

Product Pricing in a Sustainable Supply Chain in the Conditions of Market Boom and Bust

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Abstract

In this paper, the problem of product pricing in a sustainable supply chain consisting of several production centers, several distribution centers, and customers in two direct and indirect channels is modeled. This model aims to achieve more profit in a sustainable supply chain by complying with environmental and social considerations. In order to solve the model, a hybrid of genetic algorithm (GA) and grey wolf optimizer (GWO) called genetic grey wolf optimizer (GGWO) was developed, with the ability to search the problem-solving space based on the simultaneous use of the operators of the two algorithms. Analysis of the numerical example with GGWO and its comparison with other solution methods indicate that pricing in direct and indirect channels is strongly related to the price elasticity coefficient of the substitute product and the price elasticity of demand so that the market boom and bust of the depends on the proper determination of these model parameters. It is also observed that in the conditions if market boom, demand increased in both direct and indirect channels and that product prices decreased in both channels. Therefore, the marginal profit increased due to the sale of more products. The GGWO algorithm has faster convergence compared to GA and GWO, while the solution time in this method is higher than other solution methods. Analyzing different numerical examples suggest that the efficiency of the used algorithms, in particular GGWO, is higher than exact methods.

Keywords: Pricing, Sustainable supply chain, Conditions of boom and bust, Probabilistic programmi

1. Introduction

In today's competitive conditions, companies are faced with new issues such as growing markets, customer expectations exceeding, and new methods and channels of communication with customers. Competition in such conditions necessitates an analysis of work style and relationships with customers. Hence, supply chain management (SCM) is considered as a significant necessity, since the proper design of the supply chain network (SCN) is of great importance for the efficient synchronization of facilities in line with boosting the productivity of the supply chain and satisfying customers (Babaeinesami et al. 2023; Maharjan and Kato,

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2022). The SCN design tries to build the most efficient and effective supply chain by considering the operating environment of companies. A supply chain is actually a set of suppliers, production centers, distribution centers, retailers, customers, and information/product flow between them (Hajipour et al. 2021; Das et al., 2023). The problem of SCN design requires optimization because it is used as a strategic decision-making problem to make the supply chain as efficient as possible in long-term operations and activities. Design decisions on the strategic level determine the location and relationships of facilities, and on the operational level, encompass the decisions in the field of setting up distribution channels, determining the amount of production of products, the level of inventory, and also determining the number of materials or products to be transported between facilities. Thus, design decisions should not be made without considering operational decisions and their effects (Nayyeri et al., 2020; Chobar et al. 2022).

On the other hand, increasing environmental problems such as air pollution, use of toxic substances, global warming, and loss of non-renewable resources and water, which are threats to modern lifestyles, have made it necessary to increase global awareness about the need to protect the environment (Waltho et al., 2019). In this regard, some organizations have applied green principles in many scientific and industrial fields, including SCM. In order to apply these principles in the supply chain, the concept of green supply chain management (GSCM) has been proposed and many studies have been conducted in this field in recent years. Environmental concerns, on the one hand, and economic aspects in the SCN design, on the other hand, have become the basis for exchanges between environmental and economic issues, aiming at providing environmentally friendly solutions (Daneshvar et al. 2023; Zhen et al., 2019), so as to increase the total cost if the environmental damage is reduced. Emission of greenhouse gases (GHG) is known as one of the main factors of environmental pollution. The limitation of GHG emissions is included as a mandatory law for the management of companies' supply chains by governments. In the design of green supply chain networks, different strategies can be used to control GHG emissions in mathematical models. These are such as determining the limit of GHG emissions, taxes on the GHG production, and the use of product life cycle assessment (Ghasemi et al. 2023; Mahmoudi et al., 2021). This has led to a change in the SCN structure and a change in the purchase behavior of customers, especially the direct purchase of products from factories along with the indirect purchase of products from distribution centers. On the other hand, manufacturers consider the direct channel more carefully than the previous methods. One of the important issues in the design of the two-channel supply chain is determining the price competition between the channels. Direct channel customers usually have higher expectations than those who make a purchase from the indirect channel. Therefore, the total allowable delivery time of the direct channel is not more than that of the indirect one. Ernest and Young (2001) showed that two-thirds of companies choose different prices for their channels; however, in some industries, the low pricing trend is for direct channels. Amini and Lee (2015) considered the concept of pricing using the sales price quota in their model. Dual-channel supply chains can be implemented in those industries with the ability to attract customers directly and indirectly. Dual-channel design for supply chains can be used for products with two types of customers, those who directly connect to supply chains through the Internet and those who buy products indirectly (Ali Ahmadi et al., 2023). The importance of pricing green products in the sustainable supply chain (SSC) led us to modeling and solving this problem in the conditions of market boom and bust in this paper. Therefore, the proposed model seeks to maximize the profit of the sustainable supply chain network (SSCN) in the market boom and bust scenarios, where important decisions are made. Among the important decisions of the SSCN are the construction of production and distribution centers, product pricing in the direct channel (sales from the production center to the customer) and the indirect channel (sales from the production center to the customer through the

