

A Multiobjective Pricing Model in Omnichannel Retailing With Emphasis on State Interventions

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ABSTRACT In recent years, pricing and coordination among manufacturers, suppliers, and retailers in multi-level supply chains (SCs) have attracted researchers' attention. Product pricing can be considered one of the main aspects in the management of SCs. The lack of a proper pricing strategy leads to low sales numbers, customers, market share, and profit. The present study aimed at modeling optimal pricing in a multi-level SC, including suppliers, retailers, and customers, where customers place demand for different products, the price of which is a function of the set of prices defined by suppliers from different distribution channels, presented as a nonlinear scheduling problem. Minimum and maximum prices and demands for the product are defined using this model. However, according to different discount scenarios in distribution channels set by suppliers, customers' demand is determined in a minimum-maximum range. The proposed model sets pricing and ordering, determines delivery centers, and chooses routes and vehicles to maximize the SC profits. The model was devised using the combined method of simulated annealing and red deer with approximate data to sell mobile products and accessories. The results indicated that customers tended to go for online shopping more than in-person shopping. Increasing the product cost reduces demand for the product and increases demand for a competitive product. In general, the decrease in demand for a product is higher than the growth of demand for a competitive product, i.e., the decrease in demand reduces the need for shelves.

INDEX TERMS Pricing, omnichannel retailing, mathematical modeling, metaheuristic algorithm.

I. INTRODUCTION

The market's demand primarily orients the income of a supply chain (SC) [1]–[3]. This demand also depends on specific important factors such as the obtainability of the product, the retail value of the product, and the quality of the product [4], [5]. It is practically impossible to predict exactly the market needs until they are addressed by the retailer [6], [7]. Consequently, uncertainty in demand plays an important role in choosing optimum strategies. Demand uncertainty ultimately is an essential subject in operation studies, primarily within the field of supply chain management (SCM) [8]. Manufacturers, who can offer substitutable products and services to the usual retailer, compete on several levels (i.e., customer service, product quality, and technological support). Besides, cost competition among manufacturers is expected and critical [9]. Manufacturers should establish

product and service prices based on their price structures and behavior or in response to their rivals' efforts to make the highest profits [10]. Manufacturers and retailers possess the power to control decision variables within a marketing channel [11].

Studies on pricing have primarily focused on linear demands based on convincing and effective analyses with some errors. In the past, these works were particularly conducted on the issues mentioned above, providing opportunities for future works [12], [13]. The importance of financial asset pricing has invoked various theories and models in the recent fifty years [14]. Customers expect effective and simple communication with suppliers. In the current fanfare world, in which everyone is exposed to large amounts of advertisements, products, and choices, successful companies are those that can respond to their customers' demands and even wishes in any place in the shortest time by using every communication channel [15], [16]. In the current marketing context, meeting customer requirements is not enough; they should

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be considered humans, and their souls should be possessed [17], [18]. To meet customers' communication requirements in the last decades, multichannel marketing was proposed as a concept against traditional marketing. It represents the ability of companies, particularly retailers, to use communication channels such as websites and emails [19], [20].

With omnichannel (OC) pricing, retailers provide real-time price information to customers in all channels. This strategy simplifies the customer experience and enables communication with customers regardless of when the interaction takes place [21], [22]. As a result, OC pricing removes many barriers to purchase. OC pricing recognizes that customers are very sensitive to price differences; they become frustrated when prices change in the channels. It focuses on building customer loyalty, improving the competitive price picture, and increasing market share [23]. Accordingly, pricing becomes increasingly transparent and calls for a revolution in traditional pricing strategies. In the past, retailers focused on channel-specific prices using area pricing, online advertising, or some other tactics. Currently, some retailers are reviewing this strategy and adopting an OC pricing strategy that gives customers the same price per channel. With this in mind, there is room for retailers to continue channel-specific prices [24]. The ability to price different items depends on the price flexibility or sensitivity of a particular commodity. There is more price flexibility depending on the product, fashion or trend, competitiveness, value perception, or brand loyalty [16]. However, one thing is for sure: customers are constantly changing their behavior and denying everything. Successful retailers need to ensure that prices seamlessly follow customer behavior across channels to deliver goods and services everywhere, touch the brand, build brand loyalty, and increase market share. A thoughtful approach to pricing is to provide appropriate information and incentives to customers and maximize purchasing decisions at every point of contact, which is crucial in OC pricing [12]. Given the importance of OC pricing, this study presented a game theory model to examine the impact of pricing on omnichannel retail (OCR), emphasizing cost, delivery time, and demand dynamics parameters.

In this regard, a new concept known as OCR has been proposed. OCR is a mutual channel-based business model companies use to improve communication with customers [12], [25]. This approach is applied in health and medication, the public sector, financial services, retail, and telecommunication including channels such as physical places, question websites, social media, live chat, mobile applications, and telephone communication [26], [27]. Companies using the OC approach believe that customers value the ability to establish permanent communication with the company in different ways at the same time (i.e., different communication channels at the same time with the same information). In simple words, OC is multichannel marketing performed completely and correctly [28], [29]. However, social media and mobiles have been added to traditional channels such as websites and emails. In OC, the customer

behavior is completely predicted and supported in all communication channels and contact points such that customers will experience no defect problems in their purchases while they change their communication channels during their purchase processes. Individuals and technology play key roles in customer experience in OC [30].

Only a few studies on pricing have used the game theory method. For instance, Chun and Park [31] used the cost parameter and game theory to develop a model. Besides, these studies have designed a pricing strategy but have not considered its impact on the OCR system. Therefore, there is a gap in the literature on the impact of pricing on OCR. Besides, there is little research on the simultaneous use of parameters addressed in previous studies. Accordingly, an innovative contribution of the present study is to develop a multi-objective model to investigate the impact of pricing on OC with an emphasis on cost parameters, delivery time, and demand dynamics.

