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A Chaotic Bee Colony approach for supplier selection-order allocation with different discounting policies in a coopetitive multi-echelon supply chain

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Abstract Competitive models offer superiority in maximizing only a buyer's profit, and do not satisfy all members in a supply chain. However, coordinative models give benefit to the whole supply chain. Research has been carried out the application of these two types of models in the supplier selection problems. In this study, we have considered coopetition in a supply chain, with the objective of selecting a supplier from a pool of suppliers and allocating optimal order quantities for the acquisition of a firm's total requirements for a particular product. The competition in a one buyer- multiple suppliers system in the supplier selection process has been considered by applying mixed-integer nonlinear programming in first phase. On the other hand, the total cost to the whole supply chain is minimized rather than only for the buyer. Genetic Algorithm, Artificial Bee Colony, and Chaotic Bee Colony are used separately in the second phase as optimization techniques. We find that the All Units discount scheme is more preferable than the Incremental Units discount scheme. However, in the case for different values of the discount percentage and levels, or when supplier provides different type of scheme, other policies need to be explored. Finally, the proposed model is illustrated by a numerical example from the literature. A better result is found for the buyer's cost by applying the proposed two-phase method, while the result is comparable result for the supply chain cost.

Keywords Artificial intelligence · Chaotic Bee Colony · Coopetition · Expert system · Supply chain management

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Introduction

Cooperation, Coordination and Competition (the 3C's of supply chain) play major roles in supply chain management (SCM) (Iida 2012; Kaur et al. 2011). These three factors are connected to each other by one and only factor: and that is the cost (Kaur et al. 2011). The different types of cost associated with Supply Chain (SC) analysis include the holding cost, ordering or set-up cost, manufacturing cost (Arts and Kiesmüller 2013). Low production cost, good quality, higher service level, abatement in lead time uncertainty and the consequent saving of fixed and variable costs, are some of the objectives of SCM. Supplier selection and order allocation problems are two major issues in the SC design process.

Supply chain coordination models are classified based on nature of demand and decision structure (Li and Wang 2007). The Quantity discount model is preferred to implement cooperation when demand is deterministic and decentralized decision structure is followed in a supply chain. In a decentralized supply chain, the players act independently to optimize their own objective. Despite of realization that collaboration can provide better benefit, the players resists changing decentralized practices to centralization of inventory and production decisions (Li and Wang 2007). The need of a more realistic model motivates development of coopetition structure in a supply chain to align the rational supply chain members. It requires a plan to perform coopetition (i.e. both cooperation and competition in a coexisting manner) to determine the objectives of SCM. We include cooperation by considering various discounting polices for the buyer, whereas competition is there in between suppliers (they compete for order quantity).

The problem with supplier selection and in determining the allocated quantity from the selected vendor is constrained by the supplier capacity. If all the selected vendors can completely satisfy the customer's product needs then the process of supplier selection becomes easier. It is solely based on supplier selection according to the criteria involving the total value of procurement costs, product quality and vendor's reliability. But this practice increase vulnerability of the network. The multiple supplier policy helps to prevent such vulnerability. For example; Apple faced a procurement problem for one of its components for the Apple iPod (Ozer and Raz 2011). There were a limited number of suppliers for the part. Intel and Sigma Tel were two choices for Apple. Intel is a big supplier where as Sigma Tel was a new player in the market. For Apple, if a contract is signed with Intel, Intel will dominate the business contract and Apple will have to follow the conditions (mainly price), but will be guaranteed a secure supply. On the other hand, Apple can dominate contract with Sigma Tel and can get a better price at the cost of limited risk. The problem for Apple is to select a supplier and secure the supply. The competition between suppliers helps Apple to get an advantage in negotiations.

Precisely, this study examines supplier selection, quantity allocation decisions and optimal order quantity for the acquisition of a firm's total requirements for a single product from a pool of suppliers with a two phase system. The coopetition scenario motivates this study. Our focus is on analyzing the supplier selection and order placement decisions in the presence of a combination of supplier pricing schemes and supplier capacity limitations, in such a fashion that both the supplier and buyer can make a profit. In this model, suppliers offer their conditions, such as production constraints, sale prices and discounts, and the buyer selects the right supplier (from the buyer's point of view) and allocates orders to them. After the supplier selection and order allocation phase, we develop an optimal order quantity allocation phase to minimize the annual total cost incurred in the whole SC. Suppliers often offer discount schedules to induce larger purchases by offering progressively lower unit prices for progressively larger purchase quantities. Identification of the optimal set of supplier for a single product multiple supplier scenarios are difficult. Corresponding order quantity allocation to each of selected supplier is also an important decision to take.

The first phase optimizes the buyer's profit by selecting the optimal supplier set and allocating corresponding quantity. The presence of safety stock, different pricing schemes, the combination and absence of safety stock, are taken into account. The specific supplier pricing schemes examined are incremental quantity discount, an all-unit quantity discount and a combination of both. A Non-linear programming mechanism is used in the first phase and, LINGO software is used for the solution. LINGO is a comprehensive tool designed to make building and solving Linear, Nonlinear (convex & non-convex/Global), and Integer optimization models.

The combination of different pricing schemes means all suppliers are not bound to offer a single scheme. We are taking two different discounting policies and a combination of those two. In 'all-units discount' policy, the discount is equally applicable for an item applies for all units ordered. Mathematically it can be expressed as

$$PC(Q) = \begin{cases} k + c_0 \times Q \text{ for } 1 \leq \mathrm{Q} \leq \mathrm{x}_1 \\ k + c_1 \times Q \text{ for } \mathrm{x}_1 \leq Q \leq x_2 \\ k + c_2 \times Q \text{ for x2} \leq \mathrm{Q} \end{cases}$$

where PC (Q) is purchase cost of Q number of items; k is fixed ordering cost; $\mathrm{c}_0, \mathrm{c}_1, \mathrm{c}_2$ are the discounted prices for three different range of order quantity: 1 to x_1, x_1 to x_2, and more than x2.

In case of 'incremental discount' policy the discount applies only for quantities exceeding the price break quantities. For example, if the price break quantity is 100 units and the order quantity is 150 units then the first 99 units will not qualify for a discount. A discount could be used only for 51 units (that are exceeding the price break quantity). In contrast to this method an 'all-units' discount policy will apply discount for all 150 items at same discount rate. The 'incremental-unit discount' policy can be expressed mathematically as

$$PC(Q) = \begin{cases} k + c_0 \times Q \text{ for } 1 \leq \mathrm{Q} \leq \mathrm{x}_1 \\ k + c_0 \times (x_1 - 1) + c_1 \times (Q - x_1) \text{ for } \mathrm{x}_1 \leq Q \leq x_2 \\ k + c_0 \times (x_1 - 1) + c_1 \times (x_2 - x_1) + c_2 \\ \quad \times (Q - x_2) \text{ for x2} \leq \mathrm{Q} \end{cases}$$

where PC (Q) is purchase cost of Q number of items; k is fixed ordering cost; $\mathrm{c}_0, \mathrm{c}_1, \mathrm{c}_2$ are the discounted prices for three different range of order quantity: 1 to x_1, x_1 to x_2, and more than x2.