distribution center), and determining the appropriate means of product transportation. For this purpose, a new hybrid algorithm is designed to solve the problem and compared with previous algorithms.

The structure of the paper is as follows: In the second section, the review of the research literature is discussed. In the third section, the pricing model of green products in the SSC is formulated in different scenarios. In the fourth section, a new hybrid algorithm is introduced to solve the problem. In the fifth section, the results obtained from the analysis of numerical examples are presented, and in the sixth section, conclusions and future suggestions are discussed.

2. Literature review

Yang and Xiao (2017) developed three game models of GSC for pricing and green level decisions with governmental interventions under fuzzy uncertainties of production cost and consumer demand. Analytical results showed that the Stackelberg producer scenario has a lower structure than other scenarios and the Stackelberg retail scenario is superior to other scenarios for all actors under strong governmental interventions, but governmental interventions are not always beneficial for the GSC and the producer. Bae and Rishi (2018) examined factors to increase the rate of consumer participation in green pricing programs by considering monetary and non-monetary incentives as factors affecting consumer attraction. Barzinpour and Taki (2018) proposed a mathematical model to identify production locations and shipment quantity, exploiting the trade-off between costs, and emissions for a dual-channel SCN. They considered the type of transportation as a tactical decision that could affect cost and GHG emissions. He et al. (2019) studied a dual-channel closed-loop supply chain and extracted the manufacturer's optimal channel structure and pricing decisions, and the government's optimal subsidy level under the three-channel structures of no direct sales, direct sales but distribution of remanufactured products through the company or third-party platform and direct sales of remanufactured products, but distribution of new products through retailers. Heydari et al. (2019) examined the problem of optimal and coordinated decision-making for a three-tier dual-channel GSC. They investigated this problem in three different decision-making structures and developed a coordinated and environmentally friendly decision-making model, as well as a mathematical programming model, called transitional model, to achieve coordination. Chen et al. (2020) proposed an analytical framework for investigating optimal decisions in a dual-channel supply chain between a manufacturer and a retailer, focusing on retail service, direct manufacturer service, and quality. Taking into account the efficiency of different supply chain structures, they developed centralized and decentralized models and obtained the corresponding analytical equilibrium solutions through the Stackelberg game.

Hay et al. (2020) presented a single-retailer-single-vendor dual-channel supply chain model in which the vendor sells deteriorating products through its direct online channel and the indirect retail channel. They studied pricing decisions and inventory decisions for two companies simultaneously and developed centralized and decentralized problem models. Wang et al. (2020) studied integrated pricing strategies for competing dual-channel retailers with the aim of applying the buy online, pick up in-store (BOPS) method, and the effect of market factors on equilibrium outcomes. Yan et al. (2020) analyzed pricing competition in a dual-channel supply chain consisting of a capital-constrained supplier and an e-retailer that is in charge of financing. They investigated the equilibrium price and optimal quantity and associated profit in dual channels, as well as the effect of various financing, operational, and consumer-related factors on pricing and channel structure. Barman et al. (2021) in the domain of optimal pricing and greening decision, a manufacturer and a single retailer generalize a dual-channel GSC in which the manufacturer produces the product and sells it through the traditional retail channel and the online channel. Demand in both channels is sensitive to the price and greenness level

of the product. They proposed a profit maximization model by analyzing a centralized decision structure and then a decentralized decision structure to find the optimal selling price and greenness level. Chen et al. (2021) studied collection strategies and pricing decisions related to end-of-life (EOL) products with dual competing online and traditional collection channels. Taleizadeh et al. (2021) proposed a dual-tier dual-channel GSC consisting of a retailer and a manufacturer with a separate sales channel for the manufacturer. Using game theory, they compared cases in which members decide to compete or cooperate with each other in terms of pricing and production. The effect of green production on reducing the amount of carbon emissions produced was also investigated.

