	318.98	223,292	2	2	0	228,500	57.97	11,595.9
2	2	0	386,200	168.98	67,594.8						

Table 5.21 Effect of the number of trucks used by supplier 1 on CO_2 emission

CO_2 emission (kg)	Transportation cost	HDV	MDV	LDV
1091	430,700	1	3	15
437.98	408,200	1	4	6
318.98	394,700	1	5	0

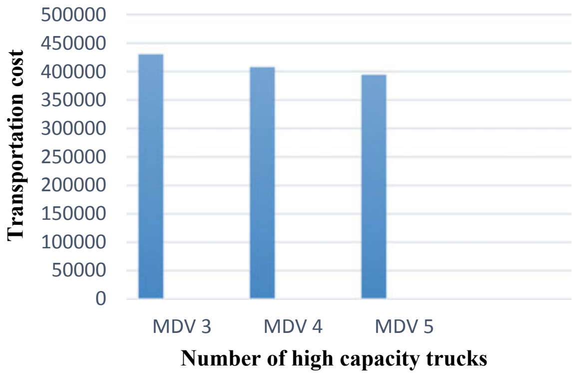

Fig. 5.2 Variation in transportation cost with no. of high capacity trucks

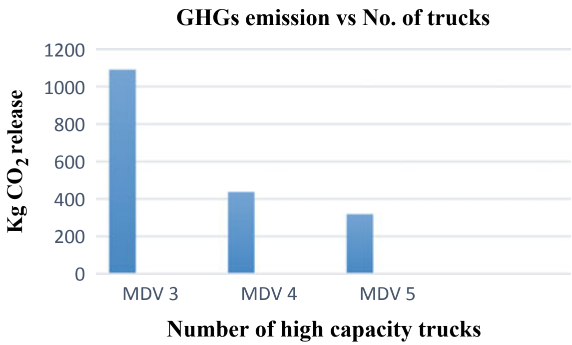

Fig. 5.3 Amount of GHGs release with a change in high capacity truck

In solution 1, supplier 1 and 3 received almost all the orders for all three items, because of the low cost offered by them. Also, for all three items in solution 1, more order is given to supplier 1 due to the lowest defective rate offered by them. In solution 2, supplier 1 did not receive any orders due to poor performance with respect to environmental criteria even though he offered the lowest cost. Supplier 2 and 3 having higher environmental scores and offering low cost are selected for order allocation in solution 2. A social criteria dominating model, as indicated in solution 3, shows that supplier 1 and 3 receives almost all the order for items due to higher performance in social aspects.

Solution 4–12 shows a shift in buyer's perspective from social/environmental dominating supply chain to the economic supply chain. As the buyer assigns more

Table 5.22 Sensitivity analysis

	Solution	1	2	3	4	5	6	7	8	9	10	11	12
Weights	W1	1	0	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	W2	0	1	0	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
	W3	0	0	1	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
Score	Eco	3858	0	0	3134	3675	3675	3858	3858	3804	3858	3858	3858
	Env	0	3089	0	2806	2224	2224	2083	2083	2346	2083	2083	2083
	Soc	0	0	3256	2950	3256	3256	3207	3207	2991	3207	3207	3207
Obj 1		68,730,845	72,483,400	72,399,845	74,624,400	72,399,845	72,399,845	68,730,845	68,730,845	68,622,405	68,730,845	68,730,845	68,730,845
Order quantity	X11	700	0	700	0	700	700	700	700	700	700	700	700
	X12	0	900	0	900	0	0	0	0	444	0	0	0
	X13	422	244	422	244	422	422	422	422	0	422	422	422
	X14	0	0	0	0	0	0	0	0	0	0	0	0
	X15	0	0	0	0	0	0	0	0	0	0	0	0
	X21	1700	0	666	0	666	666	1700	1700	1700	1700	1700	1700
	X22	0	1800	0	666	0	0	0	0	588	0	0	0
	X23	566	466	1600	1600	1600	1600	566	566	0	566	566	566
	X24	0	0	0	0	0	0	0	0	0	0	0	0
	X25	0	0	0	0	0	0	0	0	0	0	0	0
	X31	900	0	900	0	900	900	900	900	900	900	900	900
	X32	0	444	0	1100	0	0	0	0	233	0	0	0
	X33	255	700	255	44	255	255	255	255	0	255	255	255
	X34	0	0	0	0	0	0	0	0	0	0	0	0
	X35	0	0	0	0	0	0	0	0	0	0	0	0

