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An integrated optimization model for selection of sustainable suppliers based on customers' expectations

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ABSTRACT

Due to intensification of market competence and customers increasing socio-environmental concerns, sustainability has become a focal point for most organizations. Thus incorporation of customer sustainable expectations into the conventional supplier selection process has become necessary for manufacturers to sustain in the competitive market. To cope with this issue, it is necessary to model the customers' opinions and expectations into the strategic supplier selection and order allocation decision making, an area not delved upon much in the literature. Therefore, the aim of the study is to develop an analytical model for manufacturing firm for selection of suppliers based on customers' expectations which are reflected as retailers' expectation level and also for bringing in financial and socio-environmental stability to the whole SC. The research methodology adopted involves 1) use of fuzzy-TOPSIS technique using Z numbers for evaluation of suppliers based on traditional as well as social environmental attributes which reflect customer's social and green expectations, 2) development of a novel bi-objective mathematical model for selecting suppliers meeting the expectation levels, allocating orders proportionate to the performance scores of the suppliers, rewarding or penalizing the suppliers as per their sustainable performance, 3) Transformation of the bi-objective model into a weighted goal programming model for attaining a trade-off solution between the objectives of minimization of cost and maximization of sustainable value of purchase. To exemplify the efficacy of the model, case of electronics sector is presented. The findings of the result suggest that penalty and reward value incorporated in the cost objective system is effective in enhancing the sustainable performance of the suppliers and can prove to be an effective strategy for DMs. The study recommends that the proposed mathematical model can considerably aid the manufacturer in integrating supplier selection and order allocation decisions while optimizing the performance of the customer oriented supply chain.

1. Introduction

Due to globalization, trade liberalization, fierce competition and rising sustainability related needs of customers, managing supply chain (SC) has become quite complex. The whole SC is generally considered as a pull system which is customer-centric and therefore firms cannot neglect the environmental and social concerns of the customers as it can result in economic loss in terms of decreased return volumes [39,66]. Since manufacturer is a supplier to the customers and a buyer to the supplier therefore consideration of customers' transformed purchasing attitude brings additional complexities in the purchasing decisions. Further, customer satisfaction is highly dependent on the environmental and social impact of the final products and services. Hence, organizations need to be responsive enough to customer needs and must gear towards integrating sustainability aspects into their buying behavior [20,43]. Clearly organizations can improve upon their SC performance and expand their practical competence by incorporating sustainability dimensions into the supplier selection process with the focus on fulfilling customers' expectations [44,59]. However, managing a sustainable SC becomes a strategic issue for an organization in order to meet goals in terms of economic competitiveness and value creation [41]. Therefore focal firms must focus on sustainable supplier selection as a strategic response to the customer needs as environmental and social assessment of suppliers can act as an enabler towards improvement of customers' satisfaction level [52]. This satisfaction level is influenced by many different aspects that organizations need to take into account as vital parameters into the supplier selection process for the success of the SC. Although literature is abundant with sustainable

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supplier selection models, however very few studies have investigated supplier selection and order allocation models based on customers' requirements. Additionally, appropriate selection of evaluation attribute for representing the conflicting sustainability aspects [49] and need for trade-off clearly calls for a multi- attribute decision analysis [7]. Further, selecting best performing suppliers and determining the optimum purchasing allocations while minimising the SC cost, needs development of an optimisation model.

The identified gap necessitates the need to focus on how to model the customers' sustainable expectations into the supplier evaluation attributes and procure as per the environmental and social compliance of suppliers. In this regard, the contribution of the study is development of a novel customer-oriented supplier selection and order allocation SC model that can aid decision makers (DMs) of a manufacturing firm in making crucial decisions regarding selection of suppliers based on customers' expectations and also bringing in financial and socio-environmental stability to the whole SC. The key features of the proposed mathematical model are:

1) Evaluation of suppliers based on customers' environmental and social expectations in a multi- attribute decision making environment, which has not been addressed in the literature. The customer's expectation level is translated in terms of retailer's expectation level of the supplier's performance.
2) Development of a bi-objective mixed integer programming model with the objectives of minimizing the total cost of the system and maximizing the SVP. The supplier performance evaluation weights are also incorporated in the objectives.
3) Attain a trade-off between the conflicting objectives of the total cost of SC network and the Sustainable Value of Purchase (SVP), while ensuring that better performing suppliers (if selected) are rewarded and poor performing suppliers (if selected) are penalised, an aspect not considered in sustainable supplier selection models.

The research methodology adopted for achieving the above objectives entails the following: Evaluation of the suppliers is carried using fuzzy-TOPSIS with Z numbers incorporating multiple DMs' opinions while considering the degree of reliability on information on which the opinions are based. The performance evaluation weights obtained through Z-TOPSIS are incorporated in the cost objective for calculating penalty and reward value for selected suppliers and in the SVP objective for allocating the purchase order as per the performance weights of the suppliers. Goal programming methodology is effectively adopted for obtaining a trade-off between the objectives of minimisation of cost and maximisation of SVP. In order to validate the application of the proposed integrated model, a case study of an Indian manufacturer is considered in this study and managerial and practical implications of the study are presented.

The rest of the paper is organized as follows: Brief review of literature and research gap is discussed in the Section 2. Section 3 discusses the problem description and methodology is presented in the Section 4. Section 5 provides the numerical illustration. Result discussion, sensitivity analysis and managerial implications are presented in Section 6 followed by the conclusion in Section 7.

2. Literature review

The paper is presenting a bi-objective mathematical model which integrates supplier selection and allocation based on customer expectations in terms of sustainable attributes into the model while optimizing cost of the firm and maximizing SVP. The literature review presented in sub-Sections 2.1 to 2.3 gives the gist of the work done by researchers in recent years on evaluation attributes for suppliers with respect to sustainable aspects, sustainable supplier selection models and order allocation incorporating customer expectations and multi-attribute analysis approach for sustainable supplier evaluation models.

2.1. Sustainable supplier evaluation and attributes

Evaluation and selection of suppliers is one of the essential processes for attaining an efficient SC performance. This is due to the distinct role of suppliers at all stages of the SC [62]. Maintaining long-term partnerships with suppliers and using fewer reliable suppliers can help the manufacturers in increasing the value of the SC [35]. Traditionally, the manufacturers used to focus only on traditional factors such as reduction in operational cost and delivery reliability [10]. Recent studies advocate that the financial competency of the supplier is also an essential attribute for the evaluation purpose [43]. Recently, there has also been considerable discussion in the literature related to the need for inclusion of environmental aspects in supplier selection process. The environmental capabilities of the suppliers have direct influence on the environmental performance of the SC, thus, the literature has focused on the importance of necessary ecological certifications for the suppliers [18,19]. Kuo et al. [38] proposed an integrated multi- attribute method that evaluates the factors used to select a green suppliers based on their performance. Hsu et al. [27] proposed a DEMATEL based approach to analyze the performance of the suppliers based on their carbon management issues. Kannan et al. [31] has discussed the role of suppliers in helping firms in achieving maximum ecological-economic benefits. Dobos and Vörösmarty [14] proposed a data envelopment analysis (DEA) based supplier evaluation methodology for determining the influence of environmental attribute on supplier selection process.

Due to the growing need of sustainability issues, organizations have also started focusing on integrating sustainability aspects in the supplier evaluation process [43]. It is also acknowledged that incorporation of sustainable aspects in supply chain performance measurements also enhances the concern of business firms [4]. Bai and Sarkis [6] developed a modelling approach to address the supplier selection problem in sustainable environment. Authors integrated grey theory and TOPSIS methodology for the evaluation process. In another study, Govindan et al. [21] have evaluated the suppliers based on their sustainable performance. Luthra et al. [43] has ranked 'Environmental costs,' 'Quality of product,' 'Price of product,' 'Occupational health and safety systems,' and 'Environmental competencies' as top five sustainable supplier selection attribute. However, introducing the three dimensions into supplier selection process embeds a new set of trade-offs in the decision, complicating the decision making process with both qualitative and quantitative factors. It is a challenge how to measure social attribute in supplier selection against the economic and environmental management attribute and how to identify trade-offs between these three. Generally it becomes difficult to determine social sustainability parameters for supplier evaluation as DMs themselves have little conceptual understanding of the social impact of their SC and how it can be measured [17]. Recently, Bai et al. [3] proposed a decision framework in order to evaluate and select socially responsible suppliers by integrating grey-based approach with best-worst method and TODIM in order to identify the weights of social attributes and suppliers respectively. They have validated the applicability of proposed framework by taking a case study of an Iranian manufacturing company.

The growth of the focus of organization on their core competencies has led to tremendous gain in supplier selection over the past few decades [19]. In the research by Sarkis and Talluri [54], it was suggested that the organizations have started focussing more on the buyer-supplier relationship due to changing market demands which require specific skills and capabilities. Due to this current shift in the consumer environmental awareness, it has become necessary to adopt green policies and practices in supplier selection [51]. Although there are many studies concerned with developing supplier selection models but the literature lacks in studies that deal with fulfilling customers' sustainable expectations. The few studies include the following: Lin and Huang [42] identified the factors influencing consumer choice behaviour with respect to green products. They have examined the significant differences in choice behaviour and consumption values of customers on environmental issue. The study by Tseng and Hung [59] proposed model related to service quality and identified the gap between consumers' expectations and their perception with respect to green products. Coskun et al. [13] developed a model based on the customers' expectations of buying green products. Authors identified the determination level of three types of customers which affect the green network. Gücdemir and Selim [23] integrated the two approaches-customer relationship management and production planning and control. The aim of the integration was to optimally utilize the resources in order to satisfy the customers' needs. Yazdani et al. [63] utilized an integrated approach for the selection of green suppliers by taking environmental attributes. Authors first identified inter-relationships and degree of relationships between attributes and customer requirements and finally prioritize the suppliers.