Zhang et al. (2021) studied a dynamic and green pricing strategy for a dual-stage dual-channel supply chain including a manufacturer and a retailer, as well as pricing and green strategies under decentralized and centralized decision-making scenarios. Meng et al. (2021) used Stackelberg's game theory with the aim of investigating joint pricing policies of products in the dual-channel GSC and comparing optimal solutions. For this purpose, they considered two cases with government subsidy and without government subsidy. Sazegari (2022) used a data envelopment analysis (DEA) approach for pricing green products in an SSC. Using a three-step DEA approach, they analyzed data collected from nine selected home appliance companies. Liu et al. (2022) investigated the optimal pricing strategies of a manufacturer and a retailer in a dual-channel supply chain with reliable consumers. They introduced the concept of consumers' overconfidence level and its effects on demand, chain members' pricing decisions and profits, extracted and considered in modeling, and proposed several approaches to reducing it.

Xu et al. (2022) proposed a dual-channel supply chain model consisting of a retailer and a supplier, where the retailer can obtain trade credit financing from the supplier. They introduced an inconsistent pricing strategy and investigated the optimal pricing, sales-effort level decisions and profits of the dual-channel members, and to reduce the conflict between the two channels, they proposed a supplier-revenue sharing contract to coordinate the members so as to achieve the win-win performance with the global optimal supply chain profit. Xu et al. (2023) conducted a study on dual-channel pricing decisions for product recycling in GSC operations by considering the effect of consumers' aversion to the loss on the recycling price and profit of each node. The results showed that the higher the loss aversion factor, the lower the recycling price of dual-channel recyclers. Barman et al. (2023) proposed a three-layer GSC model with a dual-channel structure consisting of a supplier, a manufacturer, and a retailer, which aims to investigate and compare the optimal pricing strategy with and without government subsidies to maximize the overall profit of the supply chain. Das et al. (2023) investigated the issue of coordination of a dual-channel and two-stage supply chain consisting of a manufacturer and a retailer, considering the greenness level of the items. He et al. (2023) studied a dual-channel supply chain consisting of one manufacturer with an online direct channel and one offline retailer who distributes the manufacturer's products with the aim of identifying the manufacturer's and the retailer's optimal two-period pricing strategy and exploring how consumers' channel preference, price competition, and market change affect the strategy equilibrium. Li et al. (2023) investigated pricing strategies in a dual-channel supply chain belonging to a retailer consisting of several manufacturers and one retailer. The models were presented under different power structures, including manufacturer-Steckelberg, retailer-Steckelberg, Nash, and integrated power structures, with the aim of maximizing members' profits.

Reviewing the literature, it can be states that there are many papers in the field of pricing in SCN. In these papers, the major focus is on optimizing the profit of the supply chain, without focusing on environmental and social issues. This problem, on the other hand, needs to be

solved with hybrid meta-heuristic algorithms due to being NP-hard. Focusing on the issue of pricing in an SSC, this paper proposes a model for market boom and bust scenarios with a two-stage probabilistic programming method and a new GGWO hybrid algorithm to solve the model.

3. Problem statement

The increase in sensitivity of the government towards environmental issues has led manufacturing companies to compete with other companies along with the production of green products. The result of this competition is direct delivery of products to customers without intermediaries. The increase in customer satisfaction following the direct shipment of green products in the supply chain leads to changes in product pricing. So that the price of sending products without intermediaries is different from the price of sending products through distribution centers and many factors affect it. In this section, the definition of the problem and the modeling of a green product pricing problem in the SSC in the conditions of market boom and bust are discussed. The problem studied in this paper includes a SSC consisting of production centers, distribution centers, and customers according to Figure 1.