A combination of both the policy we mean here a supplier can take either 'all-unit discount' or 'incremental discount'; but as a whole some suppliers are using first policy and remaining suppliers are using 'incremental discounting'. How to decide these price breaks is itself a research niche indeed. One can look at this problem form the price-setting game between supplier and buyer. But we are more inclined to solve this problem for the buyer's problem. Our focus is on developing and test bio-inspired algorithms towards solving supplier-selection and allocation problem. We assume discount rates are predefined and not a decision variable for the system. To make the problem more generic "Who will chose what policy" is modeled as a random (binary) variable in our experiment. This study can be extended for multi-modal solution approach like price-setting game combined with CBC or GA. A group of supplier can offer different schemes but the combination should be done in such a way that it fulfills the requirements and maximizes the buyer's profit.

The second phase takes the output of first phase as the input, and the allocated demand to the corresponding selected supplier is set in all the different cases to find out the optimal order quantity of each selected supplier. Three heuristic methods, Genetic Algorithm (GA), Artificial Bee Colony (ABC) and Chaotic Bee Colony (CBC) are proposed for finding the optimal order quantity. Finally the proposed methods are compared with each other and also with the analytical solution of a numerical example.

The rest of the paper is structured in five major sections. "Literature review" section presents the literature review. "The proposed methodology" section presents the proposed methodology. "Developing a numerical example" section examines a case study. "Illustrative example" section demonstrates an example with results and discussion. Finally, the paper is concluded in "Conclusion" section together with future research scope.

Literature review

There is large amount of research available in the literature dealing only with supplier selection (Amid et al. 2006, 2011; Feng et al. 2011; Lin 2012; Vanteddu et al. 2011; Sharma and Balan 2012; Kang et al. 2012; Pang and Bai 2013). The order allocation is also researched as a vertical of supply chain (Chan et al. 2006; Chan and Chung 2004; Xiang et al. 2013). However, research on the joint problem of supplier selection and order allocation is relatively less addressed in the literature on production economics (Ghodsypour and O'Brien 1998; Kheljani et al. 2009; Zhang and Zhang 2011). Supplier selection and order allocation decisions can be largely influenced by supplier pricing schemes. In earlier research, the most common pricing schemes were the constant price, the all unit discounted price, and the incremental unit discounted price. Jeuland and Shugan (1983) gave another variation of a discounted pricing scheme, the linear discounted pricing scheme, where the price linearly decreases with increases in the order quantity. The motivation for using discounted pricing schemes is due to the fact that it tends to encourage buyers to procure larger quantities and to get maximum profit for the buyer. From a coordination perspective, both the buyer and the supplier can realize higher overall profits if discounting schemes are used to set transfer prices (Wang 2005). Crowther (1964) showed numerically that it is possible to improve the supplier's profit and reduce the buyer's cost simultaneously by considering a quantity discount scheme. Lal and Staelin (1984) assumed a price function which decreases exponentially as the order size increases, while Rosenblatt and Lee (1985) suggested a quantity discount pricing model which assumed the price varied as a linear function of the order size, with a negative slope. Kim and Hwang (1988) derived an incremental discount-pricing scheme with multiple customers and single price break. Weng and Wong (1993) developed a general all-unit quantity discount model to determine the optimal pricing and replenishment policy.

Unlike most supplier selection models that consider and optimize only the buyer's objectives (Ghodsypour and O'Brien 2001; Liao and Rittscher 2007; Mafakheri et al. 2011) presents a two stage dynamic programming approach for supplier selection and order allocation for multi-criteria decision making. They used AHP to rank suppliers in the first phase and then applied dynamic programming to allocate the order according to the rank of the supplier.

Sarkis and Semple (1999) discussed optimization of the total purchasing cost in the presence of business volume discounts but they considered only one period and thus did not take inventory costs and other time dependent parameters into account. Sharma et al. (1989) proposed a non-linear, mixed integer programming model for supplier selection by considering price, quality, delivery and service, where the goal was to decrease the cost in relation to the increase in purchased quantity and to increase the quality level.

Gaballa (1974) used a mixed integer programming model to decision making for the Australian Post office with the objective of minimizing the total discounted price of allocated items to the vendors, under the constraints of vendor's capacity and demand satisfaction.

Karaboga and Akay (2011) described a modified ABC algorithm for constrained optimization problems and compared the performance of the modified ABC algorithm against those of state-of-the-art algorithms for a set of constrained test problems. ABC has emerged as promising technique to solve supply chain and manufacturing problems (Ajorlou and Shams 2012; Brajevic and Tuba 2013; Akay and Karaboga 2012). Yang (2004) developed an optimal pricing and ordering policy for a deteriorating item with price sensitive demand. Kim and Hwang (1988) assumed a single incremental discount system, and developed a model from which an algorithm was derived for an optimal discount schedule for the cases investigated in which both the discount rate and the break point were unknown and either one could be prescribed.

Shiue (1990) developed a model under a deterministic demand, instantaneous delivery with quantity discounts, and any well-behaved probability distribution for time perishables good. Burke et al. (2008) showed the impact of supplier pricing schemes and supplier capacity limitations on the optimal sourcing policy for a single firm. They developed heuristic solution methodologies to identify a quantity allocation decision for the firm.

Xia and Wu (2007) improved the integrated approach of the analytical hierarchy process by rough sets theory and proposed a multi-objective mixed integer programming to simultaneously determine the number of suppliers to engage and the order quantity allocated to these suppliers, in the case of multiple sourcing, multiple products, with multiple criteria and with supplier's capacity constraints. Wan (2008) studied a transformation technique and proposed a weighted linear program for the multi-criteria supplier selection problem.

Sedarage et al. (1999) considered multiple-supplier single-item inventory systems with random item acquisition lead times and the chance of backordering. In this kind of system, the reorder level and order quantity for each supplier is determined in such a way that the expected total cost per unit time, including the fixed ordering cost, inventory holding cost and shortage cost, is minimized. They designed a mathematical model in detail to solve such a problem.