The present study aims to overcome this gap by considering social attributes along with traditional and environmental attributes in the evaluation process generally from the perspective of fulfilling customers' expectations level in terms of sustainable practices. The attributes are identified through an extensive literature survey and deliberations with multiple DMs.

2.2. Sustainable supplier selection and order allocation

In recent scenario, researchers are integrating two problems viz. supplier selection and order allocation problem in sustainable environment in order to reduce their costs and enhance the performance of their SC significantly [67]. Often it becomes difficult to meet either total demand or the attribute constraints from a single supplier, then orders must be placed with multiple suppliers. Hammami et al. [24] proposed a method for handling multiple suppliers under various currency conditions depending on the supplier location. Scott et al. [55] addresses the supplier selection problem using hybrid AHP with Quality Function Deployment and chance constrained optimization method for selection of best suppliers and simultaneous order allocation. Often multiple supplier selection problems become more complex as the requirements of DMs' increase and numerous objectives need to be satisfied simultaneously. This requires integration of multi-attribute techniques and multi-objective programming to handle conflicting attributes and trade-off among objectives [30,48]. Mohammed et al. [47] integrated multi-attribute decision making and fuzzy multi-objective optimization methodology for selecting sustainable supplier and allocating orders by considering all the three pillars of sustainability. Vahidi et al. [60] proposed a two-stage mixed possibilistic-stochastic programming approach for bi-objective optimization model for the selection of sustainable supplier and order allocation. Govindan and Sivakumar [20] suggested a two phase approach for selection of the best green supplier. The authors used fuzzy TOPSIS followed by multi-objective linear programming to minimize cost, material rejection, late delivery recycle waste and carbon emissions. Azadnia et al. [2] suggested an integrated approach of fuzzy AHP and Multi-objective Linear Programming (MOLP) for sustainable supplier selection and order allocation combined with multi-period multi-product lot-sizing problem. Moghaddam [46] proposed a multi-objective optimization problem (MOOP) in order to select the performing supplier and identify the number of parts and products in a CLSC network. Moghaddam et al. [46] developed a fuzzy multi objective model by considering the economic risk and late deliveries for supplier selection. Scott et al. [55] proposed an integrated approach using AHP- QFD combined with chance-constrained optimization algorithm for the selection of supplier and allocating optimal orders among them. Choudhary and Shankar [12] proposed a multi-objective integer linear programming model related for issues such as selection of supplier, lot sizing and selection of carrier. Jadidi et al. [29] developed the MOOP for selecting the best supplier in which three objectives were considered includes price, number of rejections and lead time.

Various authors have also considered penalty and reward system for suppliers considering varied aspects. Starbird [58] discussed the impact of penalty and reward system along with inspection policy on cost minimizing supplier. In an another study by Mathur and Shah [45] analysed the impact of penalty parameters on decisions related to suppliers' capacity, SC efficiency and distribution of SC profit among partners. Selviaridis and Norrman [56] explored various challenges related to performance based contracts for logistics service provider. They have considered reward and risk sharing incentives based on the attitude of customers and provider. Wang et al. [61] developed the penalty reward system to encourage recycling process in closed loop SC (CLSC) in order to reduce the cost and improve waste electrical and electronic equipment collection. Authors analysed several CLSC settings related to collection rate and sharing of responsibility of manufacturer and collector. Inderfurth and Clemens [28] showed the impact of risks in the buyers' and suppliers' coordination having deterministic demand.

The above studies reinforce that sustainable supplier selection and order allocation along with penalty and reward system can aid in improving the performance of suppliers. However, none of the above studies have integrated penalty-reward system in supplier selection and order allocation models based on customer expectation level as done in this study.

2.3. Multi-attribute analysis approach for sustainable supplier evaluation

The strategic decision of supplier selection requires the ability of the decision making body to consider multiple attributes to prioritize the suppliers and arrive at a final decision [26]. This causes the supplier selection process to heavily reply on multiple attribute decision models (MADM) [19]. The study by Chai et al. [10], concludes that MADM allows the DMs to simplify the supplier selection process while balancing a variety of conflicting attribute. There has been substantial discussion in literature on the employment of variety of multi-attribute decision making (MADM) approaches in supplier selection [30]. These include analytical hierarchy problem (AHP) [15], analytic network process (ANP) [25], technique for order of preference for similarity to ideal solution (TOPSIS) [53], grey system theory [5], soft computing techniques such as genetic algorithm [16], fuzzy logic [9], neural network [33], etc. Various uncertainties such as imprecision, incompleteness of data, ambiguity in the DMs' opinions also arise when dealing with social and environmental attribute [36]. In this regard, it has become essential to consider an effective method which can handle these kind of uncertainties [34,40]. Recent studies addressing this issue include the following: Amindoust et al. [1] handled the subjectivity of DMs' by using fuzzy inference system (FIS) for supplier selection problem. Shen et al. [57] proposed fuzzy multi attribute approach to evaluated suppliers with respect to their environmental performance. Hashemi et al. [25] suggested an integrated analytic network process (ANP) and Grey relational analysis (GRA) model to deal with the supplier selection uncertainties. Orji and Wei [50] integrated Fuzzy logic and system dynamics for sustainable supplier selection. Zhang and Xu [65] developed a technique based on consensus maximization and fuzzy TOPSIS which helps in solving the interval-valued intuitionistic fuzzy MADM problems. Hashemi et al. [25] integrated ANP and GRA for selection of green suppliers.

On analysing the literature review it can be seen that there is a lack of integrated methodologies which investigate the supplier selection problem from the account of customers' sustainable expectations in a fuzzy environment. This study utilises modification of TOPSIS method based on Z-numbers, called Z-TOPSIS, which is effective in quantifying the DMs' opinions while taking into account their reliability, a well suited technique for the considered problem of supplier evaluation based on multi-stakeholders' perspectives. Further, very few authors have developed optimisation models integrating supplier selection and order allocation decisions while optimising the sustainable performance of the SC network as done in this study.

2.4. Research contribution

The research gap identified in Sections 2.1–2.3 reinforces that, integrated supplier selection and order allocation SC models along with penalty-reward system to mend upon the customer satisfaction level are not found in the literature. This forms the basis of the following research contribution of the study:

- The inclusion of social attributes along with traditional and environmental aspects in the evaluation process for fulfilling the sustainable expectations of customers has not been discussed earlier. Moreover, the novel attributes chosen in the study so that the suppliers can be assessed on aspects which reflect customer's expectations.
- The study utilises Z-TOPSIS to evaluate suppliers based on customers' environmental and social expectations in a multi- attribute fuzzy decision making environment, which has not been addressed in the literature. In addition to this, the opinions of the decision makers are based on their experience and access to the information which may be uncertain or incomplete. Hence quantifying their opinions as Z numbers which takes into consideration the degree of reliability of information is very critical as is done in this study.
- A novel bi-objective mathematical model is developed which incorporates suppliers' assessment scores for selecting better performing sustainable supplier and allocating orders based on the customers' expectation level along with penalty and reward system while obtaining a trade-off solution between the objectives of minimizing SC cost and maximizing the SVP.

This model enhances the customer satisfaction by establishing a strategic partnership with the selected supplier while simultaneously optimizing the cost and value of purchase.

3. Problem description

The current study discusses the problem of a northern India based home appliance manufacturing company. The company was started around three decades ago with only a single product and subsequently climbed to become one of India's foremost OEMs in Home Appliance. Spanning across an area of 55000 sq. ft. and a manpower of around 150 employees, the state-of-the-art production facility is able to cater high volumes of customer demands for home appliances. The growing market for home appliances has inspired the company to evolve with newer ideas and product variants. When it comes to appliances, the major focus of the company has always been to involve the voice of the end-users in product development and designing, so that the products remain more user-centered and score well on market appeal. The major emphasis of the company (which is the focus of the current study) is towards one of their home appliance- toaster.

The generic SC network of the company is shown in Fig. 1. The SC actors are manufacturer, distributors, retailers, suppliers, third party logistics providers (3PLPs) and customers. The raw material for manufacturing the products is supplied by multiple suppliers at the manufacturing plant (MP) and the finished product is then send to the zonal distributors. The zonal distributors have designated distribution centres (ZDCs) where the inventory is stored and distributed to the various retail centres (RCs) in their zone as per the customer demand. The distribution of products between various facilities is managed by the 3PLPs.

In this system, it is the responsibility of the retailer to establish retail relationships with the customers. Thus, the demand of each RC varies based on the demand of the customers. The retailer is responsible for forecasting the demand of the product and identifying the satisfaction level of the customers which is then communicated to the manufacturer. The company aims to achieve their economic targets while satisfying the needs and wants of customers. Since the customers now want environmental and social benefits along with economic viability of the products they buy, therefore these requirements thereby, become the basis for the sustainable targets for the company. Therefore the company wants to enhance its SC performance by including sustainable aspects into their decision making process. However, meeting the sustainable expectation of the customers requires strategic rethinking of the SC. To begin with, the company is planning to design two new variants of toasters, based on the economic viability and green expectations of customers. The next essential decision that the company needs to make is to understand which suppliers to work with who are flexible enough towards the changing requirements and are able to meet their expectation level. Flexibility of the suppliers is required in terms of adopting new technologies, and inclination towards energy conservation and social upliftment. Thus, collaboration is needed between the suppliers and manufacturer in order to improvise upon the sustainable performance of the SC and increase the market share. This clearly requires overhauling the supplier selection process and taking appropriate decisions at strategic and tactical level. At strategic level, the need of company to evaluate and select the best performing supplier on the basis of vital sustainable attribute while at tactical level, the optimum order allocation must be identified. Since retailers are in direct communication with the customers therefore they play a key role in identifying their needs. Hence retailers' involvement in the supplier selection decision making process is crucial for choosing the attribute of evaluation which can translate the needs of the customers and assessing the satisfaction level of the customers. The customer expectation level can be modelled as retailer's expectation level of the performance of the suppliers in the evaluation process.