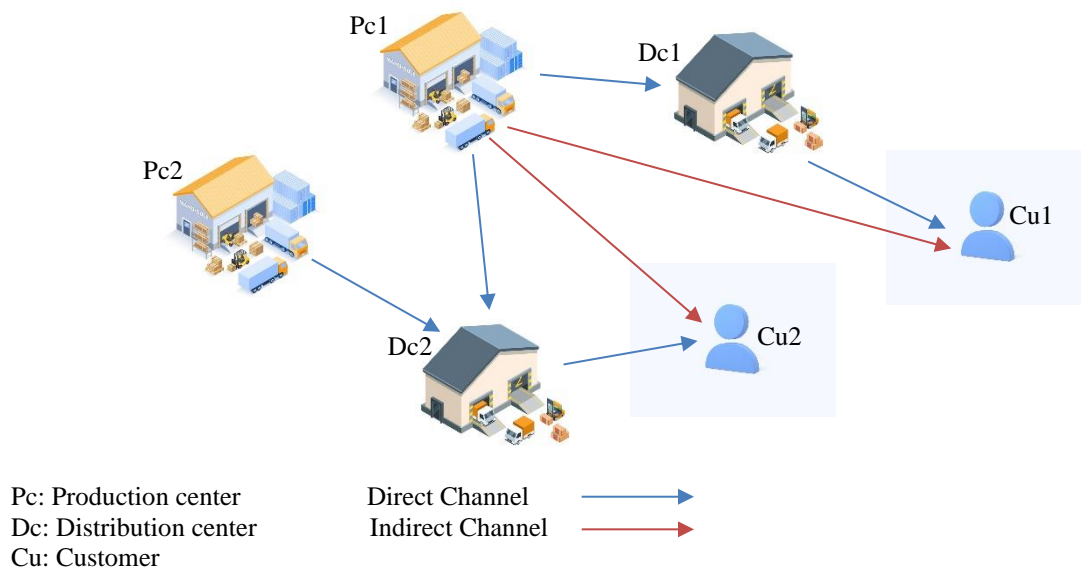


Figure 1. The proposed SSC

According to Figure 1, it can be seen that production centers send products to final customers through direct channel (online sales) and indirect channel (offline sales). Products are sold from indirect channels through distribution centers. Given that there is a possibility of boom and bust in the market, the price of the produced product can be overshadowed by the parameters of demand and supply. Therefore, these two parameters are uncertain parameters of the problem and are considered probabilistic in different scenarios. In this case, the product pricing in direct and indirect channels in each scenario will be a function of demand and demand elasticity parameters. The main objective of product pricing in the proposed SSC is to increase the total profit of the SSN by considering environmental and social aspects.

The following assumptions are stated to provide a mathematical model for the pricing of green products in the SSC in the conditions of market boom and bust:

- It is a multi-product and single-period supply chain.
- The product price in each scenario is a function of the market demand and the product price in the other channel.
- Customer demand and the capacity of production centers are considered uncertain.

- There is a limitation of minimum creation of employment opportunities in the problem.
- There is a possibility of lost sales in the supply chain.
- The amount of GHG emissions depends on production and transportation activities.
- There is a limitation of the amount of GHG emissions caused by production and transportation.

According to the above assumptions and the objective function of maximizing the total profit of the SSN, the most important decisions taken in the model include determining the optimal number of production and distribution centers, determining the price of products in direct and indirect channels, determining the amount of production and transportation of the product, and determining the optimal amount of shortage created in the network. To model the proposed SSC, the following symbols are defined:

Indices

c	Index of customer $c \in C$
l	Index of production centers $l \in L$
k	Index of distribution centers $k \in K$
v	Index of heterogeneous vehicles $v \in V$
p	Index of product $p \in P$
s	Index of scenario $s \in S$

Parameters

f_l	Fixed cost of building production center $l \in L$
g_k	Fixed cost of building distribution center $k \in K$
d_{ps}	Potential demand of product $p \in P$ in scenario $s \in S$
α'_{cps}	Price elasticity of substitute product $p \in P$ in scenario $s \in S$ for customer $c \in C$ in direct channel
α_{cps}	Price elasticity of alternative product $p \in P$ in scenario $s \in S$ for customer $c \in C$ in indirect channel
β'_{ps}	Price elasticity of demand $p \in P$ in scenario $s \in S$ in direct channel $\beta'_{ps} > \beta_{ps}$
β_{ps}	Price elasticity of demand $p \in P$ in scenario $s \in S$ in indirect channel $\beta'_{ps} > \beta_{ps}$
θ_{lps}	Production capacity of product $p \in P$ by production center $l \in L$ in scenario $s \in S$
φ_{kp}	Product distribution capacity $p \in P$ by distribution center $k \in K$
ε_{vp}	Transportation cost per product $p \in P$ by vehicle $v \in V$
π'_{cp}	Penalty cost of shortage of product $p \in P$ for customer $c \in C$ in direct channel
π_{ps}	Penalty cost of product shortage $p \in P$ for customer $c \in C$ in indirect channel
e_{lp}	Carbon dioxide emissions per production of each product $p \in P$ by production center $l \in L$
r_{vp}	The amount of carbon dioxide gas emissions per transportation of each product $p \in P$ by vehicle $v \in V$
δ	The maximum amount of carbon dioxide emissions to create the SSCN
τ_l	The number of employment opportunities created due to the construction of production center $l \in L$
ω_k	The number of employment opportunities created due to the construction of distribution center $k \in K$
ϑ	The minimum number of employment opportunities required to create the SSCN
p_s	The probability of scenario $s \in S$