Murthy et al. (2004) took the buyer's selection problem for make-to-order items with the objective of minimizing sourcing and purchasing costs, which included fixed costs, shared capacity constraints, and volume-based discounts, for bunches of items by using Lagrangian relaxation. Benton (1991) developed a nonlinear program and a heuristic procedure using Lagrangian relaxation for supplier selection to minimize the sum of purchasing costs, inventory carrying costs and ordering cost under conditions of multiple items, multiple suppliers, resource limitations and quantity discount.

Banerjee (1986) put forward an idea of joint optimization between the buyer and supplier by introducing a joint economic lot size (JELS) model with a single vendor and a single buyer to minimize the joint total relevant cost. Gheidar-Kheljani et al. (2010) developed a supplier selection model in combination with the coordination concept for multiple suppliers-single buyer systems in a centralized decision making system (DMS) framework. However, most supplier selection models optimize only the buyer's objectives, which are only one side of the mirror and ignores suppliers, the other important side of the mirror (SC), or in short, ignored the benefit of the whole SC.

Cheng and Ye (2011) put forward an order splitting strategy among parallel suppliers as one of the most important ways to improve agility and competitiveness of a supply chain. They proposed a GA based solution technique to a two objective order splitting model to minimize the comprehensive cost and to balance the production loads among the selected suppliers.

Patel et al. (2012) have addressed single buyer—multiple suppliers system for the supplier selection process in a coopetitive supply chain. It was a two-phase technique to address completion in first phase by applying mixed-integer nonlinear programming; and the cooperation by minimizing total cost of the supply chain using Artificial Bee Colony and Chaotic Bee Colony separately in second phase. In their particular numerical illustration, they found better result for buyer's cost and sound result for total supply chain cost compare to reported results available in literature.

An integrated inventory and transportation policy with strategic pricing to maximize the total profit for a ubiquitous enterprise is developed by Hong et al. (2012). They have proposed a policy which provides the optimal ordering, shipment and pricing decision. They have assumed demand for a product is a linear function of the price and gradually extend towards addressing a convex or a concave function of the price.

Here, we develop supplier selection on the basis of the buyer's objectives (using a competition paradigm) and an order allocation model to minimize the annual total cost incurred in the whole SC (using the coordination paradigm). We have assumed that the total buyer demand is constant over the time horizon (for a year) i.e. demand is seasonal and it can be forecasted. An attempt is made to incorporate constraints into the Artificial Bee Colony, Chaotic Bee Colony algorithm, and Genetic Algorithm approaches. Furthermore, a Two-Phase approach is developed to integrate NLP into the Chaotic Bee Colony algorithm. This paper differs from the existing research in the following ways.

(i) In this research we implement competition by considering the buyer's profit. Then for the entire system's benefit we try to improve coordination by varying lot-sizes.
(ii) In addition to well established cost units for each supplier, we have considered set-up cost, holding cost, transportation costs, and unit production costs for mathematical modeling.
(iii) The buyer may or may not keep safety stock: both cases are taken into account.
(iv) Two types of supplier pricing schemes, Incremental discount, All Units discount, and their combination is tried.

The proposed methodology

In this section we have introduced the proposed two-phase technique. Figure 1 represents flow chart of proposed technique. We have started with a primer on Nonlinear Programming (NLP). NLP is used to model optimization problems in diverse fields with nonlinear objective function in the presence of equality and inequality constraints. This discussion has covered the basic form of nonlinear objective function and constraints. We have further proceeded with basic concepts of Genetic algorithm, Artificial Bee Colony, and Chaotic Bee Colony algorithm in forthcoming subsec-

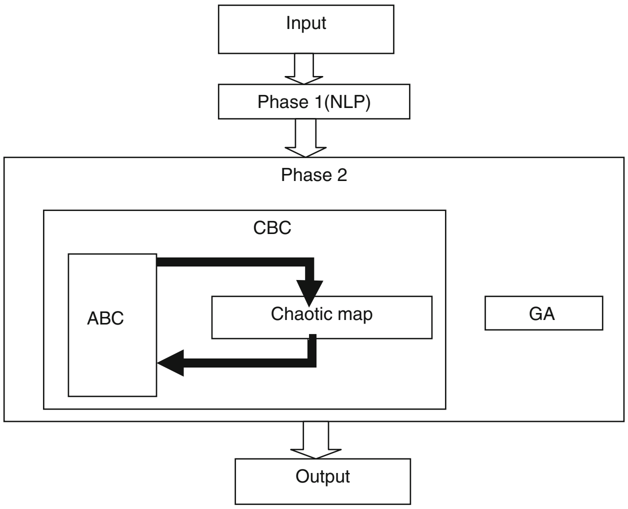

Fig. 1 Flowchart of two-phase Chaotic Bee Colony algorithm

tions. GA is widely used in optimization problems due to its robustness (Goldberg 1989) and as such, the GA is a tool used in many industrial engineering optimization problems (Gen and Cheng 2000). On contrary, ABC algorithm is much new technique and has emerged as an optimization technique inspired by the biological- behavior of the intelligent, real honeybees (Karaboga 2005). A modified version of ABC in which chaotic function is used to model movement of bees is known as Chaotic Bee Colony (CBC) algorithm.

In a NLP, the objective function is nonlinear and/or the feasible region is determined by nonlinear constraints. Thus, the general nonlinear program is stated as:

Optimize f(x),

subject to: g(x) $\leq$ constant,

Genetic algorithm

A search phenomenon in Genetic Algorithm (GA) is actually based on the mechanism of natural selection and natural genetics. The building block of GA consists of five major basics aspects:

- genetic representation of the solution
- well-defined mechanism to generate the initial population
- fitness function to evaluate solution quality
- genetic operators-crossover and mutation- analogous to biological operation to generate offspring
- parameters and values

Encoded presentations of parameters, used as chromosomes, are generally found in the form of binary or real numbers strings. Each variable is analogous to the gene of a biological chromosome, and such gene values are decoded to yield solutions to the problem. The reproduction or selection operator replicates good solutions and removes bad solutions from the population, while keeping the population size unchanged. Roulette wheel and the tournament selection process are well established for this operation; however tournament selection shows better performance in comparison to other selection operators (Deb 2001). The crossover operator is used to generate offspring from the parent chromosomes by means of interchanging substring(s). No such restriction is imposed on the exact procedure to crossover in GA; rather they are problem and domain specific. On the other hand, the mutation operator is used to change a particular allele. To provide robustness to the algorithm, flexibility has been maintained for the mutation rules.

Artificial Bee Colony algorithm

The biological behavior of the intelligent, real honeybees is the inspiration of this optimization technique (Karaboga 2005). These swarms can solve complex tasks without centralized control. In ABC, the colony consists of three groups of bees: employed bees, onlooker bees and scout bees. The colony is divided into two equal halves; the first half consists of employed bees, which are responsible for searching for available food sources (corresponds to possible solutions) and collecting the required information. The other half consists of onlooker bees.