Thus, the problem addressed in this study is to develop a supplier selection and allocation model based on customers' sustainable expectations while considering the following aspects:

- *Meeting company's target and customer's expectation*: Suppliers must be able to meet the customer expectations and goals of the company. These can be captured by evaluating the suppliers based on suitably identified list of economic, environmental and social attributes.
- *Penalty and Bonus system*: It is essential that the suppliers are selected based on their sustainable score and the better performing suppliers are rewarded and low performing suppliers are penalized.
- *Cost vs Sustainable Allocation*: Company must be able to optimise the

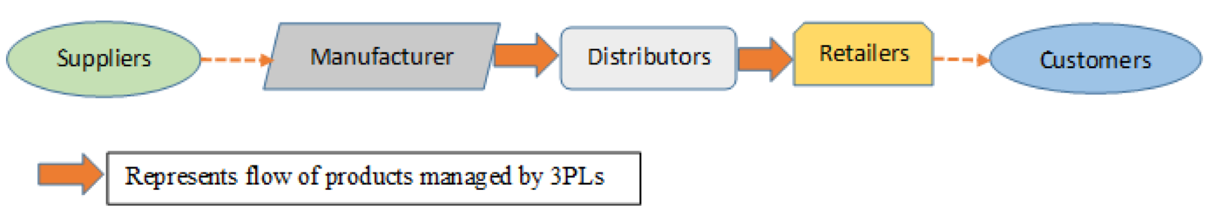

Fig. 1. Generic SC structure.

cost while allocating optimal amounts to the best performing suppliers so that the redesigned SC network brings economic stability and also enhances the sustainable performance of the company in the long run.

In order to incorporate the above aspects, an integrated model is developed in the study which aims to achieve a cost effective SC network by selecting the best performing sustainable suppliers and also optimally allocating purchase order among the selected suppliers. The suppliers are evaluated through Z-TOPSIS process based on sustainable attribute which suitably represents the customers' environmental and social expectations. The evaluation scores which reflect the customers' expectation level are then transformed as retailers' expectations level and are used as inputs in the optimisation model for selecting suppliers and allocating orders based on the penalty and reward system. The methodology adopted to develop the SC network model is discussed in detail in the next section.

4. Methodology

The methodology adopted in the study for attaining the aim of the study involves the following three phases:

Phase 1: An exhaustive supplier evaluation process is performed which includes:

- Identification of vital sustainable attribute for the evaluation of suppliers
- Computation of overall sustainable weights and socio-ecological weights of suppliers using Z-TOPSIS

Phase 2: The evaluation of suppliers' performance on the basis of significant sustainable attributes provides weights of importance of suppliers. However, the selection of suppliers purely on the basis of these assessment values is not what is desired by the company as suppliers performing upto the environmental and the social expectations of customers may demand higher cost. Further, along with the selection decision the order allocation amounts based on the capacities of supplier and the holding capacity of retailers are also to be determined. It is also required that the amount of purchase order be optimally distributed among the selected suppliers based on their sustainability scores. To encourage the suppliers to perform better, the company also wants to reward the better performing suppliers or impose penalty on the poor performing suppliers them in terms of a monetary value. Thus an optimisation model is developed in this phase, which integrates all the above aspects into a supplier selection model such that the total cost and sustainable impact of the SC network (in terms of SVP) are both optimised.

Phase 3: Weighted Goal programming approach is used to solve the bi-objective mathematical programming problem proposed in phase 2 and in attaining trade-off between the objectives, significant to the decision environment.

A summary of the Methodology is pictorially described through Fig. 2 provided below:

A detailed explanation of the three phases is provided in the following subSections 4.1–4.3.

4.1. Phase I: supplier evaluation process

4.1.1. Identification of attributes

In this study, customer sustainable (economic, environmental and social) expectations have been translated into retailers' expectations based on the feedback that the retailers have received from the customers through a structured survey. Since, the link between manufacturer and customers are the intermediary retailers. Thus, on behalf of the manufacturing firm, the regional head has consulted retailers and taken their feedback into the decision making process. The group of DMs included head of operations (having experience of 5–6 years), procurement manager (having experience of 9–11 years), head of purchasing department (having experience of 7–10 years), marketing manager (having experience of 5–8 years) and regional head (having experience of 8–12 years) as major DMs, is considered for evaluating the suppliers' performance. Eight attributes are extracted based on extensive literature survey and consensus with the DMs, as listed in Table 1.

4.1.2. Fuzzy-TOPSIS method for assessment of suppliers

A Z-number is represented by an ordered pair of fuzzy numbers as $Z = (\tilde{A}, \tilde{B})$ where $\tilde{A}$ signifies the fuzzy restriction and $\tilde{B}$ represents the reliability of $\tilde{A}$[64]. Let $\tilde{A} = \{\langle x, \mu_{\tilde{A}}(x)\rangle | x \in [0, 1]\}$ and $\tilde{B} = \{\langle x, \mu_{\tilde{B}}(x)\rangle | x \in [0, 1]\}$where $\mu_{\tilde{A}}(x)$and$\mu_{\tilde{B}}(x)$are triangular fuzzy membership functions.

Let there be 'q' DMs, $q = 1, 2, \ldots, Q$, 'k' attributes, $k = 1, 2, \cdots, K$ and 's' suppliers, $s = 1, 2, \cdots, S$. The procedure of assessment of suppliers using Z-TOPSIS approach is as follows:

Step 1: Evaluation of attributes by each DM with degree of confidence based on fuzzy linguistic terms defined in Tables 2 and 3.

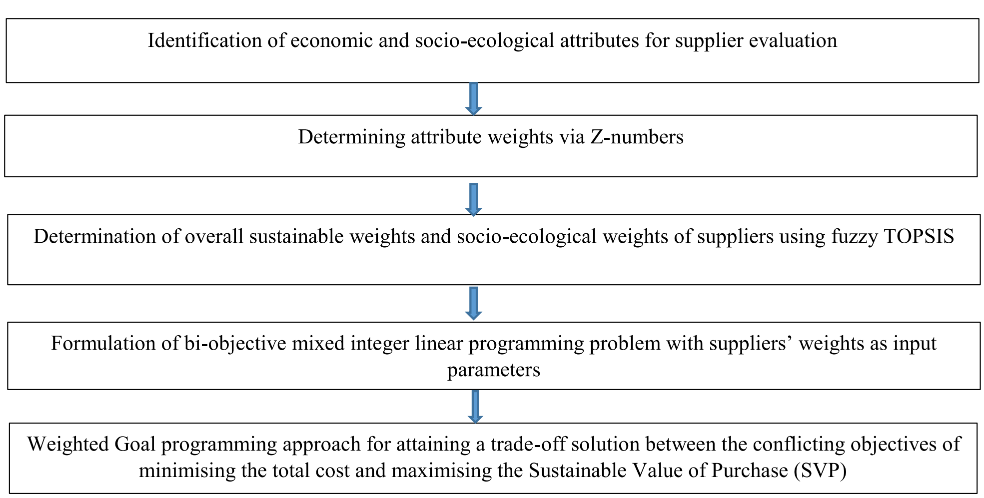

Fig. 2. Proposed framework.

Table 1
Attributes for evaluation.

S. no.	Attributes	Description	References
1	Product price (C_1)	Capability of selling the good quality product at reasonable price	Luthra et al. [43]; Hashemi et al. [25]; Kannan et al. [32]
2	Delivery efficiency (C_2)	Capability of delivering the product to the right location at the predetermined time	Luthra et al. [43]; Hashemi et al. [25]; Azadnia et al. [2]
3	Logistic & transportation efficiency (C_3)	Tendency of transporting the products as efficiently as possible	Kannan et al. [32]; Luthra et al. [43]
4	Technological capability (C_4)	Capability of adopting new technologies based on the current market demand	Luthra et al. [43]; Hashemi et al. [25]; Azadnia et al. [2]
5	Financial competence (C_5)	It refers to the financial aspects such as liquidity and profitability of the company	Büyüközkan & Çifçi [8]; Kuo and Lin [37]; Luthra et al. [43], Govindan et al. [22]
6	Flexibility (C_6)	Capability to handle variations in demand and lead time	Luthra et al. [43]; Hashemi et al. [25]
7	Social conscience (C_7)	Suppliers' responsibility towards employees' rights protection, health and safety. Level of commitment towards social enhancement of the SC.	Luthra et al. [43]; Azadnia et al. [2]; Kannan et al. [32]
8	Green Competence and Energy Efficiency (C_8)	Capability of altering the process and product which reduces effect on natural resources. Efficiently using energy as per the existing industry norms	Kannan et al. [32]; Hashemi et al. [25]

Table 2
Linguistic scale and TFN for evaluation of attributes.

Linguistic variable	Triangular fuzzy number
Very low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Medium low (ML)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
Medium high (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very high (VH)	(0.9,1,1)

Table 3
Linguistic scale and TFN for DMs' reliability.

Linguistic variable	Triangular fuzzy number
Strongly Unlikely (SU)	(0,0,0.1)
Unlikely (U)	(0,0.1,0.3)
Somewhat Unlikely (SWU)	(0.1,0.3,0.5)
Neutral (N)	(0.3,0.5,0.7)
Somewhat Likely (SWL)	(0.5,0.7,0.9)
Likely (L)	(0.7,0.9,1)
Strongly Likely (SL)	(0.9,1,1)

Step 2: Conversion of reliability assessment into crisp number using the given formula:

$$\alpha = \frac{\int x\mu_{\tilde{B}}(x)dx}{\int \mu_{\tilde{B}}(x)dx}$$

Step 3: Determination of weighted Z-number for each DM as follows:

$$\tilde{Z}^{\alpha} = \left\{\langle x, \mu_{\tilde{A}^{\alpha}}(x)\rangle | \mu_{\tilde{A}^{\alpha}}(x) = \alpha\mu_{\tilde{A}}(x), x \in [0, 1]\right\}$$

Table 4
Linguistic scale and TFN for evaluation of suppliers.