Decision variables

D'_{cps}	Actual demand of customer $c \in C$ of product $p \in P$ in scenario $s \in S$ in direct channel
D_{cps}	Actual demand of customer $c \in C$ of product $p \in P$ in scenario $s \in S$ in indirect channel
P'_{ps}	Price of product $p \in P$ in scenario $s \in S$ in direct channel
P_{ps}	Price of product $p \in P$ in scenario $s \in S$ in indirect channel
X_{lcpvs}	Product $p \in P$ transferred from production center $l \in L$ to customer $c \in C$ with vehicle $v \in V$ in scenario $s \in S$
Y_{lkpvs}	Product $p \in P$ transferred from production center $l \in L$ to distribution center $k \in K$ with vehicle $v \in V$ in scenario $s \in S$
Z_{kcpvs}	Product $p \in P$ transferred from distribution center $k \in K$ to customer $c \in C$ with vehicle $v \in V$ in scenario $s \in S$
S'_{cps}	Shortage of product $p \in P$ in scenario $s \in S$ for customer $c \in C$ in direct channel

S_{cps}	Shortage of product $p \in P$ in scenario $s \in S$ for customer $c \in C$ in indirect channel
A_l	If production center $l \in L$ is built, it takes the value of 1 and otherwise it takes the value of 0.
B_k	If distribution center $k \in K$ is built, it takes the value of 1 and otherwise it takes the value of 0.

According to the symbols defined, the non-linear model of product pricing in the SSC is formulated as follows.

$$\begin{aligned}
Max\ Profit = & \sum_s p_s \left(\sum_l \sum_k \sum_p \sum_v P_{ps} Z_{kcpvs} \right. \\
& + \sum_l \sum_c \sum_p \sum_v P'_{ps} X_{lcpvs} - \sum_l \sum_k \sum_p \sum_v r_{vp} Z_{kcpvs} \\
& - \sum_l \sum_c \sum_p \sum_v r_{vp} X_{lcpvs} - \sum_l \sum_k \sum_p \sum_v r_{vp} Y_{lkpvs} \\
& \left. - \sum_c \sum_p \sum_s (\pi'_{cp} S'_{cps} + \pi_{ps} S_{cps}) \right) - \sum_l f_l A_l - \sum_k g_k B_k
\end{aligned} \tag{1}$$

s. t:

$$D'_{cps} = d_{ps} - \alpha'_{cps} P'_{ps} + \beta_{ps} P_{ps}, \quad \forall c, p, s \tag{2}$$

$$D_{cps} = d_{ps} - \alpha_{cps} P_{ps} + \beta'_{ps} P'_{ps}, \quad \forall c, p, s \tag{3}$$

$$\sum_l \sum_v X_{lcpvs} + S'_{cps} = D'_{cps}, \quad \forall c, p, s \tag{4}$$

$$\sum_k \sum_v Z_{kcpvs} + S_{cps} = D_{cps}, \quad \forall c, p, s \tag{5}$$

$$\sum_l \sum_v Y_{lkpvs} \leq \sum_c \sum_v Z_{kcpvs}, \quad \forall k, p, s \tag{6}$$

$$\sum_k \sum_v Y_{lkpvs} + \sum_c \sum_v X_{lcpvs} \leq \theta_{lps} A_l, \quad \forall l, p, s \tag{7}$$

$$\sum_c \sum_v Z_{kcpvs} \leq \varphi_{kp} B_k, \quad \forall k, p, s \tag{8}$$

$$\sum_l \tau_l A_l + \sum_k \omega_k B_k \geq \vartheta \tag{9}$$

$$\sum_l \sum_k \sum_p \sum_v (e_{lp} + r_{vp}) Z_{kcpvs} + \sum_l \sum_c \sum_p \sum_v (e_{lp} + r_{vp}) X_{lcpvs} \tag{10}$$

$$\begin{aligned}
& + \sum_l \sum_c \sum_p \sum_v r_{vp} Z_{kcpvs} \leq \delta, \quad \forall s \\
& D'_{cps}, D_{cps}, P'_{ps}, P_{ps}, X_{lcpvs}, Y_{lkpvs}, Z_{kcpvs}, S'_{cps}, S_{cps} \geq 0 \\
& A_l, B_k \in \{0,1\}
\end{aligned} \tag{11}$$