This study primarily aimed at designing an optimization model to maximize the profitability of OCR. By proposing effective solutions, the study helps sales managers implement OCR to improve their environmental and economic performance based on different components so that they can pay attention to customers' demands and satisfaction and improve distribution systems' economic performance. The study made the following contributions:

- Maximizing OCR earnings, optimizing dynamics pricing policies, and investigating different pricing cases
- Obtaining the equilibrium point of OCR based on dynamics pricing
- Investigating participatory and advertisement policies in the OCR of seasonal products
- Considering the parameters of state interventions in product pricing and examining its impact on retail profitability
- Considering promotional parameters, such as discounts on product sale costs, in different scenarios to increase actual and potential sales

The rest of the paper is as follows: Section II includes related works. Section III includes problem statement and mathematical modeling. Section IV describes the proposed solution approach. The results of mathematical modeling are provided in Section V, and Section VI gives conclusions and a summary along with recommendations for future works.

II. RELATED WORK

Pricing is done by analyzing different aspects of the OC distribution system. Studies conducted in this field fulfilled different objectives. For example, Jiang *et al.* [34] investigated the interaction between retailers and strategies of the manufacturer for pricing and delivery of services using an online sales channel. In a study on interchangeable products, Taleizadeh *et al.* [43] discussed the approach to price two specific products in a bilevel OC chain of supply with two producers and a retailer. Given market transaction costs and

the online-to-offline market share ratio, Chun and Park [31] examined how market share in a SC could affect a manufacturer's hybrid marketing channel strategies. Leung *et al.* [44] provided a new method in using the fuzzy law extraction approach and the fuzzy logic method to discover factors affecting decisions to price products in an e-commerce website. They also developed flexible and dynamic pricing approaches for products under study. Gawor and Hoberg [45], through a conjunct analysis based on 550 online purchasers in the USA, calculated current and reasonable monetary values in a log-log regression model to extract monetary metrics and management outcomes from OC for the B2C retailer strategies. Simon and Fassnacht [46] presented a clear trend toward multi-channel strategies facilitated by the Internet, which posed unprecedented challenges to pricing management and included price differentiation between online and offline channels and the prevention of channel conflicts. Harsha *et al.* [29], following a two-year work experience with three major retailers, offered an integrated OC method for optimizing prices to match products unavailable in channels and stores.

Modak and Kelle [47] studied a SC with two channels at random customer demand, depending on price and delivery time. Gong and Hao [48] designed a bilevel channel sales model for retailers from the network channel pricing and strategy reduction perspectives. Zhuang *et al.* [49] examined two important drivers of price distribution: retail and customer purchase risk. Chen *et al.* [50] examined a strategy for optimal pricing in a perishable food SC. Hajikhani *et al.* [51] provided a fuzzy multi-objective model to choose and assign purchases to suppliers in unspecific conditions with several items, sources, and products in a bilevel SC with pricing considerations. Lei *et al.* [52] analyzed product, pricing, and purchase fulfillment with an online retailer (e-commerce), considering a limited sales horizon, limited stock for each product, and no possibility of recharging. Concerning the realized demand, Lei and Gao [53] proposed a heuristic control method, improving the first case by adaptively adjusting the main control parameters. An essential feature of the second exploratory control is that it facilitates pricing decisions and real-time realization. Kembro *et al.* [54] improved the understanding of how operations and warehouse design affected the movement toward OC. Saha *et al.* [55] examined optimal pricing strategies and features of a bilevel SC with two channels considering the high sensitivity of demand to price and delivery duration. Kienzler and Kowalkowski [56] introduced a strategy for current state pricing by analyzing 515 papers published in journals from 1995 to 2016. The study by Wang [57] presented a hybrid channel model to facilitate optimal pricing decisions by traditional and online retailers.

According to the literature review results, many studies, such as those performed by Taleizadeh *et al.* [43], Chun and Park [31], Leung *et al.* [44], Gawor and Hoberg [45], Simon and Fassnacht [46], Harsha *et al.* [29], Modak and Kelle [47], Gong and Hao [48], and Zhuang *et al.* [49],

discussed OC pricing; they employed various methods, such as game theory Zhang and Guizani [58], Taleizadeh *et al.* [43], Chun and Park [31], Zhuang *et al.* [49], Chen *et al.* [50], Basak *et al.* [59], mathematical modeling Modak and Kelle [47], and the fuzzy logic technique Leung *et al.* [44], among others.

These studies examined different parameters, such as cost Hajikhani *et al.* [51], Lei *et al.* [52], Kembro *et al.* [54], and Bayram [62], delivery time Saha *et al.* [55], Modak [60], and Wollenburg *et al.* [61], and the dynamics of demand Harsha *et al.* [29] and Bayram [62]. However, some research also used a combination of these parameters, such as the study by Modak [60], which simultaneously used delivery time and demand dynamics parameters in pricing using mathematical modeling. According to the obtained results, limited studies used the game theory method, and among them, only Chun and Park [31] designed a pricing model using the cost parameter. These studies also addressed the design of pricing strategies and showed the pricing impact on the OC distribution system. However, no study examined the impact of pricing on the OC distribution system, and according to parameters used in previous studies, no study utilized these parameters simultaneously. Accordingly, it is innovative to present mathematical modeling to investigate the impact of pricing on OC, emphasizing cost parameters, delivery time, and demand dynamics. The present research innovations were as follows:

- Designing a dual-purpose model to maximize profitability and selling price
- Considering the parameters of state interventions in product pricing and examining its impact on retail profitability
- Considering promotional parameters, such as discounts on product sale costs, in different scenarios to increase actual and potential sales

III. PROBLEM STATEMENT

In recent years, pricing and coordination among manufacturers, suppliers, and retailers in multi-level SC systems have attracted researchers' attention. Product pricing is one of the main topics in SCM [63], [64]. It is crucial when considering management, stock control, and purchase programming simultaneously. The lack of a proper pricing strategy leads to low sales numbers, customers, market share, and profit. It is possible to price products correctly based on the manufacturing cost, customers, and competitors and create a suitable profit margin utilizing the right strategies [65], [66].

Today, the increase in competition between companies and the need for a rapid response to various demands of customers require optimal SCM [67], [68]. Integration is a key aspect of managing SCs. The OC distribution strategy is one of the new strategies that can help with the integration and distribution of products in distribution channels and organizations. In this way, they can respond rapidly and more accurately to customers' needs and expectations, paving the way for SC

profitability [37], [69]–[71]. Shopping through computers, mobile phones, and various applications, along with traditional methods such as shopping in stores or choosing from catalogs, has covered all society segments with all kinds of tastes and habits. The use of all available facilities, called OC, equips organizations with more control over pricing and product choice and assists them in receiving appropriate feedback from the market and customers to guide production and pricing more effectively.