Linguistic variable	Triangular fuzzy number
Very poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very good (VG)	(9,10,10)

Step 4: Transformation of weighted Z-number into Triangular Fuzzy Number (TFN) as follows:

$$\tilde{Z}' = \sqrt{\alpha} \times \tilde{A}^{\alpha} = (\sqrt{\alpha} \times l, \sqrt{\alpha} \times m, \sqrt{\alpha} \times n)$$

Step 5: Determination of attribute weights $\tilde{W} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_K)$ by aggregating the weighted Z-numbers of all DMs using the formula.

$$\tilde{w}_k = \frac{1}{q}[\tilde{w}_k^1 + \tilde{w}_k^2 + ...+\tilde{w}_k^q]$$

Step 6: Steps 1 to 5 are repeated to determine the aggregated suppliers' weight $\tilde{x}_{sk}$ for s^{th} supplier with respect to k^{th} attribute, using the linguistic variables defined in Tables 3 and 4.

Step 7: Construction of fuzzy decision matrix $\tilde{D}_1$ as follows:

$$\tilde{D}_1 = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & ... & \tilde{x}_{1K} \\ \tilde{x}_{21} & \tilde{x}_{22} & ... & \tilde{x}_{2K} \\ ... & ... & ... & ... \\ \tilde{x}_{S1} & \tilde{x}_{S1} & ... & \tilde{x}_{SK} \end{bmatrix}, s = 1, 2, ..., S, k = 1, 2, ..., K$$

Where $\tilde{x}_{sk} = \frac{1}{Q}[\tilde{x}_{sk}^1 + \tilde{x}_{sk}^2 + \cdots\cdots+\tilde{x}_{sk}^Q]$

Step 8: Construction of normalized fuzzy decision matrix $\tilde{D}_2$ as follows:

$$\tilde{D}_2 = [\tilde{y}_{sk}]_{SxK}, s = 1, 2, ...,S, k = 1, 2, ...,K$$

Where

$$\tilde{y}_{sk} = \left(\frac{l_{sk}}{n_k^*}, \frac{m_{sk}}{n_k^*}, \frac{n_{sk}}{n_k^*}\right) \text{and } n_k^* = \max_s n_{sk} \text{ (Forbenefitattribute)}$$

$$\tilde{y}_{sk} = \left(\frac{l_k^-}{n_{sk}}, \frac{l_k^-}{m_{sk}}, \frac{l_k^-}{l_{sk}}\right) \text{and } l_k^- = \min_s l_{sk} \text{ (Forcostattribute)}$$

Step 9: Computation of weighted normalized decision matrix $\tilde{D}_3$using the following formula:

$$\tilde{D}_3 = [\tilde{z}_{sk}]_{S\times K}, s = 1, 2, ...,S, k = 1, 2, ...,K$$

where $\tilde{z}_{sk} = \tilde{y}_{sk}(.)\tilde{w}_k$

Step 10: Computation of fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) for each alternative as follows:

$$B^* = (\tilde{z}_1^*, \tilde{z}_2^*, ...\tilde{z}_K^*) \text{where } \tilde{z}_k^* = (1, 1, 1), k = 1, 2, ...,K$$

$$B^- = (\tilde{z}_1^-, \tilde{z}_2^-, ...\tilde{z}_K^-) \text{where } \tilde{z}_k^- = (0, 0, 0), k = 1, 2, ...,K$$

Step 11: Determination of distance of each alternative from FPIS and FNIS as follows:

$$d_s^* = \sum_{k=1}^{K} d_z(\tilde{z}_{sk}, \tilde{z}_k^*), s = 1, 2, ...,S$$

$$d_s^- = \sum_{k=1}^{K} d_z(\tilde{z}_{sk}, \tilde{z}_k^-),\ s = 1, 2, \ldots, S$$

where $d_z(\tilde{z}_{sk}, \tilde{z}_k)$ represents distance measurement between two fuzzy numbers $\tilde{z}_{sk}$ and $\tilde{z}_k$.

Step 12: Computation of closeness coefficient (CC_s) of each alternative using equation:

$$CC_s = \frac{d_s^-}{d_s^- + d_s^*},\ s = 1, 2, \ldots, S$$

Step 13: Rank the alternatives according to the closeness coefficient. The best alternative is closest to the FPIS and farthest to the FNIS.

4.2. Bi-objective optimisation model

The optimisation model is formulated as bi-objective programming problem (BOP) under the following assumptions:

Assumptions

- All parameters are known and deterministic.
- Demands are divisible among suppliers and known with certainty.
- Multi-planning period is considered.
- Single product having two different variants is considered.
- Suppliers' performance with respect to social and environmental attribute below expectations is penalized and gets additional bonus if performance is above expectations.
- All suppliers have different capacities, lead time and procurement cost.
- Fixed capacities of suppliers and retailers are considered.
- Quality of the product is same.

The sets, parameters, decision variables, objectives and the constraints considered in the model are as follows:

Sets

$p \in P$ Set of products
$s \in S$ Set of suppliers
$r \in R$ Set of retailers
$t \in T$ Set of time periods
$k \in K$ Set of sustainable attributes where $K = K^{Tr} \cup K^{SE}$
$K^{Tr} = \{K_1, K_2, \ldots, K_6\}$ is set of Traditional attributes and
$K^{SE} = \{K_7, K_8\}$ is set of Socio-ecological attributes

Parameters

- H_{prt}: per unit inventory holding cost of p^{th} product at r^{th} retailer in t^{th} time period
- Pc_{psrt}: procurement cost of p^{th} product supplied by s^{th} supplier to r^{th} retailer in t^{th} time period
- Tc_{psrt}: transportation cost per unit of p^{th} product transporting products from s^{th} supplier to r^{th} retailer in t^{th} time period
- D_{prt}: demand of p^{th} product at r^{th} retailer in t^{th} time period
- C^1_{pst}: capacity of p^{th} product at the s^{th} supplier in t^{th} time period
- C^2_{prt}: capacity of p^{th} product at r^{th} retailer in t^{th} time period
- I_{pr0}: Initial Inventory of the p^{th} product at r^{th} retailer
- $W_s^{overall}$: performance evaluation scores of s^{th} supplier with respect to all attributes obtained from Z-TOPSIS
- E^{SE}: retailer expectation with respect to socio-ecological performance of suppliers
- W_s^{SE}: performance evaluation score of s^{th} supplier with respect to the socio-ecological attributes $K^{SE} = \{K_7, K_8\}$ obtained from Z-TOPSIS
- α_1: penalty determination multiplier for performance value of supplier being less than the retailer's expectation level
- β: market bonus multiplier for performance value of supplier being greater than the retailer's expectation level
- s_{max}: maximum number of suppliers that can be selected

Decision variables

- I_{prt}: inventory of p^{th} product at r^{th} retailer in t^{th} time period
- X_{psrt}: quantity flowing of p^{th} product from s^{th} supplier to r^{th} retailer in t^{th} time period
- V_s: binary value taking value 1 if s^{th} supplier is selected, 0 otherwise
- η_s^+: positive deviational variable measuring the increase in the socio-ecological performance value of s^{th} supplier for K^{SE}, than the retailer expectation level
- η_s^-: negative deviational variable measuring the deficit in the socio-ecological performance value of s^{th} supplier for K^{SE}, than the retailer expectation level

Objectives

The cost objective given by Eq. (1) minimizes the total cost of the system. The first term represents the procurement cost, the second term shows transportation cost, the third term corresponds to inventory holding cost and the last two terms shows the penalty and bonus amount.

$$\text{Min Total Cost} = \text{Min } Z_1 = \sum_p \sum_s \sum_r \sum_t Pc_{psrt} X_{psrt} V_s + \sum_p \sum_s \sum_r \sum_t Tc_{psrt} X_{psrt} V_s + \sum_p \sum_r \sum_t H_{prt} I_{prt} + \alpha_1 \sum_s \eta_s^- V_s - \beta \sum_s \eta_s^+ V_s \tag{1}$$

Eq. (2) represents the objective of maximizing SVP which calculates the total procurement amount while assigning the maximum order to suppliers with highest sustainable weights.

$$\text{Max Sustainable Value Purchase (SVP)} = Max\ Z_2 = \sum_p \sum_s \sum_r \sum_t X_{psrt} W_s^{overall} V_s \tag{2}$$

Constraints

Eq. (3) restricts the minimum and maximum number of suppliers required.

$$1 \le \sum_s V_s \le s_{\max} \tag{3}$$

Eqs. (4) and (5) are the inventory balancing equations of each retailer for t^{th} time period.

$$I_{prt} = I_{pr0} + \sum_s X_{psrt} V_s - D_{prt} \quad \forall\ p, r, t = 1 \tag{4}$$

$$I_{prt} = I_{prt-1} + \sum_s X_{psrt} V_s - D_{prt} \quad \forall\ p, r, t > 1 \tag{5}$$

Eq. (6) limits the capacity of retailer in t^{th} time period.

$$I_{prt} + \sum_s X_{psrt} V_s \le C^2_{prt} \quad \forall\ p, r, t \tag{6}$$

Eq. (7) ensures that the demand of retailer is satisfied.

$$\sum_r \sum_t I_{prt} + \sum_s \sum_r \sum_t X_{psrt} V_s \ge \sum_t \sum_r D_{prt} \quad \forall\ p \tag{7}$$

Table 5
Assessment of attributes by DMs.