The employed bees transfer their collected information to Onlooker bees. Onlooker bees find out good food sources depending on the probability values associated with the food sources and search the area within the neighborhood to generate new ones. Every food source is assigned to one employed bee which means that the number of employed bees is equal to the number of food sources around the hive. Some of the employed bees fail to find good food source within a number of limited chance or iteration. Those bees are then converted to unemployed and become scouts. The food source information so far collected by them discarded. The scout bee restarts their food search from a random source again.

In the ABC algorithm, after initialization, each cycle consists of three steps: moving the employed bees onto the food sources and calculating their nectar amounts (fitness/quality of that source); placing the onlookers onto the food sources and calculating the nectar amounts; determining the scout bees and directing them onto possible food sources (Karaboga 2005).

$$v_{ij}(t+1) = x_{ij}(t) + \text{rand}(-1 \text{ to } 1)[x_{ij}(t) - x_{kj}(t)] \quad (1)$$

Here v_{ij} is the position of the onlooker bee. The iteration number is t. x_k is the randomly chosen employed bee. i, k= 1, 2,… N is the number of employed bees and i not equal to k. j = 1, 2…D and D is the number of optimization parameters.

If the new food source is equal or better in quality than the old one, then the old one is replaced by the new one. If the quality of the food source is not improved throughout the trial value (limit), it is abandoned by the corresponding employed bee and then the employed bee becomes a scout. The scout searches for a new food source in the vicinity of the hive as Eq. 2. In Eq. 2, lb and ub are the lower and upper boundaries of x_i, respectively; rand (0, 1) is a random number in (0, 1).

$$x_{ij} = lb_j(t) + \text{rand}(0, 1) * (ub_j - lb_j) \tag{2}$$

When all employed bees finish their search process, they share the information about the nectar amounts and the locations of good sources with the onlookers. Thus in the ABC algorithm, the exploitation and exploration process are carried out by a group of employed bees, onlooker bees and scouts bees, respectively. This process is repeated until the termination criterion is satisfied.

Chaotic Bee Colony algorithm

Chaos represents randomness of a simple deterministic dynamical system. A chaotic system is considered as a source of randomness (Coelho and Mariani 2008). It can be used to generate and store random number sequences because of their spread-spectrum characteristic and ergodic properties. A chaotic map is a discrete-time dynamical system running in a chaotic state represented as $x_k + 1 = f(x_k)$, where $0 < x_k < 1$ and $k = 0, 1, 2 \ldots$ In the proposed ABC algorithm, chaotic systems are employed for producing the initial population i.e. the initial artificial colony is generated by iterating the selecting one from the chaotic map. A randomly distributed initial population P of N solutions is generated by Eq. 3.

$$x_{ij} = lb_j + ch_{kj} * (ub_j - lb_j) \tag{3}$$

where, $i = 1, 2 \ldots N$; $j = 1, 2 \ldots D$ represents number of parameters; lb_j, ub_j are the lower and upper bounds for the dimension j, respectively; k (1, 2.......K) represents number of chaotic iterations. The pseudo-code of Chaotic Bee Colony algorithm has been adapted from Kim and Hwang (1988).

In the proposed two-phase method (as shown in Fig. 1), first phase involves order splitting among the suppliers to maximize the buyer's profit using NLP for different cases. In the second phase, the buyer shares the total SC cost to minimize the total supply chain cost. GA, ABC and CBC are used separately as optimization techniques for Phase two. We have considered two different discounting policies in this problem. All Units discounts refer to discounts that lower the price on every unit purchased when the purchasing quantity are equal or more than the given quantity threshold, whereas Incremental Units discounts refers to discounts that lower the price on every unit purchased within the threshold quantity range.

Developing a numerical example

We are assuming a supply chain network where 'm' suppliers are connected with a single buyer. The problem horizon is one year, with a definite annual demand denoted by 'D', which is distributed to each supplier as 'D_i'. In order to meet the buyer's demand, the ordered quantities 'Q_i' are split into small lot sizes 'q_i' and delivered over multiple elementary periods 'N_i'. By doing this, the supplier needs to hold the inventory throughout the production of each lot size. Furthermore, we assume that the buyer pays transportation costs in order to facilitate frequent deliveries. The objective is to distribute demand to each supplier so that the total cost to the buyer is minimized, and then to assign the order quantity to each supplier so that the total cost of the SC is minimized. In this problem 'Q_i'', 'N_i' and 'D_i' have considered as decision variables keeping other parameters constant.

Mathematical modeling

We need to define and model buyer's and supplier cost components (sub-models) in order to model total supply chain cost. In this section we have started with modeling costs bear by buyer followed by costs bear by suppliers. The major costs considered at buyer side are ordering cost, inventory holding cost, transportation cost, and purchasing cost. Each supplier has to bear setup cost and inventory holding cost at their own site. The total cost of supplier side is summation of cost bear by the each supplier. Furthermore, we have presented different discounting policies in subsections.

Assume 'D_i' is the annual buyer's demand assigned to ith supplier and 'Q_i' is the production lot size at ith supplier (unit). Thus number of orders to ith supplier is (D_i/Q_i) per year. We are assuming 'A_b' is the fixed ordering cost paid by the buyer for each order. So, the annual ordering cost is $(A_b \times D_i/Q_i)$. Hence, Total annual ordering cost for all suppliers will be summation of the annual ordering cost for each supplier (presented in Eq. 4).

$$\sum_{i=1}^{m} A_b \times (D_i/Q_i) \tag{4}$$

where $i = 1, 2, 3, \ldots$m| 'm' is the number of suppliers.