According to the literature, the area of research is optimal pricing modeling in a bilevel SC involving suppliers, retailers, and customers. Customers in this chain place demand for different products, some of which depend on the price set by the supplier from different distribution channels, presented as a nonlinear scheduling problem. This model defines minimum and maximum prices and demands for the product. According to different scenarios for distribution discounts determined by suppliers, the magnitude of demand is determined within a certain range. The proposed model involves pricing and ordering products, determining delivery centers, and choosing routes and vehicles to maximize chain profits. The present study aimed at seeking the following innovations:

- Pricing products in discount scenarios offered to lure customers into making a purchase
- Benefiting suppliers through setting a price for products (considering that customers mostly choose and order through online distribution channels)
- Modeling the problem in the form of a nonlinear programming problem
- Preventing credit and customer loss (the shortage is prevented)
- Meeting all consumer demands through various distribution channels

The following assumptions were used to design mathematical modeling:

- The location of distribution channels is predefined.
- Discount is an independent factor and not a function of the purchase amount.
- The retailer discount given to the customer while ordering through the distribution channel is a maximum of 10% of the total price set in each period.
- The multi-product model is multi-period based and can be supplied from several retailers.

A. SETS AND INDEX

- I A set of suppliers $i = \{1, 2, 3, \dots, I\}$.
- J A set of retailers $j = \{1, 2, 3, \dots, J\}$.
- K A set of customers $k = \{1, 2, 3, \dots, K\}$.
- R A set of distribution channels $r = \{1, 2, 3, \dots, R\}$.
- M A set of products $m = \{1, 2, 3, \dots, M\}$.
- Se A set of scenarios $se = \{1, 2, 3, \dots, Se\}$.
- T Time Periods $t = \{1, 2, 3, \dots, T\}$.

B. PARAMETERS

Suppliers

- P_{mir}^{Se} The amount of product m supplied by supplier i through distribution channel r in period t based on scenario Se .
- Q_{mit}^{Se} The wholesale price of product m set by supplier i in period t is based on scenario Se .
- C_{mit} The cost of ordering product m from supplier i in period t .
- TR_{ijt} The cost of transporting the product from supplier i to retailer j in period t .
- T_{mijt}^{Se} The VAT percentage of sales of each unit of product m from supplier i to retailer j in period t based on scenario Se .

Retailers

- D_{mjkt}^{Se} Demand placed for product m sold by retailer j through customer k in period t based on scenario Se .
- Q_{mijkrt}^{Se} The amount of product m sold by retailer j to customer k through distribution channel r in period t based on scenario Se .
- S_{mrt}^{Se} The percentage of product m sold through distribution channel r in period t based on scenario Se .
- TR_{jkt} The cost of transporting products from retailer j to customer k in period t .
- In_{jt} The product maintenance cost borne by retailer j in period t .
- T_{mjkt}^{Se} The VAT percentage of sales of each unit of product m from retailer j to customer k in period t based on scenario Se .
- R_{mrt}^{Se} Percentage discount for product m supplied through distribution channel r in period t based on scenario Se .

State interventions

- S_{mi} State subsidy for supplier I of product m .
- TE_i The percentage of tax exemption for supplier i in period t .
- TE_j The percentage of tax exemption for retailer j in period t .

Others

- U'_{mrt}^{Se} The potential rate of sales of product m supplied through distribution channel r in period t based on scenario Se .
- J'_{mrt}^{Se} The actual potential rate of sales of product m supplied through distribution channel r in period t based on scenario Se .
- H'_{mrt}^{Se} The minimum expected profit from the sale of product m supplied through distribution channel r in period t based on scenario Se .
- Pr_{Se} The probability of scenario Se .

C. DECISION VARIABLES

- X_{mrt}^{Se} The selling price of each unit of product m supplied through distribution channel r in period t based on scenario Se .
- W_{jkrt}^{Se} Retail discount amount j to customer k for purchase from distribution channel r in period t based on Se scenario (based on the percentage of the sale price).
- Z_r Customers' desire to buy through distribution channel r for the discount offered by the retailer to customers.
- Y_{mrt}^{Se} Binary variables: one if product m is sold through distribution channel r in period t according to scenario Se ; otherwise, zero.

D. OBJECTIVE FUNCTIONS

$$\begin{aligned}
 & \text{Max } Z_1 \\
 & = \sum_{Se} Pr_{Se} \left[\sum_i \sum_j \sum_m \sum_k \sum_r \sum_t \left[\left(X_{mrt}^{Se} - Q_{mit}^{se} \right) \cdot D_{mjkt}^{se} \right. \right. \\
 & \quad \times \left(T_{mjkt}^{se} - TE_i \right) \left. \left. - \sum_i \sum_r \sum_m \sum_t P_{mirt}^{se} \cdot C_{mit} \cdot Q_{mit}^{se} \right. \right. \\
 & \quad + \sum_i \sum_j \sum_k TR_{ijt} + TR_{jkt} \\
 & \quad \left. \left. - \sum_j \sum_k \sum_m \sum_n \left(D_{mjkt}^{se} - Q_{mjkt}^{se} \right) In_{jt} \right] \right] \quad (1)
 \end{aligned}$$

$$\begin{aligned}
 & \text{Max } Z_2 \\
 & = \sum_{Se} Pr_{Se} \left[\sum_i \sum_j \sum_k \sum_m \left[\left(D_{mjkt}^{se} \right. \right. \right. \\
 & \quad \left. \left. - Q_{mjkt}^{se} \right) X_{mrt}^{Se} \cdot \left(H_{mrt}^{Se} \cdot U_{mrt}^{Se} \cdot J_{mrt}^{Se} \cdot Y_{mrt}^{Se} \right) \right. \\
 & \quad \left. \left. - \sum_j \sum_m \sum_t R_{mrt}^{Se} \cdot Z_r \right] \right] \quad (2)
 \end{aligned}$$

The purpose of the first objective function is to maximize the profit from the sale of products. In this function, the first two terms belong to the revenue earned from selling products supplied by different suppliers. The most important part of the revenue aspect is the subsidy received from the state, allocated based on the coefficient of product amount supplied by the supplier in the SC, which reduces the VAT percentage and in turn increases sales revenue. The other two terms of this objective function include supply, shipping, and product maintenance costs borne by the supplier or retailer.