	K_1 (A,B)	K_2 (A,B)	K_3 (A,B)	K_4 (A,B)	K_5 (A,B)	K_6 (A,B)	K_7 (A,B)	K_8 (A,B)
DM_1	(VH,L)	(H,N)	(VH,L)	(MH,N)	(H,L)	(M,N)	(H,N)	(H,L)
DM_2	(VH,SL)	(MH,L)	(H,SL)	(H,N)	(VH,SL)	(H,N)	(VH,N)	(VH,SL)
DM_3	(H,L)	(VH,L)	(H,L)	(H,L)	(VH,L)	(MH,L)	(H,L)	(VH,L)
DM_4	(H,L)	(H,L)	(VH,L)	(MH,L)	(MH,L)	(H,L)	(VH,L)	(H,L)
DM_5	(VH,L)	(MH,N)	(H,SL)	(M,N)	(H,L)	(H,N)	(VH,N)	(VH,SL)

Eq. (8) restricts the capacity of each supplier in t^{th} time period.

$$\sum_p X_{psrt} V_s \le \sum_p C_{pst}^1 \quad \forall\, s, r, t \tag{8}$$

Eq. (9) evaluates suppliers according to the expectations of retailers with respect to the socio- environmental attributes.

$$V_s(W_s^{SE} + \eta_s^- - \eta_s^+) = E^{SE} V_s \quad \forall\, s \tag{9}$$

Eq. (10) ensures that the performance evaluation scores of each of the selected supplier must be greater than the threshold.

$$W_s^{overall} V_s \ge 0.43 * V_s \quad \forall\, s \tag{10}$$

The non-negativity and binary restrictions are enforced by Eqs. (11) and (12)

$$I_{prt},\ X_{psrt},\ \eta_s^+,\ \eta_s^- \ge 0 \tag{11}$$

$$V_s \in \{0, 1\} \tag{12}$$

4.3. Goal programming (GP) approach

Goal programming (GP), developed in early 60 s by Charnes and Cooper [11], is an efficient technique for dealing with multi-objective optimization models having conflicting goals. The basic aim of GP is to assign an aspiration level to each objective function. Afterwards, minimizes the weighted sum of undesirable deviances between actual goals and aspiration levels. The most commonly used GP approach is weighted goal programming (WGP). The objective of WGP is minimizing the sum of deviations between goals and aspirations.

The steps for the GP approach are as follows:

Step 1: Solve the following Single Objective programming Problems (SOPs) to obtain the aspiration levels for each objective:
SOP1:
Minimize Z_1
Subject to constraints 3)–((12)
SOP2:
Maximize Z_2
Subject to constraints 3)–((12)

Let Z_1^* and Z_2^* be the optimal values of SOP1 and SOP2 respectively.

Step 2: In this step, negative and positive deviational variables η_i *and* ρ_i are added in the objective functions and constraints as follows:

$$Z_i(X) + \eta_i - \rho_i = Z_i^*, \quad i = 1, 2$$

subject to $g_j(X) + \eta_j - \rho_j = b_j;\ j = 3, 4, \ldots, 12$

$\eta_i, \rho_i \ge 0$

Step 3: The problem is first solved using rigid constraints only with the objective to minimize the specific deviational variables as follows:

For Minimisation objective Z_1 the deviational variable ρ_1 is minimised and for Maximisation objective Z_2 the deviational variable η_2 is minimised.

For constraints if $g_j(X) \le b_j$ then ρ_j is minimized if $g_j(X) \ge b_j$ then η_j is minimized and if $g_j(X) = b_j$ then $\eta_j + \rho_j$

The problem can be reformulated incorporating the optimal solution of the problem (P3) as follows:

Step 4: The following programming problem SOP3 is formulated for finding the compromised solution to the bi-objective problem developed in Section 4.2 (assuming all constraints are rigid).
SOP3
$Minimize = \lambda_1 \rho_1 + \lambda_2 \eta_2$
Subject to
$(Z_1/Z_1^*) + \eta_1 - \rho_1 = 1$
$(Z_2/Z_2^*) + \eta_2 - \rho_2 = 1$

and constraints (3)-(12)where ρ_1, η_2 are normalised deviations from the objectives and λ_i $(i = 1,2)$ is the weight assigned to the i^{th} objective.

The procedure given above helps in achieving the compromised solution which helps in creating a trade-off between objectives.

5. Numerical illustration

The present study focuses on an example problem for a northern India based home appliance manufacturing company. As discussed in the problem description (Section 3), the focus of the proposed study is to aid the company in achieving their economic targets while satisfying the sustainability targets. In order to achieve this, the company needs to understand which suppliers to work with and who are able to meet their expectation level in terms of socio-environmental aspects. In order to

Table 6
Attribute evaluation matrix with Z-numbers.

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
DM_1	(0.84,0.93,0.93)	(0.49,0.63,0.70)	(0.84,0.93,0.93)	(0.35,0.49,0.64)	(0.65,0.84,0.93)	(0.64,0.71,0.71)	(0.49,0.63,0.70)	(0.65,0.84,0.93)
DM_2	(0.88,0.98,0.98)	(0.47,0.65,0.84)	(0.69,0.88,0.98)	(0.49,0.63,0.70)	(0.88,0.98,0.98)	(0.49,0.63,0.70)	(0.35,0.49,0.64)	(0.88,0.98,0.98)
DM_3	(0.65,0.84,0.93)	(0.84,0.93,0.93)	(0.65,0.84,0.81)	(0.65,0.84,0.93)	(0.84,0.93,0.93)	(0.47,0.65,0.84)	(0.65,0.84,0.93)	(0.84,0.93,0.93)
DM_4	(0.65,0.84,0.93)	(0.65,0.84,0.93)	(0.84,0.93,0.93)	(0.47,0.65,0.84)	(0.47,0.65,0.84)	(0.65,0.84,0.93)	(0.84,0.93,0.93)	(0.65,0.84,0.93)
DM_5	(0.84,0.93,0.93)	(0.35,0.49,0.64)	(0.69,0.88,0.98)	(0.64,0.71,0.71)	(0.65,0.84,0.93)	(0.49,0.63,0.70)	(0.35,0.49,0.64)	(0.88,0.98,0.98)

Table 7
Fuzzy decision matrix for evaluation of suppliers w.r.t. sustainable attributes.

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
S_1	(5.45,7.33,8.66)	(3.03,4.80,6.58)	(3.64,5.55,7.45)	(2.87,4.46,5.91)	(2.80,4.69,6.38)	(3.05,4.64,5.90)	(4.73,6.32,7.40)	(3.25,5.15,7.06)
S_2	(5.13,7.04,8.56)	(4.08,5.78,7.20)	(4.37,6.27,7.99)	(3.34,5.05,6.55)	(4.31,6.20,7.71)	(4.89,6.67,7.88)	(4.41,6.02,7.31)	(4.80,6.70,8.22)
S_3	(5.11,7.01,8.55)	(4.95,6.55,7.79)	(5.56,7.29,8.65)	(5.40,7.08,8.38)	(5.65,7.60,8.95)	(4.71,6.33,7.60)	(4.88,6.67,8.08)	(5.11,6.83,8.17)
S_4	(5.97,7.89,9.24)	(6.35,7.66,8.27)	(6.36,8.09,9.24)	(6.30,7.89,8.78)	(6.70,8.22,9.15)	(6.13,7.36,7.93)	(5.85,7.73,9.04)	(7.09,8.64,9.43)
S_5	(3.23,5.13,7.04)	(2.11,3.70,5.29)	(2.21,4.00,5.79)	(3.52,5.16,6.79)	(2.43,4.31,6.20)	(2.29,4.06,5.83)	(2.67,4.27,5.86)	(2.22,4.03,5.85)

demonstrate the validity the proposed model, a small data set of two variants marked as M1 and M2 of toasters is taken for four planning horizons. The demand of 2 distributors catering to a total of 10 retail stores is considered. For procuring the models, there is a pool of five suppliers ($S = 5$) who are capable enough to supply as per the requirement of both the variants. The manufacturer aims to evaluate the suppliers based on customers' socio-environmental expectations. The customer's expectation level is translated in terms of retailer's expectation level of the supplier's performance and based on that understanding a total of eight evaluation attributes ($K = 8$) are considered. The six traditional attributes and two socio-ecological attributes are listed in Section 4.1.1.

Following Z-TOPSIS methodology given in Section 4.1.2, firstly the decision opinions have been collected from five DMs ($Q = 5$) in terms of the linguistic variables and then fuzzy linguistic assessment scale provided in Tables 2–4 in Section 4.1.2, is used to express them into Z-numbers. For example, the evaluation of all DMs for all attributes is provided by Table 5. In this table, the notation 'VH' in (VH, L) represents the importance of attribute K_7 for DM_4 is very high and value 'L' signifies that the reliability of information provided by DM_1 is likely. Similarly, the other values have been interpreted.

Next, the importance of attribute K_7 given by DM_4 is expressed in Z-number as: $\tilde{Z} = (\tilde{A}, \tilde{B}) = ((0.9, 1, 1), (0.7, 0.9, 1))$

Further, the reliability of DM is converted into precise value and we get the following weighted Z-number: $\tilde{Z}^{\alpha} = (\tilde{A}, \alpha) = ((0.9, 1, 1); 0.87)$

The weighted Z-number is transformed into fuzzy number as: $\tilde{Z}' = (\sqrt{0.87} \times 0.9, \sqrt{0.87} \times 1, \sqrt{0.87} \times 1) = (0.84, 0.93, 0.93)$

Repeating the process for each judgement, the weighted Z-numbers of all DMs with respect to attributes are obtained as shown Table 6.