Equation (1) shows the profit of the SSCN. This profit is the result of the difference in income from selling products to customers in direct and indirect channels from fixed and variable costs. Equations (2) and (3) indicate the actual demand of customers for different products based on product pricing. Equations (4) and (5) show the number of products transferred to customers in direct and indirect channels based on actual demand, respectively. Equation (6) shows the number of products transferred through distribution centers in each scenario. Equation (7) shows that if the production center is built, its maximum capacity can be used. Equation (8)

shows that if the distribution center is built, its maximum capacity can be used. Equation (9) shows that minimum employment opportunities have been created and must be respected. Equation (10) guarantees that the amount of carbon dioxide emissions in the production and transportation of products by vehicles must be less than the permissible limit. Equations (11) and (12) demonstrate the decision variables of the problem.

In Equation (1), due to the multiplication of two continuous variables together, the problem is formulated as a different integer non-linear programming model. On the other hand, the integration of strategic decisions such as the construction of centers with tactical decisions such as product pricing and the optimal amount of product transfer is known as a mathematical model of NP-Hard problems, which requires the use of meta-heuristic algorithms. In this paper, genetic algorithm (GA) and grey wolf optimizer (GWO) and a hybrid algorithm called genetic grey wolf optimizer (GGWO) are used to solve the problem. The hybrid algorithm consists of the operators of GA and GWO algorithms.

4. GGWO algorithm

The GGWO algorithm is a hybrid meta-heuristic algorithm consisting of GA and GWO, which is inspired by nature. GWO mimics the behavior of grey wolves and their leadership hierarchy and hunting method (Mirjalili et al., 2016). In GWO, based on group hunting, wolves are classified into three groups: alpha, beta, and delta. The alpha wolf is the leader of the hunt. Beta is probably alpha's best candidate to play the role of alpha's assistant and group moderator. Delta wolves follow alphas and betas and occasionally rule. The best solution to the problem is the leading wolves with alpha. While in GA, crossover and mutation operators are implemented to generate the superior generation. By combining GA and GWO operators, the advantages of the two algorithms can be used. Figure 2 displays the pseudocode of GGWO.

```

    Input model data, Npop, pc, pm, maxit, A, C
    Generate initial population based initial solution
    Evaluate Profit for each initial solution
    Define Xα, Xβ, Xδ as the best, second best and third best solution
    For i = 1 to maxit
    For j = 1 to each population
        Update the position of the current solution based on:
             $\vec{D} = |\vec{C} \cdot \vec{X}_p(i) - \vec{X}(i)|; \vec{X}(i+1) = \vec{X}(i) - \vec{A} \cdot \vec{D}$ 
             $\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a}; \vec{C} = 2\vec{r}_2$ 
             $\vec{A} = 2\vec{a} \cdot \vec{r}_1 - \vec{a}; \vec{C} = 2\vec{r}_2$ 
             $\vec{D}_\alpha = |\vec{C}_1 \cdot \vec{X}_\alpha - \vec{X}|, \vec{D}_\beta = |\vec{C}_2 \cdot \vec{X}_\beta - \vec{X}|, \vec{D}_\delta = |\vec{C}_3 \cdot \vec{X}_\delta - \vec{X}|$ 
             $\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1 \cdot \vec{D}_\alpha, \vec{X}_2 = \vec{X}_\beta - \vec{A}_2 \cdot \vec{D}_\beta, \vec{X}_3 = \vec{X}_\delta - \vec{A}_3 \cdot \vec{D}_\delta$ 
             $\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3}$ 
        End For
    For j = 1 to each population
        Select 2 individuals as selected wolfs
        Perform two point crossover operation based on figure (3)
    End For
    For j = 1 to each population
        Select an individual as selected child
        Perform one point mutation operation based on figure (4)
    End For
    Update A, C
    Repair new population based on combining of fsprings and parents
    Calcuatue the crowded distance
    Select the Xα based crowded distance
    Update Xα, Xβ, Xδ
    End For

```

Figure 2. Pseudocode of GGWO

In GGWO, the use of crossover and mutation operators leads to a better search of the problem space due to the creation of a superior generation of grey wolves. Figure 3 and 4 demonstrate how to perform combination and crossover operators, respectively.