The second objective function, which is based on the difference between the wholesale and retail prices, the potential sales rate of the product, and the actual sales rate after the price reduction, maximizes the retailer's gross profit when the price is below the market price, regardless of the sales rate. The potential sales rate refers to the price offered to potential customers who have decided to buy a product but

have not purchased it yet because of the mismatch in the price offered to potential customers and that offered to regular customers. When the price goes down, depending on the reduction, it is expected that some of the customers who purchased before buy more or those who have not made a purchase thus far because of the price make a purchase for the first time. It should be noted that price reduction alone is not enough to change the buying decision of potential customers, and other factors, such as advertising, shortages, increase in the price of the same product, and special conditions such as competitors' prices, can also affect the sales rate. On the other hand, the retail price, introduced as a decision variable, is a price lower than the market price to encourage customers to make purchases. The price should generally be more than the wholesale price to prevent sellers from suffering and less than the market price to encourage customers to buy and pull them out of the competitor market. Finally, this price is achieved when the product is offered for sale to the channel. According to the second objective function, pricing is based on the following parameters: actual and potential rates and the expected minimum profit. Hence, the supplier can increase the price when actual and potential demands are at the desired level, and the discount percentage is also considered to encourage the customer to buy; otherwise, when the price is at its lowest, profitability also decreases.

E. CONSTRAINS

$$\sum_j \sum_m D_{mjkt}^{Se} \cdot U_{mrt}^{Se} \leq P_{mirt}^{se} \cdot Y_{mrt}^{Se} \quad \forall t \in T, k \in K, r \in R, se \in Se \quad (3)$$

$$\sum_j \sum_k Q_{mjkt}^{se} \cdot S_{mrt}^{se} \leq D_{mjkt}^{se} \quad \forall t \in T, m \in M, r \in R, se \in Se \quad (4)$$

$$\sum_m \sum_j C_{mit} \left(T_{mjkt}^{Se} - TE_i \right) \leq \sum_m \left(X_{mrt}^{Se} - Q_{mit}^{Se} \right) \quad \forall t \in T, k \in K, r \in R, se \in Se \quad (5)$$

$$\sum_m H_{mrt}^{Se} \leq \sum_j \sum_m D_{mjkt}^{Se} \cdot J_{mrt}^{Se} \left(X_{mrt}^{Se} - Q_{mit}^{Se} \right) \quad \forall t \in T, k \in K, r \in R, se \in Se \quad (6)$$

$$U_{mrt}^{Se} \leq \sum_j D_{mjkt}^{Se} \cdot X_{mrt}^{Se} \quad \forall m \in M, k \in K, t \in T, r \in R, se \in Se \quad (7)$$

$$\sum_j \sum_k W_{jkrt}^{Se} \cdot Z_r < Q_{mit}^{Se} \quad \forall t \in T, m \in M, r \in R, se \in Se \quad (8)$$

$$\sum_m X_{mrt}^{Se} < D_{mjkt}^{Se} \cdot W_{jkrt}^{Se} \cdot Y_{mrt}^{Se} \quad \forall t \in T, j \in J, r \in R, k \in K, se \in Se \quad (9)$$

$$0.05 H_{mrt}^{Se} \leq S_{mi} \leq 0.10 H_{mrt}^{Se} \quad (10)$$

$$0 \leq W_{jkrt}^{Se} \cdot Z_r \leq 0.10 Q_{mit}^{Se} \quad (11)$$

$$X_{mrt}^{Se}, Y_{mrt}^{Se} \geq 0 \quad (12)$$

$$0 \leq W_{jkrt}^{Se} \leq 1 \quad (13)$$

$$0 \leq Z_r \leq 1 \quad (14)$$

Constrain (3) indicates that the maximum supply of demand for a product is equal to its supply by the supplier. It also ensures that the magnitude of demand supplied should be less than or equal to that supplied by the supplier, given the sales potential. Constrain (4) indicates the magnitude of supply of demand for a product by the supplier and ensures that the amount of product sold, considering the sales percentage through the distribution channel, should be equal to the amount demanded by the retailer. Constrain (5) ensures that the maximum supply cost is equal to sales revenue because if the supply cost exceeds the sales revenue, it will not be economically viable and will lead to the breakdown of the system. Given the objective function of profit maximization, it is not cost-effective to supply a product with a higher cost than the profit.

The left-hand side of Constrain (6) indicates the minimum expected profit from the sale of products, and its right-hand side gives demand for products and their actual sales. Therefore, the limitation shows that the sales profit can at most be equal to demand for each product and the actual amount of their sales because this profit is earned when different distribution channels face an actual demand; otherwise, there will be neither demand nor profit. Constrain(7) represents the maximum potential of sales of products supplied by suppliers. This maximum potential depends on discount and pricing scenarios considering the left-hand side of the limitation.

Constrain (8) indicates that, given the discount percentage, customers' desire for discount in products supplied through distribution channels should be at most less than the supply cost to be economically viable because supply cost is calculated based on the wholesale price, which includes a discount more than what is affordable for the supplier. The left-hand side of Constrain (9) indicates pricing and the proper demand for products, according to discount scenarios, if product m is sold through distribution channel r in period t based on scenario Se . Therefore, this limitation indicates that the maximum selling price of products should be less than or equal to the product demand, depending on the discount percentage allocated by the distribution channel.

Constrain (10) indicates the minimum and maximum subsidies that the state can pay to suppliers for supplying the product demanded by customers, according to the chosen discount scenarios. The amount of subsidy is a percentage of the minimum profit expected from sales of products through distribution channels. Constrain (11) indicates minimum and maximum discounts given to customers by suppliers according to demand for the product. The discount can vary based on payment scenarios (online, cash on delivery, and pay after delivery), distribution channels, and the number of purchases.