The attribute weights obtained for all the DMs are aggregated using the average function and we get the following attribute weights:

$$\tilde{W} = (\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_8) = \begin{pmatrix} (0.77, 0.90, 0.94), (0.56, 0.71, 0.80), (0.74, 0.89, 0.93), \\ (0.44, 0.59, 0.72), \\ (0.70, 0.85, 0.92), (0.64, 0.76, 0.80), (0.35, 0.49, 0.64), \\ (0.74, 0.89, 0.95) \end{pmatrix}$$

Similarly the aggregated weights of all suppliers are obtained and the following fuzzy decision matrix $\tilde{D}_1 = [\tilde{x}_{sk}]_{5X8}$as shown in Table 7 is constructed.

Table 9
Final sustainable performance values of suppliers.

Suppliers	S_1	S_2	S_3	S_4	S_5
d_s^-	2.10	2.30	2.53	2.66	2.13
d_s^*	2.75	2.55	2.33	2.17	2.83
$CC_s = W_s^{overall}$	0.43	0.47	0.52	0.55	0.43

Next, normalized decision matrix $\tilde{D}_2 = [\tilde{y}_{sk}]_{5X8}$is constructed (provided in Table A in the appendix).

For example for supplier S_1 with respect to attribute K_1 which a cost attribute, $l_1^- = \min_s l_{s1} = 3.23$and $\tilde{y}_{11} = (3.23/8.66,\ 3.23/7.33,\ 3.23/5.45) = (0.37,\ 0.44,\ 0.59)$

Further, the weighted normalized matrix $\tilde{D}_3 = [\tilde{z}_{sk}]_{5X8}$is computed as shown in Table 8.

For example $\tilde{z}_{11} = \tilde{y}_{11}.\ \tilde{w}_1 = (0.37,\ 0.44,\ 0.59).\ (0.77,\ 0.90,\ 0.94) = (0.29,\ 0.40,\ 0.56)$

Next, the FPIS and FNIS for each supplier are calculated as:

$$B^* = [(1,\ 1,\ 1)_1,\ (1,\ 1,\ 1)_2,\ \ldots,(1,\ 1,\ 1)_5] \text{ and } B^- = [(0,\ 0,\ 0)_1,\ (0,\ 0,\ 0)_2,\ \ldots,(0,\ 0,\ 0)_5]$$

Subsequently, the distance of each supplier from FPIS and FNIS is calculated and the closeness coefficient is calculated as shown in Table 9.

Similarly the evaluation scores of suppliers with respect to the social and environmental attribute set $K^{SE}$are obtained which are as follows: $W_s^{SE} = (0.45,\ 0.39,\ 0.40,\ 0.40,\ 0.45)$.

Next, in order to select the suppliers based on the above evaluation scores, the optimisation model developed in Section 4.2 needs to be solved. For this, the values of the parameters of the mathematical model need to be defined as per the following information given by the company.

The penalty determination multiplier if performance evaluation of supplier is less than the retailer expectation is taken as 3. While the market bonus multiplier if performance evaluation of supplier is greater than the retailer expectation is taken as 2.

Table 8
Weighted normalized matrix for evaluation of suppliers w.r.t. sustainable attributes.

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
S_1	(0.29,0.40,0.56)	(0.20,0.41,0.64)	(0.29,0.54,0.75)	(0.14,0.30,0.49)	(0.21,0.43,0.64)	(0.25,0.44,0.59)	(0.28,0.47,0.63)	(0.23,0.38,0.65)
S_2	(0.29,0.41,0.59)	(0.28,0.49,0.70)	(0.35,0.61,0.80)	(0.17,0.34,0.54)	(0.33,0.57,0.78)	(0.40,0.64,0.79)	(0.26,0.45,0.62)	(0.20,0.30,0.44)
S_3	(0.29,0.42,0.59)	(0.33,0.56,0.76)	(0.45,0.71,0.87)	(0.27,0.48,0.69)	(0.43,0.70,0.90)	(0.38,0.61,0.76)	(0.29,0.50,0.69)	(0.20,0.29,0.41)
S_4	(0.27,0.37,0.51)	(0.43,0.65,0.80)	(0.51,0.78,0.93)	(0.31,0.53,0.72)	(0.51,0.76,0.92)	(0.50,0.71,0.80)	(0.35,0.58,0.77)	(0.17,0.23,0.30)
S_5	(0.35,0.57,0.94)	(0.14,0.32,0.51)	(0.18,0.39,0.58)	(0.17,0.35,0.56)	(0.19,0.40,0.63)	(0.19,0.39,0.59)	(0.16,0.32,0.50)	(0.28,0.49,0.95)

Table 10
Per unit inventory holding cost and demand of product for retailers.

Time period		Holding cost (in INR)cost										Demand (in units)									
		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}
M1	**t1**	4.8	4.5	5	4.7	4.9	4.8	4.9	5	4.6	4.7	32	24	24	48	40	28	32	36	40	32
	t2	4.7	4.4	4.9	4.6	5	4.8	5	4.9	4.7	4.6	40	32	32	44	48	36	40	40	48	36
	t3	4.8	4.5	5	4.7	4.9	4.8	4.9	5	4.6	4.7	32	24	24	48	40	28	32	36	40	32
	t4	4.7	4.4	4.9	4.6	5	4.8	5	4.9	4.7	4.6	40	32	32	44	48	36	40	40	48	36
M2	**t1**	4.6	4.7	4.5	4.8	4.9	4.7	4.8	4.9	4.7	4.8	28	32	28	28	40	36	32	44	40	28
	t2	4.7	4.8	4.7	4.8	5	4.8	4.7	4.9	4.8	4.9	40	36	32	36	52	48	40	48	56	40
	t3	4.6	4.7	4.5	4.8	4.9	4.7	4.8	4.9	4.7	4.8	28	32	28	28	40	36	32	44	40	28
	t4	4.7	4.8	4.7	4.8	5	4.8	4.7	4.9	4.8	4.9	40	36	32	36	52	48	40	48	56	40

In this study, customer expectations has been translated into retailers' expectations (E^{SE}) with respect to socio-ecological performance of suppliers. Customer satisfaction level has been identified based on the survey. The survey was designed to complement the measures of feedback from customers on socio-ecological aspects. Retailers are requested to provide questionnaires to individual customers who visited to them in order to get the true picture of their satisfaction level. Thus, retailers' expectation scores with respect to the social and environmental attribute set$K^{SE}$are taken as: $E^{SE} = 0.40$.

For each time period, the procurement amount to be determined by the model must not exceed the demand of the retailers and it also contributes towards the cost of the network. The demand of 10 retailers and the inventory holding costs are provided in Table 10. Also, the procurement amount ordered to each supplier must not exceed his capacity and the inventory to be stocked at each retail store must not exceed the capacity of the retailer. Table 11 yields the capacities of suppliers to deliver and the capacities of retailers for storing inventory. Further, the procurement cost of the model M1 and model M2 with cost per unit of transporting the finished goods from supplier to retail stores is given in Table B (in appendix).

The data considered here helps in solving the proposed SC network. The next section presents the results and provides its practical implications.

6. Result discussion and implications

6.1. Result

The Z-TOPSIS methodology discussed in Section 4.1 generates assessment scores of the suppliers based on their performance which are further utilized in the bi-objective optimization model developed in Section 4.2. The mathematical model is further solved using WGP technique explained in Section 4.3 to obtain a trade-off between the contradictory goals of minimizing the total cost and maximising the SVP. To obtain the trade-off solution to the bi-objective problem, first the aspiration levels for both objectives are to be determined. For this, initially two Single Objective Problems (SOPs) are solved over the same set of constraints using LINGO 11.0: SOP1 with the "Total cost" objective and SOP2 with "SVP" objective. The optimal objective values of SOP1 and SOP2 are the highlighted values shown in Table 12. The value of SVP obtained while minimising the total cost objective in SOP1 and the total cost incurred when maximising SVP objective in SOP2 are also provided.

Using the aspirational values attained from the above table, first the deviational variables are introduced in the two objectives and the soft constraints. For the demand restrictions and SVP objective function, under-achievement needs to be penalized. On the other hand, in case of capacity constraints and cost objective the over-achievement needs to be penalized. The bi-objective problem is transformed to a single objective problem (SOP3) of minimising the achievement function defined in terms of the unwanted normalized deviational variables. The equivalent weighting structure by assigning the preferential weights of all the unwanted deviations equal to one is being employed after discussion with DMs. The optimal solution of SOP3 is provided in Table 13 which is the trade-off solution to the BOP developed in Section 4.2. Table C presents the inventory procured by the retail store in all time periods.

6.2. Result discussion

The aim of this research is to design an integrated framework for selection of suppliers as to incorporate the customer sustainable expectations in the SC network of an Indian electronic manufacturer. The manufacturer wants to meet the sustainable expectation of the

Table 11
Capacities of the retailers and suppliers.

Time period		Capacity of retailers										Capacity of suppliers				
		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	S_1	S_2	S_3	S_4	S_5
M1	**t1**	40	32	28	56	44	36	36	40	44	36	140	152	160	128	120
	t2	48	36	36	48	60	36	44	44	52	40	152	160	160	136	128
	t3	40	32	28	52	44	36	36	40	44	36	140	152	160	128	120
	t4	48	36	36	48	52	40	44	44	52	40	152	160	160	136	128
M2	**t1**	36	40	32	40	48	40	36	52	48	36	156	132	128	164	168
	t2	44	40	36	40	56	52	44	52	60	44	160	140	140	176	180
	t3	36	40	32	40	48	40	36	52	48	32	156	132	128	164	168
	t4	44	40	36	40	60	52	44	52	60	44	160	140	140	176	180

Table 12
Optimal solutions of SOP1 and SOP2.