Average inventory is half of difference between maximum and minimum inventory level along with safety stock (SS). It can expressed as $(q_i/2) + (z \times sd_i\sqrt{LT_i})$ (Regular consumption is assumed), where 'q_i' is delivery size per trip at ith supplier, 'z' is safety factor (here 0.67 for 75 % in-stock probability), 'sd_i' is distributed standard deviation in annual demand of the buyer ('D') to ith supplier, and 'LT_i' is Lead time (month) of ith supplier. We can replace q_i with Q_i/N_i (where 'N_i' is the number of deliveries per inventory cycle at ith supplier). The Annual inventory holding cost becomes the annual holding cost at buyer per unit ('h_b') multiplied by summation of average inventory cost for each supplier (as presented in Eq. 5).

$$h_b \sum_{i=1}^{m} \left[(Q_i/2N_i) + \left(z \times sd_i \sqrt{LT_i} \right) \right] \tag{5}$$

The number of deliveries per year is D_i/q_i. We can replace q_i with Q_i/N_i and the expression becomes $N_i \times (D_i/Q_i)$. Assume fixed transportation cost per delivery from ith supplier paid by the buyer is 'F_i'. Thus total transportation cost will be summation of cost incurred for each supplier (as shown in Eq. 6).

$$\sum_{i=1}^{m} F_i \times N_i(D_i/Q_i) \tag{6}$$

Assume the unit purchase cost at ith supplier (per unit) is 'C_i'. Thus total purchasing cost for 'm' number of suppliers will be as in Eq. 7.

$$\sum_{i=1}^{m} C_i \times D_i \tag{7}$$

Equation 8 is the expression for annual total cost of buyer (TC_b) which comprises ordering cost, inventory holding cost, transportation cost, and total purchasing cost.

$$\sum_{i=1}^{m} \left[(A_b + F_i N_i) \left(\frac{D_i}{Q_i} \right) + \left(\frac{h_b Q_i}{2N_i} \right) + \left(h_b z \times sd_i \times \sqrt{LT_i} \right) + C_i D_i \right] \tag{8}$$

For supplier side, assuming the average inventory levels at ith supplier is $\left(\frac{Q_i}{2N_i} \left(\frac{D_i(2-N_i)}{P_i} + (N_i - 1) \right) \right)$, where '$P_i$' is annual production rate of ith supplier (Joglekar 1998). Thus total annual holding cost will be summation of holding cost of each supplier as presented in Eq. 9 where 'h_i' is Holding cost of ith supplier to keep in stock one unit of product during one year.

$$\sum_{i=1}^{m} \left(\frac{Q_i h_i}{2N_i} \left(\frac{D_i(2-N_i)}{P_i} + (N_i - 1) \right) \right) \tag{9}$$

Let, 'S_i' is setup cost paid by ith supplier for each delivery. Thus total setup cost for 'm' number of supplier will be summation setup cost paid for (D_i/Q_i) number of deliveries in a year for each supplier (as Eq. 10).

$$\sum_{i=1}^{m} S_i(D_i/Q_i) \tag{10}$$

Thus Annual total costs of suppliers (TCs) becomes as Eq. 11.

$$\sum_{i=1}^{m} \left(\left(\frac{Q_i h_i}{2N_i} \left(\frac{D_i(2-N_i)}{P_i} + (N_i - 1) \right) \right) + (S_i D_i/Q_i) \right) \tag{11}$$

Thus annual total cost of supply chain (TC) becomes summation of total buyer's cost and total supplier's cost (TC_b+TC_s). We have to examine behavior of total supply chain cost in presence of different supplier pricing schemes. The mathematical formulation for them is presented in next subsections. They are an all-unit quantity discount, incremental quantity discount, and a combination of both with total supply chain cost. The combination of both the scheme is considered to generalize the problem more. It will help to depict the case where suppliers are using different policies.

All units discount scheme

In this policy, the discount is equally applicable for an item applies for all units ordered. Let 'd_{ir}' is discount factor connected to the discount interval 'r' function of expenses ith supplier, 'x_{ir}' is product quantity in the interval of discount 'r' which will be ordered from the ith supplier, and 'Y_{ir}' is a binary variable which may have values 0 or 1. 'Y_{ir}' will be 1 if the value of procurement form the ith supplier falls into the interval rand its function of expenses, and will be 0 in other cases. The upper limit in the interval of discount 'r' for the ith supplier is denoted by 'ul_{ir}' and '$ul_{ir}*$' is insignificantly less than 'ul'_{ir}. 'k_i' is total no of discount interval of ith supplier. The objective function for minimizing purchase cost 'PC' is as Eq. 12 and the constraints are presented in Eq. 13 to Eq. 21.

$$\min \sum_{i=1}^{m} \sum_{r=1}^{k} (1 - d_{ir}) x_{ir} C_i \tag{12}$$

subject to

$$\sum_{r=1}^{k} x_{ir} = D_i; \text{ where } i \in m \tag{13}$$

$$\sum_{r=1}^{k} Y_{ir} \le 1; \text{ where } i \in m \tag{14}$$

$$x_{ir} \le ul^*_{ir} \times Y_{ir}; \text{ where } i \in m, r = 1, \ldots k-1 \tag{15}$$

$$x_{ik} \le ul_{ik} \times Y_{ik}; \text{ where } i \in m \tag{16}$$

$$x_{i,r+1} \ge ul_{i,r} \times Y_{i,r+1}; \text{ where } i \in m; r = 1, \ldots, k-1 \tag{17}$$

$$x_{ir} \ge 0; \text{ where } i \in m; r = 1, \ldots, k \tag{18}$$

$$Y_{ir} \in \{0, 1\}; \text{ where } i \in m; r = 1, \ldots, k \tag{19}$$

$$\sum_{i=1}^{m} D_i = D \text{ where } i \in m \text{ (Total demand satisfaction)} \tag{20}$$

For implementation quantity should be within the limits of production capacity as Eq. 21 below where 'Z_i' denotes the annual production capacity of ith supplier (in units).

$$0 \le D_i \le Z_i;\ \text{where } i \in m \tag{21}$$

Incremental unit discount scheme

In this policy the discount applies only for quantities exceeding the price break quantities. As we have already discussed an example in introduction section, here we are directly presenting mathematical model of 'incremental-unit discount' policy in Eq. 22.

$$\min \sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{j=1}^{r-1}\big[(C_i(1-d_{i,j}) \times (ul_{i,j}-ul_{i,j-1})) + (C_i(1-d_{i,r}) \times (x_{i,r}-ul_{i,r-1})Y_{i,r})\big] \tag{22}$$

subject to similar constraints as in Eqs. 13–21.

Combination of all units discounts and incremental unit discount scheme

We have assumed that a supplier can take either 'all-unit discount' or 'incremental discount' but not both the policies at the same time to make this problem more generalized. From the buyer's perspective suppliers are using different policy, and she has to minimize the purchase cost at given price offer by supplier. The objective is to select supplier and allocate number of quantity to order form a particular supplier so that the overall cast will be minimum (mathematically presented in Eq. 23).

$$\min \begin{pmatrix} \sum_{i=1}^{m}\sum_{r=1}^{k} R_i(1-d_{ir})x_{ir}C_i + \\ \sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{j=1}^{r-1} W_i\big[(C_i(1-d_{i,j}) \\ \times(ul_{i,j}-ul_{i,j-1})) + (C_i(1-d_{i,r}) \\ \times(x_{i,r}-ul_{i,r-1})Y_{i,r})\big] \end{pmatrix} \tag{23}$$

subject to the constraints in Eqs. 13–21, where 'R_i' and 'W_i' is binary variable.

$$\mathrm{R_i}, \mathrm{W_i} = 0, 1 \tag{24}$$

We assume that only one of the schemes will be selected (presented in Eq. 25).

$$\sum_{i=1}^{m} R_i + W_i = 1 \tag{25}$$

Problem formulation

In this section we have presented the mathematical formulation. There are four different situations in supplier selection with two different policies for inventory. In supplier selection situations are based on discounting policy followed by supplier and denoted as Case 1: without discount, Case 2: with all unit discounts, Case 3: With Incremental unit discounts, and Case 4: Combination of both schemes. These situations are coupled with order quantity allocation problem with two assumptions—Case 1: With safety stock Case 2: Without safety stock.