IV. SOLUTION APPROACH

According to the mathematical model described in the third section, the developed model was an NP-hard type, and, hence, meta-algorithms should be used to solve it; however, the combined method of Simulated Annealing (SA) and Red Deer Algorithm (RDA) was employed in the present study.

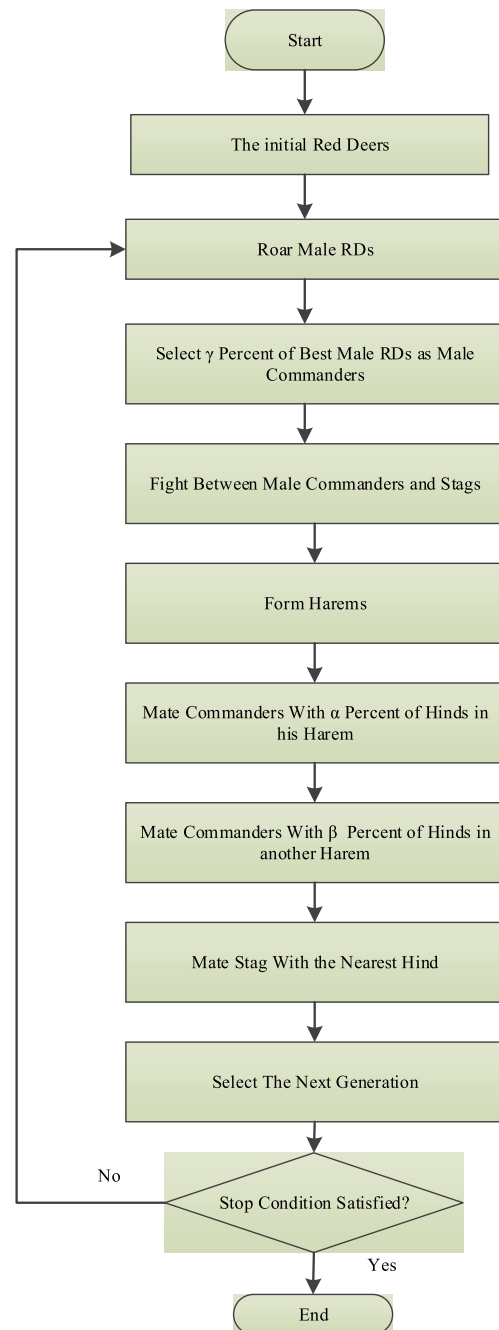


FIGURE 1. The RDA flowchart.

A. RED DEER ALGORITHM

RDA was presented by Hajiaghaei-Keshteli and Fathollahifard [72] and contains a population categorized into two groups of female and male deer. Based on an evolutionary algorithm, there is a competition between males to attract females for mating. During the breeding season, the male roars repeatedly. The roaring rate is directly proportional to female deer's attraction, success in mating, and struggling capacity [73].

The male deer roaring rate is a maximum of eight per minute before initiating the fight, and the player continues to roar in the absence of competitors. For the struggle, first,

The Combined RDA-SA Algorithm

1. Initialize the Red Deer's population.
 2. Calculate the fitness, sort them, and form the hinds (N_{hind}) and male RDs (N_{male}).
 3. Set the Pareto optimal fronts.
 4. **while** ($t <$ maximum number of iteration)
 5. **for** each male RD
 6. sub=1;
 7. **while** (sub< maximum number of sub-iteration)
 8. Create a neighbor of this solution by a procedure, which is depicted in Fig. S.3.2 from Supplementary Material S.3.
 9. **if** the new solution is better than prior
 10. Replace the old solution with the new solution.
 11. **Else**
 12. **Compute** $\delta, \delta = |f_{old} - f_{new}|$.
 13. **If** $rand < exp(-\delta/T)$
 14. Replace the new solution.
 15. **End if**
 16. **End if**
 17. sub=sub+1;
 18. **end while**
 19. **end for**
 20. Update T .
 21. Sort the males and form the stags and the commanders.
 22. Form harems: $(V_n = v_n - \max_i\{v_i; p_n = \left\lfloor \frac{v_n}{\sum_{i=1}^{N_{com}} v_i} \right\rfloor; N_{harem_n} = round(p_n \cdot N_{hind})$.
 23. **for** each male commander
 24. Mate male commander with the selected hinds of his harem randomly.
 25. New = $\frac{com+hind}{2}$;
 26. Select a harem randomly and name it k .
 27. Mate male commander with some of the selected hinds of the harem.
 28. **end for**
 29. **for** each stag
 30. Calculate the distance between the stag and all hinds and select the nearest hind.
 31. New = $\frac{stag+hind}{2}$;
 32. Mate stag with the selected hind.
 33. **end for**
 34. Select the next generation with roulette wheel selection.
 35. Update the Pareto optimal solutions.
 36. $t = t+1$
 37. **end while**
 38. Consider the best front and evaluate the solutions by assessment metrics.
-

the deer stand in front of each other and roar, and then they start fighting. Male deer are categorized into "commanders" and "ordinary deer." Commanders form a group of female deer called a harem. Two factors of roaring and struggling ability in commanders affect the size of each harem [74]. A competition occurs between commanders and male deer of the harem after its formation. Commanders are allowed to mate with females in their harem and other harems. Also, regardless of the defined restrictions for harems, male deer can mate with the nearest female.

In summary, the local search in the solution space determines the roar of a male deer. In addition, competition among

commanders and male deer is defined as a local search; however, only the best solutions are accepted. Each commander is allocated to a harem based on his abilities and can mate with 1% of females in his harem or other ones. After roaring and struggling, harems are created. Offspring results from mating, resulting in the development of new solutions in the space of solution [75]. The blue, red, and green areas are the focus phase, the variation phase, and escape from the local optimum, respectively, as shown in Figure 3. Among the stop conditions of our algorithm, the frequency of repetitions, the most optimal response quality obtained, and the execution time are noteworthy.

TABLE 1. Candidate factors and levels in combined RDA-SA algorithm.