Optimisation problem	Objective	Total cost (INR)	SVP	Suppliers selected	Sustainable weights of selected suppliers	Socio-ecological weights of selected suppliers	Procurement amount	Deviation from retailers' socio-environmental expectation level
SOP1	Minimisation of Total cost	4840663	1311.95	S_1 S_2 S_3 S_4	0.43 0.47 0.52 0.55	0.44 0.39 0.40 0.40	294 299 2493 103	+ 0.05 - 0.01 + 0.01 + 0.01
SOP2	Maximisation of SVP	5092599	1578.372	S_3 S_4	0.52 0.55	0.40 0.40	1110 1753	+ 0.01 + 0.01

Table 13
Optimal solution of SOP3.

Optimisation problem	Total cost (INR)	SVP	Suppliers selected	Sustainable weights of selected suppliers	Socio-ecological weights of selected suppliers	Procurement amount	Deviation from retailers' socio-environmental expectation level
SOP3	492363	1421.36	S_1 S_3 S_4	0.43 0.52 0.55	0.44 0.40 0.40	290 1497 1402	+ 0.05 + 0.01 + 0.01

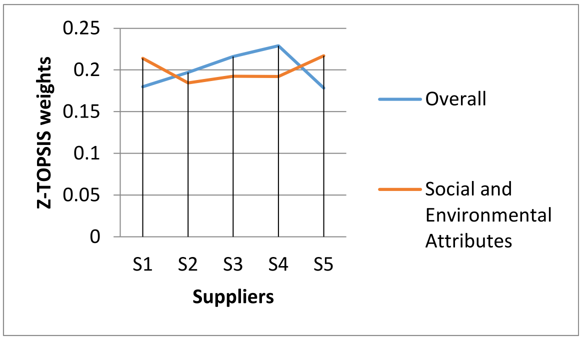

Fig. 3. Z-TOPSIS weights of suppliers.

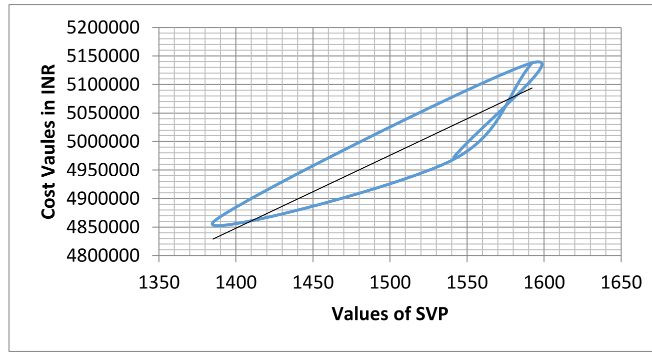

Fig. 4. Pareto frontier.

customers, so as to work with suppliers with who are flexible enough towards the changing customer requirements. In order to incorporate the above aspects, the suppliers are evaluated through Z-TOPSIS process based on sustainable attribute which suitably represents the customers' environmental and social expectations in the first phase. Z-TOPSIS (steps given in Section 4.1) generates evaluation scores of the suppliers which reflect the customers' expectation level are then transformed as retailers' expectations level and are used as inputs in the optimisation model for selecting suppliers and allocating orders based on the penalty and reward system.

To elaborate upon the evaluation process, in the first phase, we use Z-TOPSIS generate the weights of the suppliers. As demonstrated through the Fig. 3, it is difficult to say which supplier is performing better by simply looking at the scores obtained using Z-TOPSIS. Clearly, the rankings are sensitive to the metric considered, and the final selection based purely on the aggregated ranking may not be desirable. Hence, the mathematical model is proposed for the final selection based on certain SC constraints so that the overall aim of the DM is satisfied.

To capture the trade-off between the objectives, WGP approach is utilized. Following the steps of the SOPs are solved individually. Table 12 provides the details of the cost and SVP objectives along with the aspiration values. It can be seen from Table 12 that there exists conflict between the two objectives. The optimal solution of SOP1 is INR 4840663 in which suppliers S_1, S_2, S_3 and S_4 are selected with Z-TOPSIS weights as 0.43, 0.47, 0.52 and 0.55 respectively with the SVP value obtained as 1312.116. Maximum number of suppliers is selected with supplier 5 not selected Comparing with the high optimal SVP value of 1578.372 obtained after solving SOP2 shows that the first model has clearly compromised on the sustainable performance of the suppliers in the selection decision. Similarly, the difference in the values of the cost of the network obtained in SOP2 and SOP1, which is approximately INR 251936 shows that if the company wants to select suppliers purely on the basis of fulfilling customers' expectations then it will have to bear financial loss. However it can be observed that in both scenarios, suppliers selected have positive deviation from retailer's expectation level of socio-environmental performance so no suppliers will be penalised and would be rewarded. Overall, it can be stated that two individual objectives are in conflict with each other in the attainment of the aspired values of the objectives.

This justifies the need for an effective solution technique such as WGP utilised in the study to attain a compromised solution as per the DMs' opinions. The WGP model helps in attaining a compromised solution with cost of INR 492363 and SVP value of 1421.36. Suppliers S_1, S_3 and S_4 are selected.

Thus, results clearly validate the effectiveness of proposed model by selecting best performing supplier while efficiently distributing products among the best suppliers so that total cost of the system is optimized. The model has to compromise the cost for achieving the sustainable value of purchase while fulfilling the customers' expectations.

6.3. Sensitivity analysis

The objective of the multi-objective optimization programming is to find the most efficient solution which best satisfies all the objectives simultaneously. In the above problem, the aim is to find a "trade-off" solution which would give the best values of the cost and SVP objective functions that are acceptable to the DM.

Therefore it is important to present a range of the trade-off solutions to the DMs to choose from, and understand the variation in the values of both the objectives as the weights of importance the objectives are changed, justifying the application of WGP. This can be used as quantitative indicators for highlighting the efforts of the company towards inclusion of socio-economic parameter into the decision making process. Based on the company's strategic vision, the DMs can choose the

Table 14
Sensitivity analysis.

Scenario	Objectives	Weights	Objective values	Suppliers selected	Procurement amount	Inventory
1	Minimisation of Total cost	0.5	INR 4972480	S_1 S_3 S_4	2796	196
	Maximisation of SVP	0.5	1541.435			
2	Minimisation of Total cost	0.1	INR 5137873	S_1 S_4	2888	409
	Maximisation of SVP	0.9	1592.154			
3	Minimisation of Total cost	0.9	INR 4857991	S_1 S_2 S_3 S_4	2792	200
	Maximisation of SVP	0.1	1385.045			
4	Minimisation of Total cost	0.7	INR 4965834	S_1 S_3 S_4	2792	200
	Maximisation of SVP	0.3	1539.23			
5	Minimisation of Total cost	0.3	INR 5137848	S_1 S_3 S_4	2888	410
	Maximisation of SVP	0.7	1592.154			

most satisfactory solution from among the few efficient solutions presented in Table 14.

It can be seen from the table that on assigning varying weights to the objectives, the values of the cost and SVP vary. Although in scenario 1 and 4, the same suppliers are selected, but the variations in the cost objective are caused due the fluctuation in inventory and procurement amount. In case of scenario 2, when we are giving more preference to the SVP objective, the model yields a performance score of 1592.15 from the selection of suppliers S_1 and S_4. The focus of this scenario is more towards the selection of those suppliers who perform high on the sustainable credentials, rather then selection those which will give least cost. The cost obtained in this scenario is INR 5137873, which clearly demonstrates that the model has compromised on the cost profit to select the suppliers who are high on sustainable performance. Similarly, it can be seen in the scenario 3, that when more preference to cost objective the selection is occurring in such a manner that least cost is obtained, while satisfying the demand. Although more number of suppliers are selected in this scenario yet the overall SVP is lower than in the other scenarios. As can be seen from the above table that is difficult to say which solution is superior over the other (non-dominated solution), we plot all these and join then together in curve known as **efficient frontier or pareto-optimal front.** The Pareto optimal curve of the problem is illustrated in Fig. 4.

All the solutions lying on the efficient frontier are efficient or pareto optimal solutions to the problem. As a decision maker, it becomes easy to read the all possible alternative optimal solutions through a graphical representation and select the one that suits the goals of the organization.

6.4. Implications

The implications drawn from the result discussion lead to the achievement of the research objectives of the study. These can aid managers in making crucial decisions as discussed below:

- This study helps the DMs in optimizing the cost of the system while keeping customer expectation in consideration. The results show that penalty and reward value incorporated in the cost objective system is effective in enhancing the sustainable performance of the suppliers. Hence, penalising or rewarding suppliers based on their performance can prove to be an effective strategy for DMs.
- The objective of maximizing SVP in the mathematical model ensures that the procurement amount is calculated as per the performance of the supplier. The results also validate the claim that the model selects the best performing suppliers and are also benefitted in terms of getting higher procurement order. This is another way of giving financial incentives to better performing suppliers.

7. Conclusion

This study contributes to the relevant area of research in the field of sustainable supplier selection and order allocation problem by developing an integrated optimization model for selection and evaluation of sustainable suppliers, reflection of customers' needs and green expectations and optimising firm's economic performance. The key features of the integrated model are as follows: 1) selection of suppliers based on traditional as well as customers' socio-ecological expectations transformed in terms of retailers' expectation using fuzzy-TOPSIS methodology with Z-numbers, 2) Incorporation of penalty-reward system into the cost objective to award or penalize suppliers according to their socio-ecological performance, 3) allocation of appropriate order quantity to best performing suppliers, 4) obtaining a trade-off between two conflicting objectives of minimizing the SC cost and maximizing the SVP. The bi-objective mathematical model is solved using WGP to get the efficient solution. The model is then illustrated using a data set of an electronic organization to validate the results. The results clearly relate the effectiveness of model. Outcomes of the proposed model can be summarized as:

- The main decision of the management concerned with the collaborating with sustainable suppliers, determining the optimum purchasing allocations while minimising the SC cost, is effectively realised through development of an optimisation model.
- The penalty-reward system incorporated in the optimisation model is effective in providing incentives to better performing suppliers and scope of improvement for other suppliers.