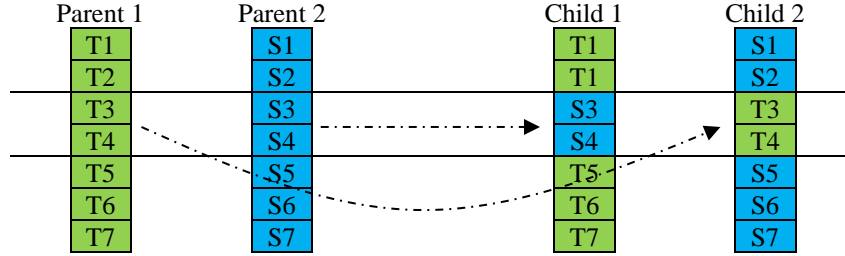


Figure 3. Two-point crossover operator

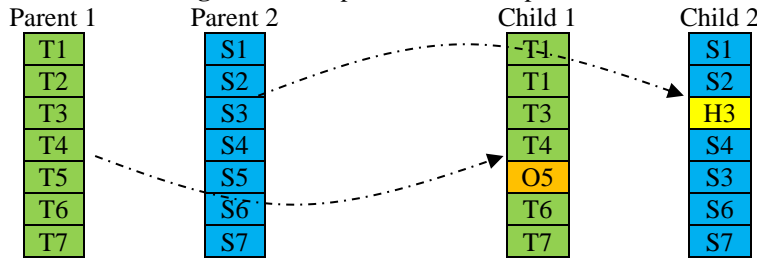


Figure 4. Single-point mutation operator

In order to improve the efficiency of the GGWO algorithm, the initial parameters of the algorithm need to be set. Taguchi method is used for this purpose. In this method, for each parameter, three levels are selected by the decision maker and the values of each level are determined. By designing Taguchi tests, each test is performed with a combination of different levels, and the RPD value of each test is obtained using Equation (13).

$$RPD_i = \frac{Profit^* - Profit_i}{Profit^*}, \quad \forall i \quad (13)$$

In the above equation, $Profit^*$ is the best profit obtained from performing all tests and $Profit_i$ is the profit obtained in performing each Taguchi test. After performing Taguchi tests, the mean of SN ratios diagram is obtained according to Figure 5. In this figure, the best combination for setting the parameters of GGWO is the highest level of each parameter. With this definition, the optimum level and optimum value of each parameter are given in Table 1.

Table 1. Parameter setting of GGWO with Taguchi

Parameter	Optimum Level	Optimum Value
$Maxit$	3	200
$Npop$	3	200
p_c	2	0.04
p_m	1	0.7
A	2	2
C	1	1

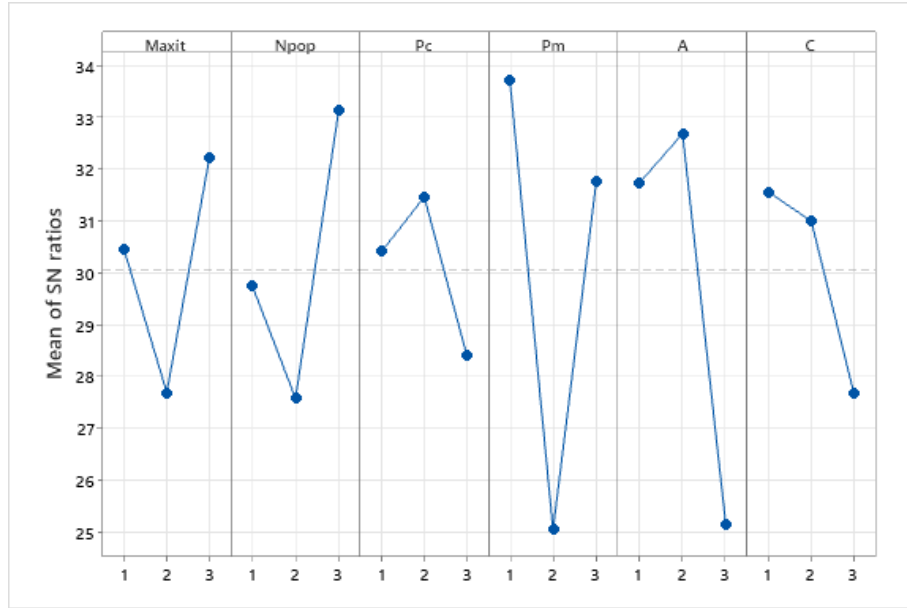


Figure 5. Diagram of mean of SN ratios

After setting the parameters of GGWO, different numerical examples are analyzed.