Parameter	Level 1	Level 2	Level 3
Maximum iteration	100	150	200
Population size	100	100	300
Number of males	20	35	50
Percentage of commanders	0.5	0.6	0.8
Percentage of mating inside the harems	0.4	0.6	0.7
Percentage of mating outside the harems	0.3	0.5	0.5

TABLE 2. Design of experiments with level 9 orthogonal array for combined RDA-SA algorithm.

Execution Order	Algorithm Parameters						MID
	Iteration	Population	Males	Commanders	Inside	Outside	
1	1	1	1	1	1	1	6.952
2	2	2	1	2	2	1	37.16
3	3	3	1	3	3	1	3.081
4	2	1	2	2	1	2	9.465
5	3	2	2	3	2	2	5.657
6	1	3	2	1	3	2	9.575
7	3	1	3	1	1	1	16.375
8	1	2	3	2	2	1	14.213
9	2	3	3	3	3	1	7.923

B. COMBINED RDA-SA ALGORITHM

RDA is a population-based algorithm and includes several steps. The hybrid RDA and SA algorithm is developed to reduce the computational time and eliminate some steps by replacing them with the SA rules. RDA and SA enhance the exploitation properties by a simple SA sub-loop. In this regard, an intelligence interaction between the exploitation and exploration phases is implemented in the proposed RDA and SA algorithm. Therefore, RDA and SA are hybridized in which RDA acts as the main loop, and SA improves the characteristic of the intensification phase by considering the SA rule instead of the roaring operator in RDA.

According to what mentioned above, combined algorithms are commonly applied in actual optimization. In the present study, SA and RDA were combined, with adjusted parameters based on the desired dimension, to develop a novel hybrid algorithm [72]. In this hybrid algorithm, RDA is the main ring, and SA can be used for local search. However, RDA does not contain roaring and struggling stages. Hence, SA was used as a search tool instead of these two stages. SA and RDA used the focus phase and the variation phase, respectively. Every male deer of each generation is an initial response to SA [76]. The algorithm stages are shown in Figure 1. A hybrid optimization algorithm, i.e., a mixture of SA and RDA, called H-RS, was used in the present study. As an algorithm based on population, RDA has several stages. In this way, it was attempted to reduce computational time and eliminate some steps by replacing them with the SA rules. These algorithm stages were performed in the order shown in the following pseudo-code [76].

C. ADJUSTING PARAMETERS

Values of the input parameter determined the results of meta-heuristic algorithms. Also, the stop condition was considered to reach after 20 iterations. The experiment design is extensively applied in several systems. The tool is very useful

TABLE 3. Values given by the objective functions separately.

	Objective functions		
			Second
1	5 _r	478414	478983
2	5 _r	459498	459227
3	1 _c	513582	485045
4	1 _c	572653	558718
5	2 _c	668797	644612
6	2 _c	934814	917581
7	2 _c	734047	741284
8	2 _c	1000450	1021234
9	3 _c	673021	657067
10	3 _c	890816	868335
11	3 _c	1183635	1174468
12	3 _c	1304632	1251081
13	3 _c	1082616	1050060
14	4 _c	1160548	1138023
15	4 _c	1305200	1279772
16	4 _c	1228238	1200361
17	5 _c	1162677	1151263
18	5 _c	1324376	1128701
19	5 _c	1071419	1063668
20	5 _c	1160817	1145069

in assessing process performance and process refinement. Parameter adjustment methods are as follows [3], [77]:

- Referring to previous studies
- Using the trial-and-error method
- Performing complete tests
- Using the Taguchi method
- Determining the level response
- Using neural and adaptive fuzzy neural networks
- Using meta-heuristic algorithms (before or during execution)

The present study used the Taguchi method. Genichi Taguchi [78] expanded the knowledge of design of experiments. The method introduced by Taguchi can be applied as an engineering technique to design a product or process to minimize alternations and the sensitivity of perturbation

TABLE 4. Sensitivity analysis of objective functions.

Problem	Objective functions						
	First			Second			
	Upper bound	Optimum	Lower bound	Upper bound	Optimum	Lower bound	
1	5#2#2#2#2	513098	478414	448983	515582	478983	419227
2	5#2#4#2#2	514998	459498	419227	617134	459227	465045
3	10#2#4#2#2	612758	513582	465045	511383	485045	328718
4	15#3#6#3#3	627052	572653	528718	179323	558718	614612
5	20#3#6#3#3	684757	668797	614612	91830	64612	557581
6	20#4#8#4#4	960872	934814	957581	971230	917581	419227
7	25#3#6#3#3	7619334	734047	711284	773348	741284	657581
8	25#4#8#4#4	1105375	1000450	911234	1080687	1021234	711284
9	30#4#6#3#3	7139437	673021	647067	761890	657067	551134
10	30#4#8#4#4	9140264	890816	828335	874060	868335	647067
11	32#5#10#5#5	1264842	1183635	1114468	1195016	1174468	828335
12	35#5#10#5#5	1333464	1304632	1251081	1744923	1251081	1014468
13	38#5#10#5#5	1164437	1082616	1050060	1068808	1050060	1011081
14	40#5#10#5#5	1183096	1160548	1138023	1662736	1138023	1050060
15	45#5#10#5#5	1342214	1305200	1089772	7576414	1279772	1138023
16	48#5#10#5#5	1285473	1228238	1150361	1686542	1200361	957581
17	50#5#10#5#5	1194309	1162677	1051263	1644138	1151263	711284
18	53#5#10#5#5	1418665	1324376	1028701	1765623	1128701	1011234
19	55#5#10#5#5	1100367	1071419	1003668	1576966	1063668	647067
20	58#5#10#5#5	1194366	1160817	1015069	1615454	1145069	828335

TABLE 5. Percentage of pricing changes in the omnichannel system.

Product	In-person shopping		Online shopping		Percentage of purchase changes			Percentage of profitability changes
	Actual	Omnichannel	Actual	Omnichannel	Actual	Omnichannel	Others	
Mobile phone	81	93	90	77	+16	-1	+3	+10
Tablet	81	90	79	85	+15	+10	+11	+12
Accessories	81	93	90	77	+11	+5	+6	+6

TABLE 6. Optimal values of decision variables.