The limitations of the current study are explained here which further help in reinforcing the SC network design. First, SC network in this paper depends upon the known demands. But, variations in demand directly impact the performance of the organization which can be further analysed. Secondly, the model developed in this model is specific for an electronic sector. However, the model can be applied to other industries also.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.orp.2019.100113.

Appendix

Table A, Table B, Table C.

Table A
Normalized matrix.

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
S_1	(0.37,0.44,0.59)	(0.37,0.58,0.79)	(0.39,0.60,0.81)	(0.33,0.51,0.67)	(0.31,0.51,0.70)	(0.38, 0.58, 0.74)	(0.52,0.70,0.82)	(0.31,0.43,0.68)
S_2	(0.38,0.46,0.63)	(0.49,0.70,0.87)	(0.47,0.68,0.86)	(0.38,0.57,0.75)	(0.47,0.68,0.84)	(0.62,0.84,0.99)	(0.49,0.67,0.81)	(0.27,0.33,0.46)
S_3	(0.38,0.46,0.63)	(0.60,0.79,0.94)	(0.60,0.79,0.94)	(0.61,0.81,0.95)	(0.62,0.83,0.98)	(0.59,0.80,0.96)	(0.54,0.74,0.89)	(0.27,0.32,0.43)
S_4	(0.35,0.41,0.54)	(0.77,0.93,1.00)	(0.69,0.88,1.00)	(0.72,0.90,1.00)	(0.73,0.90,1.00)	(0.77,0.93,1.00)	(0.65,0.85,1.00)	(0.24,0.26,0.31)
S_5	(0.46,0.63,1.00)	(0.25,0.45,0.64)	(0.24,0.43,0.63)	(0.40,0.59,0.77)	(0.27,0.47,0.68)	(0.29,0.51,0.74)	(0.30,0.47,0.65)	(0.38,0.55,1.00)
Attribute Weight	(0.77,0.90,0.94)	(0.56,0.71,0.80)	(0.74,0.89,0.93)	(0.44,0.59,0.72)	(0.70,0.85,0.92)	(0.64,0.76,0.80)	(0.54,0.68,0.77)	(0.74,0.89,0.95)

Table B
Procurement and transportation cost of products from suppliers to retailers.

Retailers	Supplier	Procurement cost								Transportation cost							
		M1				M2				M1				M2			
		t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
R_1	S_1	1760	1765	1760	1765	1605	1610	1605	1610	4.9	4.8	4.9	4.8	4.99	4.9	4.99	4.9
	S_2	1750	1755	1750	1755	1600	1620	1600	1620	5	4.9	5	4.9	5	4.9	5	4.9
	S_3	1860	1865	1860	1865	1760	1770	1760	1770	4.2	4.3	4.2	4.3	4.1	4.3	4.1	4.3
	S_4	1800	1810	1800	1810	1699	1700	1699	1700	4.8	4.9	4.8	4.9	4.89	4.92	4.89	4.92
	S_5	1897	1899	1897	1899	1799	1800	1799	1800	4.3	4.4	4.3	4.4	4.15	4.2	4.15	4.2
R_2	S_1	1750	1760	1750	1760	1699	1700	1699	1700	4.89	4.95	4.89	4.95	4.96	4.99	4.96	4.99
	S_2	1720	1730	1720	1730	1675	1680	1675	1680	4.99	5	4.99	5	5.01	5	5.01	5
	S_3	1830	1850	1830	1850	1760	1780	1760	1780	4.22	4.25	4.22	4.25	4.11	4.15	4.11	4.15
	S_4	1790	1799	1790	1799	1720	1750	1720	1750	4.88	4.9	4.88	4.9	4.95	4.99	4.95	4.99
	S_5	1860	1870	1860	1870	1788	1799	1788	1799	4.31	4.4	4.31	4.4	4.17	4.2	4.17	4.2
R_3	S_1	1799	1791	1799	1791	1615	1620	1615	1620	4.98	5.01	4.98	5.01	4.99	5	4.99	5
	S_2	1790	1799	1790	1799	1610	1605	1610	1605	5	4.99	5	4.99	5	4.99	5	4.99
	S_3	1880	1875	1880	1875	1770	1775	1770	1775	4.15	4.2	4.15	4.2	4.13	4.2	4.13	4.2
	S_4	1815	1810	1815	1810	1658	1660	1658	1660	4.87	4.93	4.87	4.93	4.98	5.01	4.98	5.01
	S_5	1887	1890	1887	1890	1787	1790	1787	1790	4.23	4.27	4.23	4.27	4.19	4.25	4.19	4.25
R_4	S_1	1810	1805	1810	1805	1710	1720	1710	1720	4.97	4.99	4.97	4.99	4.99	5	4.99	5
	S_2	1800	1810	1800	1810	1699	1700	1699	1700	5	5.02	5	5.02	5	5.01	5	5.01
	S_3	1867	1870	1867	1870	1775	1770	1775	1770	4.21	4.25	4.21	4.25	4.11	4.15	4.11	4.15
	S_4	1830	1835	1830	1835	1720	1725	1720	1725	4.92	4.95	4.92	4.95	4.98	5.01	4.98	5.01
	S_5	1880	1889	1880	1889	1780	1785	1780	1785	4.28	4.35	4.28	4.35	4.21	4.25	4.21	4.25
R_5	S_1	1810	1815	1810	1815	1700	1699	1700	1699	4.99	5.01	4.99	5.01	4.99	5	4.99	5
	S_2	1789	1790	1789	1790	1699	1705	1699	1705	5	4.99	5	4.99	5	4.99	5	4.99
	S_3	1860	1865	1860	1865	1758	1760	1758	1760	4.22	4.25	4.22	4.25	4.05	4.12	4.05	4.12
	S_4	1830	1840	1830	1840	1720	1725	1720	1725	4.98	4.99	4.98	4.99	4.99	5.01	4.99	5.01
	S_5	1878	1880	1878	1880	1760	1755	1760	1755	4.24	4.29	4.24	4.29	4.17	4.2	4.17	4.2
R_6	S_1	1805	1805	1805	1805	1690	1695	1690	1695	4.97	4.99	4.97	4.99	4.98	5	4.98	5
	S_2	1787	1790	1787	1790	1676	1680	1676	1680	5	5	5	5	5	5.02	5	5.02
	S_3	1857	1857	1857	1857	1778	1780	1778	1780	4.19	4.25	4.19	4.25	4.16	4.2	4.16	4.2
	S_4	1827	1830	1827	1830	1716	1719	1716	1719	4.96	4.99	4.96	4.99	4.95	4.99	4.95	4.99
	S_5	1869	1869	1869	1869	1780	1780	1780	1780	4.25	4.3	4.25	4.3	4.19	4.25	4.19	4.25
R_7	S_1	1799	1799	1799	1799	1750	1750	1750	1750	5	5.01	5	5.01	4.99	4.99	4.99	4.99
	S_2	1789	1790	1789	1790	1720	1720	1720	1720	5	4.99	5	4.99	5	5	5	5
	S_3	1870	1875	1870	1875	1778	1778	1778	1778	4.16	4.2	4.16	4.2	4.17	4.2	4.17	4.2
	S_4	1799	1800	1799	1800	1760	1760	1760	1760	4.98	5	4.98	5	4.95	4.99	4.95	4.99
	S_5	1879	1880	1879	1880	1784	1785	1784	1785	4.22	4.25	4.22	4.25	4.2	4.25	4.2	4.25
R_8	S_1	1789	1790	1789	1790	1696	1699	1696	1699	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99
	S_2	1765	1770	1765	1770	1689	1689	1689	1689	5	5.01	5	5.01	5	5	5	5
	S_3	1873	1875	1873	1875	1772	1772	1772	1772	4.19	4.2	4.19	4.2	4.21	4.25	4.21	4.25
	S_4	1799	1800	1799	1800	1767	1770	1767	1770	4.97	4.99	4.97	4.99	4.97	4.99	4.97	4.99
	S_5	1882	1885	1882	1885	1786	1789	1786	1789	4.24	4.29	4.24	4.29	4.26	4.29	4.26	4.29
R_9	S_1	1789	1789	1789	1789	1722	1725	1722	1725	4.98	4.99	4.98	4.99	4.99	4.99	4.99	4.99
	S_2	1764	1769	1764	1769	1705	1710	1705	1710	5	5	5	5	5	5.01	5	5.01
	S_3	1875	1875	1875	1875	1775	1775	1775	1775	4.21	4.25	4.21	4.25	4.16	4.2	4.16	4.2
	S_4	1850	1850	1850	1850	1730	1730	1730	1730	4.9	4.99	4.9	4.99	4.98	4.99	4.98	4.99
	S_5	1888	1889	1888	1889	1785	1785	1785	1785	4.27	4.29	4.27	4.29	4.22	4.29	4.22	4.29
R_{10}	S_1	1822	1825	1822	1825	1720	1720	1720	1720	4.99	4.99	4.99	4.99	5	5	5	5
	S_2	1790	1790	1790	1790	1700	1700	1700	1700	4.99	5	4.99	5	5	5	5	5
	S_3	1878	1879	1878	1879	1783	1785	1783	1785	4.2	4.25	4.2	4.25	4.14	4.2	4.14	4.2
	S_4	1845	1845	1845	1845	1730	1730	1730	1730	4.98	4.99	4.98	4.99	4.99	4.99	4.99	4.99
	S_5	1890	1890	1890	1890	1788	1789	1788	1789	4.3	4.35	4.3	4.35	4.26	4.3	4.26	4.3

Table C
Inventory at retail stores for all time periods.

Product variants	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}
I1	**4**	**13**	**9**	**11**	**9**	**13**	**9**	**9**	**9**	**5**
I2	**13**	**13**	**2**	**17**	**0**	**9**	**16**	**0**	**13**	**17**

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