Supplier selection

Here, for all cases, we assume that Q_i is supplied only in a single lot, that is (qi = Qi)

Case 1: any supplier do not provide any discount

$$\mathrm{Min\ TC} = \sum_{i=1}^{m}\left[(\mathrm{A_b}+\mathrm{F_i})\left(\frac{\mathrm{D_i}}{\mathrm{Q_i}}\right) + \left(\frac{\mathrm{h_bQ_i}}{2}\right) + \left(\mathrm{h_b z} \times \mathrm{sd_i} \times \sqrt{\mathrm{LT_i}}\right) + (\mathrm{C_iD_i})\right] \tag{26}$$

$$\text{subject to } \mathrm{Q_i}, \mathrm{D_i}, \ \mathrm{sd_i}, \ \mathrm{LT_i}, \mathrm{F_i}, \ \mathrm{C_i} > 0; \tag{27}$$

$$\sum_{i=1}^{m} D_i = D \text{ where } i \in m \tag{28}$$

$$sd_i \le 0.1 * Di;\ \text{ where } i \in m \tag{29}$$

$$D_i \le Z_i;\ \text{ where } i \in m \tag{30}$$

Case 2: every supplier provides all unit discounts

$$\mathrm{Min\ TC} = \sum_{i=1}^{m}\sum_{r=1}^{k}(1-\mathrm{d_{ir}})\mathrm{x_{ir}C_i} + \sum_{i=1}^{m}\left[(\mathrm{A_b}+\mathrm{F_i})\left(\frac{\mathrm{D_i}}{\mathrm{Q_i}}\right) + \left(\frac{\mathrm{h_bQ_i}}{2}\right) + \left(\mathrm{h_b z} \times \mathrm{sd_i} \times \sqrt{\mathrm{LT_i}}\right)\right] \tag{31}$$

subject to the constraints in Eqs. 13–21, 27, and 29.

Case 3: every supplier provides Incremental unit discounts

$$\begin{aligned} \mathrm{Min\ TC} = {} & \sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{j=1}^{r-1}\big[(C_i(1-d_{i,j}) \times (ul_{i,j}-ul_{i,j-1})) \\ & + (C_i(1-d_{i,r}) \times (x_{i,r}-ul_{i,r-1})Y_{i,r})\big] \\ & + \sum_{i=1}^{m}\left[(A_b+F_i)\left(\frac{D_i}{Q_i}\right) + \left(\frac{h_bQ_i}{2}\right) \right. \\ & \left. + (h_b z \times sd_i \times \sqrt{LT_i})\right] \end{aligned} \tag{32}$$

subject to the constraints 13 to 21, 27, and 29.

Case 4: Combination of both schemes (suppliers are following different discounting policies)

$$\mathrm{Min\ TC} = \sum_{i=1}^{m}\sum_{r=1}^{k} R_i(1-d_{ir})x_{ir}C_i + \sum_{i=1}^{m}\left[(A_b+F_i)\left(\frac{D_i}{Q_i}\right)\right.$$

$$+\left(\frac{h_b Q_i}{2}\right)+\left(h_b z \times sd_i \times \sqrt{LT_i}\right)\Bigg]$$
$$+\sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{j=1}^{r-1} W_i\left[\left(C_i(1-d_{i,j})\times(ul_{i,j}-ul_{i,j-1})\right)\right.$$
$$\left.+\left(C_i(1-d_{i,r})\times(x_{i,r}-ul_{i,r-1})Y_{i,r}\right)\right] \tag{33}$$

subject to the constraints in Eqs. 13–21, 24, 25, 27, and 29.

Order quantity allocation

We have considered two cases. First is Case 1 where the problem is to deciding order quantity assuming the manufacturer will keep safety stock. In this case, Total Purchasing Cost (PC) in case of no discount (from Eq. 7) is $C_i D_i$. So, Total Purchasing Cost in case of all unit discounts (from Eq. 12) is $\sum_{i=1}^{m}\sum_{r=1}^{k}(1-d_{ir})x_{ir}C_i$. We can derive PC in the case of Incremental unit discount from Eq. 22 as Eq. 34.

$$\sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{j=1}^{r-1}\left[\left(\mathrm{C_i(1\text{-}d_{i,j})}\times(\mathrm{ul_{i,j}}-\mathrm{ul_{i,j-1}})\right)\right.$$
$$\left.+\left(\mathrm{C_i(1\text{-}d_{i,r})}\times(\mathrm{x_{i,r}}-\mathrm{ul_{i,r-1}})\mathrm{Y_{i,r}}\right)\right] \tag{34}$$

PC in the case where both the schemes are assumed is linear combination of Eqs. 12 and 22. Thus the optimization of total cost can be expressed as Eq. 35 where TC_{scm} is total purchase cost depending of discounting policy offered by suppliers.

$$\text{Min TC} = \text{TC}_{\text{scm}} + \sum_{i=1}^{m}\Bigg[(A_b+F_iN_i)(D_i/Q_i)$$
$$+\left(h_b\left(\frac{Q_i}{2N_i}+(z\times sd_i\sqrt{LT_i})\right)\right)\Bigg]$$
$$+\sum_{i=1}^{m}\Bigg[\left(\frac{Q_ih_i}{2N_i}\left(\frac{D_i(2-N_i)}{P_i}+(N_i-1)\right)\right)$$
$$+(S_i(D_i/Q_i))\Bigg]$$
$$\text{subject to } Q_i, N_i > 0;\ \text{where } i \in m \tag{35}$$

In second case we are assuming that the manufacturer will not keep any safety stock. Then the order allocation problem can be expressed as Eq. 36.