Z_r	Channels	Scenario	Product	X_{mrt}^{Se}	Y_{mrt}^{Se}
0.55	1	1	1	5000	50
			2	4500	45
			3	7500	43
		2	1	5400	47
			2	5100	40
			3	7400	45
		3	1	4900	53
			2	4800	42
			3	7200	56
		4	1	5500	47
			2	4800	43
			3	7800	42
0.45	2	1	1	4800	45
			2	7400	43
			3	5100	47
		2	1	5300	40
			2	7400	45
			3	4500	45
		3	1	7500	43
			2	5400	47
			3	5100	40
		4	1	7500	43
			2	5400	47
			3	5100	40

parameters. In an efficient parameter design, the primary goal is to recognize and change factors to minimize response variable alternations, and the secondary objective is to identify controllable and uncontrollable factors. Taguchi specifically

introduced the concept of the loss function. The loss function combines cost, target, and variation and derives a measurement criterion from which the specifications of secondary importance are derived [79]. In addition, he extended the

TABLE 7. Comparison of validation criteria between the RDA-SA and NSGA-II methods.

Problem No.		RDA-SA			NSGA-II		
		NPS	MID	MS	NPS	MID	MS
1	5#2#2#2#2	11	0.1233	5656	8	0.3616	4326
2	5#2#4#2#2	13	0.7741	12276	9	0.8845	10126
3	10#2#4#2#2	8	0.5463	7232	6	0.639	6535
4	15#3#6#3#3	6	0.2154	5747	4	0.42	5243
5	20#3#6#3#3	9	0.5512	7636	7	0.6863	7624
6	20#4#8#4#4	6	0.2342	4507	5	0.3645	3033
7	25#3#6#3#3	11	0.4354	6732	9	0.5742	6029
8	25#4#8#4#4	7	0.4522	6459	8	0.6125	6459
9	30#4#6#3#3	9	0.7461	10661	7	0.8963	0455
10	30#4#8#4#4	9	0.3423	4917	7	0.4523	3613
11	32#5#10#5#5	5	0.3428	4625	4	0.4328	4227
12	35#5#10#5#5	4	0.008	2802	3	0	2412
13	38#5#10#5#5	5	0.1286	8535	4	0.2286	7734
14	40#5#10#5#5	6	0.2257	4245	5	0.3897	3849
15	45#5#10#5#5	5	0.2859	45894	4	0.3549	3574
16	48#5#10#5#5	6	0.7871	9825	5	0.8631	8329
17	50#5#10#5#5	8	0.5233	8215	7	0.6617	7917
18	53#5#10#5#5	8	0.5359	7448	6	0.6569	7144
19	55#5#10#5#5	10	0.4332	6911	9	0.6562	5815
20	58#5#10#5#5	7	0.6325	7389	5	0.7305	6956

concept of robustness. This technique intends to find the ideal combination of controllable parameters. The basis of Taguchi’s philosophy is a robust design. The first step to use the design is to enter the window DOE using the Minitab 16 and choose the Taguchi method [80]. The next step is to select the number of factors that should be used to determine the frequency and composition of test levels. Measuring the performance of multi-objective algorithms is highly complicated compared to single-objective ones, and according to the proposed criteria, an evaluation index is not enough to examine the response obtained from the proposed algorithms. In general, a response provided by multi-objective algorithms should have the following features [81], [82]:

- 1) The distance between dominants obtained by solving the problem with the Pareto optimal solution set should be minimal.
- 2) The distribution of responses should be uniform in the Pareto optimal solution set.
- 3) The resulting responses should cover a large part of each objective function value. Turner et al. [83] used the following indices to compare the algorithms:

- **The Number of Pareto Solutions (NPS):** To use this index, Pareto solutions obtained from each algorithm are considered together, and then a better algorithm is achieved by comparing their numbers so that the higher number of Pareto solutions is preferred in the algorithm.
- **The Mean Ideal Distance (MID):** It is the distance between the algorithm’s Pareto points and the ideal point. In the present study, considering the objective functions, which are both maximization points, the maximum of each objective function in all algorithms was considered the ideal point.

- **Maximum Spread (MS):** It demonstrates the distortion uniformity of the Pareto solutions in the solution space.

According to the orthogonal arrays, Level 9 was considered a suitable design of the experiment to adjust the proposed parameters. The level 9 array is a design of an experiment using nine experiments. The design of experiments for the algorithm is given in Table 2.

The developed meta-heuristic algorithm was applied to each Taguchi experiment; the mean ratio of each level of factors and optimal levels of the algorithm’s input parameters is presented in Table 1.

V. RESULTS & ANALYSIS

To confirm the accuracy of the proposed mathematical model, numerical experiments were performed using near-reality data. Since the right data was not accessible, data based on the logical view of the authors were created and utilized in the mathematical model.

The present research aimed at optimizing profitability and pricing. Mobile phones and their accessory market were used as an example to solve the model. The research problem was solved as a near-realistic example, and the execution of the solution algorithm on the mathematical model presented in Section 3 was examined. It was carried out by solving the model with the proposed algorithm for 20 iterations, finding the best and worst values, and, finally, calculating the mean of the objective functions. The mean of the objective functions corresponding to suppliers, retailers, customers, products, and scenarios is listed in Table 3. It is noteworthy that according to the model assumptions, distribution channels in both online and in-person shopping were also considered monthly in 12 monthly periods.

Table 6 represents the optimal values of variables or decisions. According to the data shown in this table, the

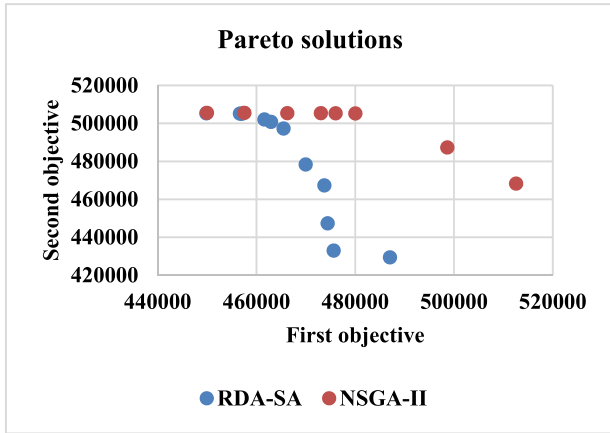


FIGURE 2. Non-dominated solutions in the first test problem.

customer’s desire was 55% for online shopping and 45% for in-person shopping. The reason for more interest in the online method is the ease of purchase and the discount retailers allocate to online shopping. Table 6 also indicates that with a decrease in the product’s price, the sales increased. For example, in online shopping, the sales rate increased with increasing retail discount percentage.