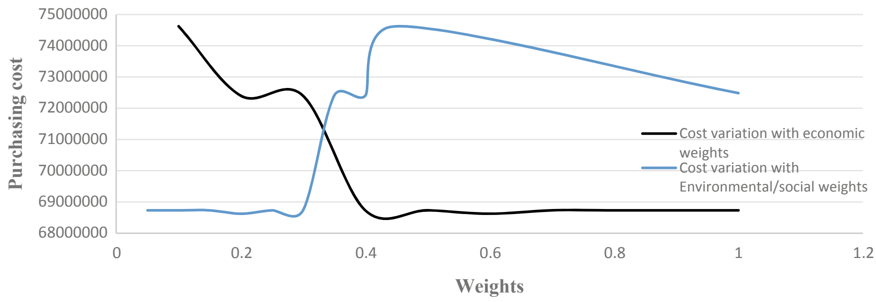

Fig. 5.4 Sensitivity analysis curves

weight to economic criteria, which means giving more preference to cost minimization, procurement cost decreases. In contrast to this, as shown in solution 4–12, when more weight is given to social and environmental criteria, buyer suffers higher procurement cost because, the supplier has to spend more money to manufacture eco-friendly items with minimum waste disposals, avoiding child labors, and providing the worker with occupational safety (Fig. 5.4).

5.7 Conclusion

Identifying the right sustainable suppliers and splitting the orders of multiple items between the selected suppliers has become a major challenge for buying firms. With the advent of sustainability concepts in the recent world, companies are aligning themselves toward the sustainability-driven strategies where they have to consider the three pillars of sustainable development viz. economic, environmental, and social criteria in the decision-making the process. This study presents a multi-objective MIP approach that can assist the DM's in framing SS&OA problems. TOPSIS method, an MCDM approach is used to rank suppliers on the basis of Sustainable performance. The proposed model is more effective in handling real situations since the selection process is multi-objective in nature with multi-items and multi-suppliers. It also incorporates all quantity discount schemes to attract buyers, imposes a penalty on defective parts, late deliveries, and most importantly penalty on greenhouse gases emissions (GHGs). The model also considers the truck allocation problem which helps suppliers to use available trucks efficiently and effectively while delivering items to the buyer. The applicability of the proposed model is justified by a case study of the Indian Automobile industry. Further, the impact of disruptions like defective quality in shipment and late delivery in the procurement process is studied and is compared with the scenarios where disruptions are absent. Joint consideration of disruptions and discount makes the model more complex and realistic which help the DM's to take SS&OA decisions more effectively. The applicability of the proposed model is justified by a case study in the automobile industry in Central

India. Case 1 of scenarios 1 and 2 in the computational results provide the DM's to analyze the effect in demands and purchasing cost due to disruptions which helps the decision-makers to switch suppliers. Sensitivity analysis has been performed in which weights of criteria is varied to select potential suppliers who have optimal performance with respect to sustainability dimensions. Graphical results display that giving 0.3 weight to economic performance and 0.35 to both the environmental and social performance of the supplier provides optimum purchasing strategy for the buyer. The model has been solved using MS Excel solver. Finally, the results from phase three of model, i.e., truck delivery reveal that Greenhouse gases emissions and transportation cost from transportation activities increase when more LDV trucks are used by supplier for items delivery instead of HDvs and MDVs.

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