$$\text{Min TC} = \sum_{i=1}^{m}\left[(A_b+F_iN_i)(D_i/Q_i)+h_b\left(\frac{Q_i}{2N_i}\right)\right]$$
$$+\sum_{i=1}^{m}\Bigg[\left(\frac{Q_ih_i}{2N_i}\left(\frac{D_i(2-N_i)}{P_i}+(N_i-1)\right)\right)$$
$$+C_iD_i+(S_i(D_i/Q_i))\Bigg]$$
$$\text{subject to } Q_i, N_i > 0;\ \text{where } i \in m \tag{36}$$

Solution algorithm of supplier selection and order quantity allocation

By taking the first derivatives of the objective function with respect to Q_i and equating it to zero, given, $Q_i^* = \sqrt{2(A_b+F_i)(D_i/h_b)}$. Substituting this value in the objective function, and we solve the objective function by NLP for D_i, using LINGO solver. Output value of D_i is used for solving order quantity allocation in second phase. By taking the first derivatives of the objective function with respect to Q_i and N_i, and equating them to zero and solving both simultaneously, given,

$$N_i^* = \sqrt{2(A_b+S_i)\{P_i(h_b-h_i)+2D_ih_i\}/(F_ih_i(P_i-D_i))}$$
$$Q_i^* = \sqrt{2(A_b+S_i)[D_i/h_i(1-(D_i/P_i))]}$$

By calculating the numerical value of N_i^*, substituting it in objective function and optimizing the objective function by the ABC and CBC algorithms for Q_i. These Q_i values are compared with Q_i^*.

Illustrative example

A purchasing manager would like to buy a product from 5 suppliers. The annual demand is 300,000, with 30000 as a safety stock to tackle demand uncertainty. Safety stock is also distributed to each supplier with the constraint that it not be greater than 10 % of demand distributed to each supplier. The annual holding cost per unit (h_b) is 14 and the fixed order cost (A_b) is 7500.

Table 1 represents supplier's discount scheme and Table 2 represents the supplier information, such as different types of costs, capacity etc. These data represent compiled experience gathered through discussion with several industrial experts from the automobile manufacturing industries. This example is designed from the perspective of automobile component (parts) procurement for the manufacturer.

ABC and CBC are run 100 times with population size 2000; cycle limit 3000 and scout limit 20 %. The GA is run 20 times with 1000 generations, and the cross over and mutation probability is 0.98 and 0.1, respectively. The results are presented in the next subsection.

Discussion of results

Table 3 contains comparisons of the total SC cost in the absence of safety stock and discount, calculated by ABC, CBC and GA algorithms, and the result from Gheidar-Kheljani et al. (2010). The result shows that our result optimizes both the buyer's profit and total SC cost with not much difference in total cost as compared to Gheidar-Kheljani et al.

Table 1 Discount schemes of different supplier

Supplier 1	Quantity (Q) range (units)	Q < 10000	10000 ≤ Q < 25000	25000 ≤ Q < 36000
	Discount (%)	0	0.6	0.95
Supplier 2	Quantity (Q) range (units)	Q < 15000	15000 ≤ Q < 40000	40000 ≤ Q < 60000
	Discount (%)	0	0.25	0.75
Supplier 3	Quantity (Q) range (units)	Q < 10000	10000 ≤ Q < 30000	30000 ≤ Q < 52000
	Discount (%)	0	0.5	0.85
Supplier 4	Quantity (Q) range (units)	Q < 15000	15000 ≤ Q < 45000	45000 ≤ Q < 84000
	Discount (%)	0	0.45	1
Supplier 5	Quantity (Q) range (units)	Q < 20000	20000 ≤ Q < 60000	60000 ≤ Q < 120000
	Discount (%)	0.2	0.8	1.2

Table 2 Supplier's information

Supplier[a]	Z_i	F_i	h_i	C_i	S_i	P_i
1	36,000	133	13.5	55	800	60,000
2	60,000	298	13.2	53.5	850	95,000
3	52,000	115	13	53	820	90,000
4	84,000	525	13.6	52	900	100,000
5	120,000	670	13.1	54	950	120,000

Z_i: Annual production capacity of *i*th supplier (in units)
F_i: Fixed transportation cost per delivery from *i*th supplier paid by the buyer
h_i: Holding cost of *i*th supplier to keep in stock one unit of product during one year
C_i: Unit purchase cost at *i*th supplier (per unit)
S_i: Setup cost paid by *i*th supplier for each delivery
P_i: Annual production rate of *i*th supplier
[a] Following are the meaning of notations used as heading of this table

(2010). In Table 3 we have used 'G2F-2010' as acronym for algorithm developed by Gheidar-Kheljani et al. (2010).

Table 4 shows the total SC cost with safety stock, and various types of discounts schemes calculated by the ABC, CBC and GA algorithms. Table 5 gives the total buyer's cost and total purchase cost with safety stock and various types of discount schemes, by solving the constrained NPL using LINGO. Here total buyer's cost for all unit discounts and a combination of all-unit and incremental discount is equal. We associate a binary decision variable for choosing discounting policy. As all-unit discount is always better than incremental-unit discount, the optimization process to select 'all-unit discount' policy as much as possible number of supplier. Since we don't impose any constraint like -'a supplier is restricted to a particular policy only', the solver is taking a biased decision and selects 'all-unit discount' policy mostly. Hence the result is same for this particular example. This experiment can be further extended to remove such biasness and generalize the case.

We determine the demand distribution to each supplier in various schemes with consideration of safety stock, calculated by solving the constrained NPL using LINGO. The values are 0, 60000, 52000, 84000, 104000 units for supplier 1, supplier 2, supplier 3, supplier 4, and supplier 5, respectively. The values are the same for the four different schemes- without discount, all-units discount, incremental-unit discount, and a combination of last two policies.

Table 6 shows D and N* values for the supplier. These values are used in the next phase to calculate Q* in Table 7. Table 7 shows the average of near optimal solutions (N*, Q*) found by running ABC and CBC 100 times and algorithms with 10 times safety stock and discount schemes, all units discounts, incremental units discounts and a combination of both discounts schemes, respectively; and their comparison with analytical value.