Various tests ($n = 20$) with both small and large complexities, developed against benchmarks mentioned in the literature, were used to analyze the algorithms. In total, lower and upper bounds were defined for each solution following metaheuristics’ Pareto solutions. In addition, the optimal solution was considered, which was defined as the mean of Pareto fronts (see Table 4). Table 7 lists the three-assessment metrics outputs. The non-dominated sorting genetic algorithm (NSGA-II), which is a well-established algorithm, was used to check the hybrid RDA-SA algorithm performance. As shown in Table 7, the proposed hybrid algorithm had a considerably better performance than NSGA-II. The first test problem (5#2#2#2#2) was used with Pareto solutions. The NSGA-II solutions by the two algorithms are provided in Figure 2. Clearly, the RDA-SA solutions outperformed the NSGA-II solutions.

Each assessment metric interval plot was depicted to further analyze the performance of the algorithms. Therefore, first, all data were normalized and depicted to reveal the robustness of the algorithms. As shown in Figure 3, when lower values were applied, more accuracy and robustness were achieved. Figures 3(a), (b), and (c) picture the NPS, MID, and MS metrics, respectively. As shown in all the plots, the proposed RDA-SA had a higher efficiency than NSGA-II concerning all criteria.

VI. MANAGEMENT IMPLICATIONS

According to the findings of this research, OCR in a B2B environment is more strongly impacted by constraints than by variables in its favor. In other words, a more restrictive environment entails a greater impact on OCR than any

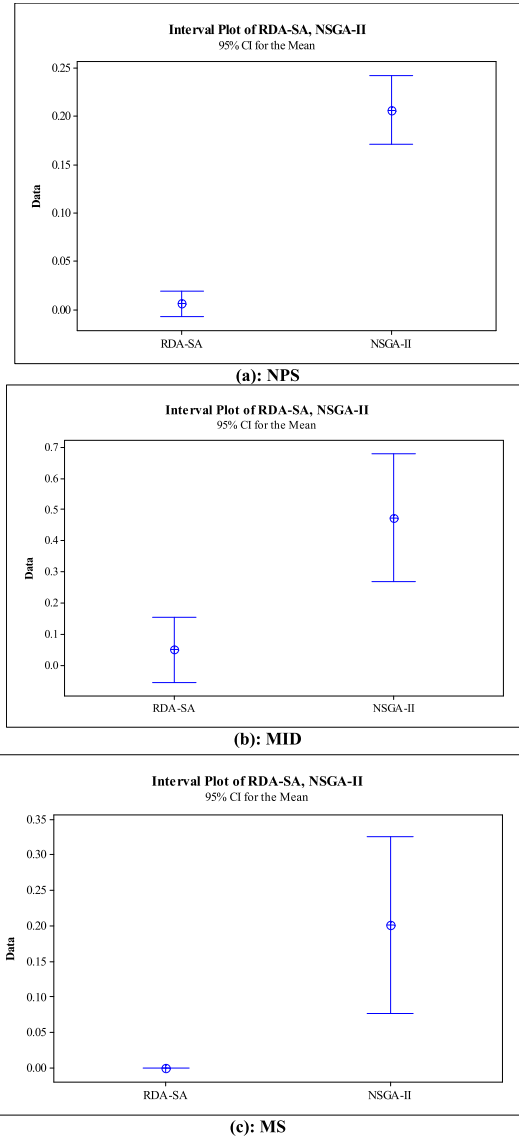


FIGURE 3. Interval plots for the robustness of RDA-SA and NSGA-II.

attempts to improve the context of the variables that favor such management.

Thus, for example, if we review how the Channel Integration value repository has been treated in research to date, it can be concluded that greater channel integration has a positive impact on OCR. Our study confirms this conclusion, given that a new channel favors OCR. However, from a management point of view, it would be advisable to make a greater effort to mitigate negative scenarios such as the one shown in results, instead of opening a new channel.

In companies and organizations affiliated with the retail industry, creating coordination between different units is possible only through processes and process management. Given the multiplicity of units and organizations involved in decision making, the process can converge the activities of the above units in line with predetermined goals.

Another suggestion of this research is to consider the factors affecting retail. Regardless of the establishment of the proposed process, paying attention to the factors identified in this study can have a great impact on product pricing. Undoubtedly, in the contingency of decision-making, each of the above factors has a different degree of importance. Use decision-making and evaluation methods to be more accurate.

VII. CONCLUSION

The present study discussed pricing issues with an emphasis on increasing profitability by maximizing the selling price. The research problem was to model optimal pricing in a bilevel SC, namely suppliers, retailers, and customers. Customers in this chain demand different products, the number of which depends on the price set by the supplier from different distribution channels, presented as a nonlinear scheduling problem. Minimum and maximum prices and demands were defined for the product in the model. However, the magnitude of customer demand was determined within a minimum and maximum range according to different scenarios for distribution channel discounts, determined by suppliers. Compared to previous studies, the pricing model proposed in the present study had some innovations, such as pricing in the OC system and measuring the impact of state interventions, including subsidies and tax rates, on pricing. The following results were obtained from the model presented with OC features:

- Ease of purchase makes customers show more interest in online shopping than in-person shopping.
- Increasing the discount rate by the retailer has a very positive effect on product demand.
- Increasing the product cost reduces demand for the product and increases demand for a competitive product. In general, the decrease in demand for a product is higher than the growth of demand for a competitive product, i.e., the decrease in demand reduces the need for shelves.
- Increasing the market potential of a product positively affects the optimal price and the retail price.
- The retailer can change the impact of market potential or manufacturing costs on aggregate demand or the retail price through demand management.
- Depending on its ability to enhance either the market potential or the product purchase, a company can adapt to a specific strategy and take advantage of the effects of market potential and mutual price sensitivities as a focused profit.

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