Table 3 Total costs of different algorithms when there is no safety stock and discount

Algorithm	G2F-2010	Analytical value of our algorithm	ABC	CBC	GA
Total SC cost	16,333,600	16,341,023	16,342,317	16,341,772	16,328,855

Table 4 Total supply chain cost with for different cases

	Analytical value	ABC	CBC	GA
Total cost (SC) without safety stock and discount	16,341,023	16,342,317	16,341,772	16,328,855
TC (SC) with safety stock and without discount	16,463,099	16,446,680	16,446,140	16,380,879
Total cost (SC) with safety stock and all units discount	16,304,529	16,288,040	16,287,400	16,224,933
Total cost (SC) with safety stock and incremental unit discount	16,386,529	16,369,970	16,369,490	16,305,493
TC (SC) with safety stock and combination of discount	16,304,529	16,287,930	16,287,540	16,223,191

Table 5 Total buyer's cost for different cases with safety stock

	Without discount	All units discount	Incremental units discount	Combination of both
Total buyer's cost	16,077,900	15,919,330	16,001,330	15,919,330
Total purchase cost of buyer	15,950,000	15,791,430	15,873,430	15,791,430

Table 6 D and N* for cuppliers

Supplier	1	2	3	4	5
D	0	60,000	52,000	84,000	104,000
N*	0	10	15	13	13

From the results in Table 7, we can see that the GA outperforms CBC, and CBC gives better results than ABC. All three algorithms give comparable results to the analytical value. Our distributed demands to all suppliers give lower buyer's cost than the result reported by Gheidar-Kheljani et al. (2010), if we put the demand value in (Eq. 26). This means our results give benefit to the buyer without harming the total supply chain's benefit. The purchase cost (for buyer) of a product/ material becomes less when supplier provides the 'all unit discounts' schemes than the 'incremental units discount' scheme. Thus, if we apply a combination of both schemes, LINGO rejects the Incremental Unit discount scheme and distributes the demand to the suppliers according to all the unit discounts. Despite all unit discount schemes giving better results, a combination of both discount schemes is applied because in cases of different discount intervals, with different discount factors for both schemes, or in cases where all suppliers do not give same type of discount scheme, the optimization technique may distribute the demand to suppliers with a combination of both discounts schemes.

Managerial insights

The proposed model makes a mathematical representation of the supplier-buyer relationship and helps both the buyer and the supplier to develop managerial insights for achieving their goals. The model introduces coordination by the sharing of the supply chain cost by both the buyer and suppliers. Another contribution of this study is the introduction of different pricing schemes. Consequently, due to the introduction of safety stock, it helps to manage supply disruption problems. This research also helps to comprehend the long-term effect on profit generation. The proposed model not only fulfills the buyer's requirement at optimum cost, but also makes the buyer distribute the order in such a way that

Table 7 Average value of near optimal solutions for order quantity using four different methods in five different procurement policy

S	Analytical Q* value					Q* value using ABC				
	A*	B*	C*	D*	E*	A*	B*	C*	D*	E*
1	0	0	0	0	0	0	0	0	0	0
2	14,354	14,354	14,354	14,354	14,354	15,272	15,380	15,290	15,346	15,381
3	12,555	12,555	12,555	12,555	12,555	13,356	13,312	13,410	13,361	13,423
4	25,466	25,466	25,466	25,466	25,466	26,214	26,136	26,188	26,409	26,308
5	31,721	31,721	31,721	31,721	31,721	31,639	32,068	31,781	32,499	32,225
	Q* value using CBC					Q* value using GA				
1	0	0	0	0	0	0	0	0	0	0
2	15,300	15,428	15,529	15,396	15,502	13,285	15,491	15,014	14,173	13,373
3	13,126	13,121	13,084	13,152	13,148	14,723	12,278	10,095	10,635	12,213
4	26,215	26,262	26,170	26,200	26,328	24,925	25,111	22,617	26,704	21,195
5	32,610	32,641	32,530	32,653	32,652	28,108	27,338	25,336	31,109	28,883

A*, B*, C*, D*, E*, and S in the table are corresponds to following.
A. with safety stock and all unit discounts
B. with safety stock and incremental unit discounts
C. with safety stock and combination unit discounts
D. without safety stock
E. with safety stock and no discount
S. Supplier

the overall profit generation will be increased. The results of the experiments give an insight on how pricing schemes, capacity constraints, and fixed and variable costs affect the procurement operation.

The managerial insight for suppliers in this research indicates the benefits of cooperation in the supply chain. Introduction of different pricing schemes can attract buyers. The best part is the introduction of a combination of two types of pricing schemes which selects the best possible combination for the buyer and also allows suppliers to offer different pricing schemes. Different Heuristic approaches show fair solutions which are not only close enough to the analytical value but also are proven better in some cases. The focus is on elaborating how this system will improve cooperation between supply chain players without affecting the competition.

The case discussed here can be extended to address procurement problems for other sectors (Hingley 2005; Zhao et al. 2008). The level of pricing flexibility may vary across industries depending on the market competition, but from the supply chain perspective, the objectives and decision variables are the same. The proposed model inherits the basic model of supply chain cost calculation and generalized forms of discounting models. This consideration improves the generalizibility of the proposed model.

Conclusion

The need for coopetition in all organizations within the SC is becoming increasingly critical because of uncertainty and market pressures. The analysis of alternate supplier base pricing schemes in this paper provides guidance for a buying firm's optimal sourcing strategy. Given a total order quantity that the buying firm must procure, a deterministic model is analyzed which highlights the importance of supplier capacity on the buying firm's sourcing decision. Here, a combination of both types of pricing schemes is shown and the results allow the choice of a discounting policy.

The key takeaway of this research is the insight that the application of CBC in solving supplier selection and order allocation problem. We did the experiment with different type of discounting policies- all-units discount, incremental discount, and a combination of these two. The results are sensitive to discount values. Although which policy is better (in general) can be conclude form this experiment, it will serve the purpose of a decision support system. The proposed model indicates that the buyer has to share the total SC cost by certain amount in order to minimize the total cost. Furthermore, we present a comparative study on the application of GA, ABC and CBC in solving the supplier selection and order allocation problem.

An idea about how pricing schemes, capacity constraints, and fixed and variable costs affect the procurement operation can be developed from the results of this experiment. This research also projects the benefits of cooperation in the supply chain for suppliers. In a real-life scenario, suppliers are supposed to be rational and they often maintain different discounting policy to get competitive advantage. It is difficult to decide how this system will improve cooperation between supply chain players without affecting the competition. Our illustration is designed to capture such critically into system model. Furthermore the proposed model inherits the basic model of supply chain cost calculation with generalized forms of discounting policies. This study is very much aligned with engineering manufacturing sector. The case discussed here can be extended to address problems for other sectors (Hingley 2005; Zhao et al. 2008). The proposed model can be extended for perishable and non-perishable goods supply chain as we have considered inventory model with provision of keeping safety stock as well as running without safety stock.

This paper is limited to the analysis of cases with a seasonal demand pattern, but in real life scenarios, demand or supply disruption and other uncertainties may change the scenario. One can expand this research by removing some of the assumptions like demand are constant, transportation cost is fixed or shortage and excess stock is not allowed. In addition, increasing the number of products purchased from vendors, quality and uncertainty can be studied in future research. The proposed methodology is demonstrated with an illustrative example where it has produced output in a reasonable execution time.

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