5. Analysis of numerical examples

The non-linearity and NP-Hardness of the green product pricing model in the SSC led to the use of hybrid algorithms to achieve decision variables. Accordingly, in this section, the 12 numerical examples are analyzed according to Table 2 with GGWO, GA, and GWO methods. Due to the non-linearity of the proposed mathematical model, it is validated through GAMS 24.8.2 commercial software with Baron solver.

Table 2. Sizes of numerical examples

Sample Problem	Production Center	Distribution Center	Customer	Products	Vehicles	Scenario
1	3	3	5	2	4	2
2	3	3	7	2	4	2
3	4	4	9	2	4	2
4	4	4	11	3	6	3
5	6	6	13	3	6	3
6	6	6	15	3	6	3
7	8	8	17	4	8	4
8	8	8	19	4	8	4
9	10	10	21	4	8	4
10	10	10	23	5	10	6
11	12	12	25	5	10	6
12	15	15	28	5	10	8

To analyze the designed numerical examples, random data with a uniform distribution function is used according to Table 3. The data given in this table are applied based on the justification of the mathematical model.

Table 3. Interval limits of the problem parameters

Parameter	Value	Parameter	Value
f_l	$\sim U(10000,12000)$	φ_{kp}	$\sim U(1200,1500)$
g_k	$\sim U(8000,10000)$	ε_{vp}	$\sim U(5,8)$
d_{ps}	$\sim U(500,600)$	π'_{cp}	$\sim U(80,120)$
α'_{cps}	$\sim U(20,40)$	π_{ps}	$\sim U(90,150)$
α_{cps}	$\sim U(10,30)$	e_{lp}	$\sim U(5,8)$

β'_{ps}	$\sim U(10,20)$	r_{vp}	$\sim U(0.5,1)$
β_{ps}	$\sim U(4,10)$	δ	1500
θ_{lps}	$\sim U(1500,2000)$	τ_l	$\sim U(20,80)$
ϑ	$\sim U(50,60)$	ω_k	$\sim U(15,40)$
p_s	$\frac{1}{ S }$		

After designing different numerical examples, they are analyzed. In order to reduce the calculation error by meta-heuristic algorithms, each numerical example is executed five times by the algorithms and the best profit value is obtained, as well as the average calculation time is shown in Table 4.

Table 4. Profit of the supply chain and calculation time obtained with different solution methods

Sample Problem	Profit				CPT			
	Baron	GGWO	GWO	GA	Baron	GGWO	GWO	GA
1	42563.95	41814.34	41372.16	40861.39	58.67	9.15	8.60	8.00
2	43158.28	42640.38	41518.27	41820.37	76.18	11.27	10.59	9.75
3	45982.48	43959.25	43821.30	44143.18	112.38	13.67	12.58	11.70
4	47165.66	46363.84	45279.03	45703.52	197.68	16.92	15.74	14.95
5	49786.34	48691.04	48541.68	47844.67	269.84	19.66	18.48	17.37
6	52489.03	50494.45	50441.96	50336.98	445.68	24.84	22.60	20.57
7	55846.48	54003.55	55064.63	54282.78	627.99	29.94	26.95	24.52
8	57931.48	55034.91	56772.85	56309.40	914.68	36.84	33.16	30.50
9	-	57716.13	57956.86	59160.54	>1000	47.95	43.18	38.81
10	-	62282.97	60695.74	62029.02	>1000	57.96	54.48	49.03
11	-	64205.52	63017.75	63743.61	>1000	69.24	65.09	59.88
12	-	69847.64	69215.85	66829.10	>1000	82.48	77.53	69.78

The results of Table 4 show that with the increase in the number of customers in the SSCN, the costs associated with the construction of production and distribution centers are increased. On the other hand, this increase in the number of customers leads to an increase in the income from the sale of products. Based on this, it can be seen that the total profit of the SSCN increased with the increase in the number of customers.

On the other hand, the results obtained from solving sample problems with different solution methods suggest that the maximum relative difference between meta-heuristic and Baron algorithms is less than 5%. Also, Baron is unable to solve sample problems 9 to 12 in less than 1000 seconds. With the investigations carried out in the two indicators of the objective function and the solution time, it is observed that GGWO obtained the highest profit on average. While GA had the lowest solution time among the solution methods. Figures 6 and 7 illustrate the best profit obtained by different solution methods and its solution time with different solution methods.

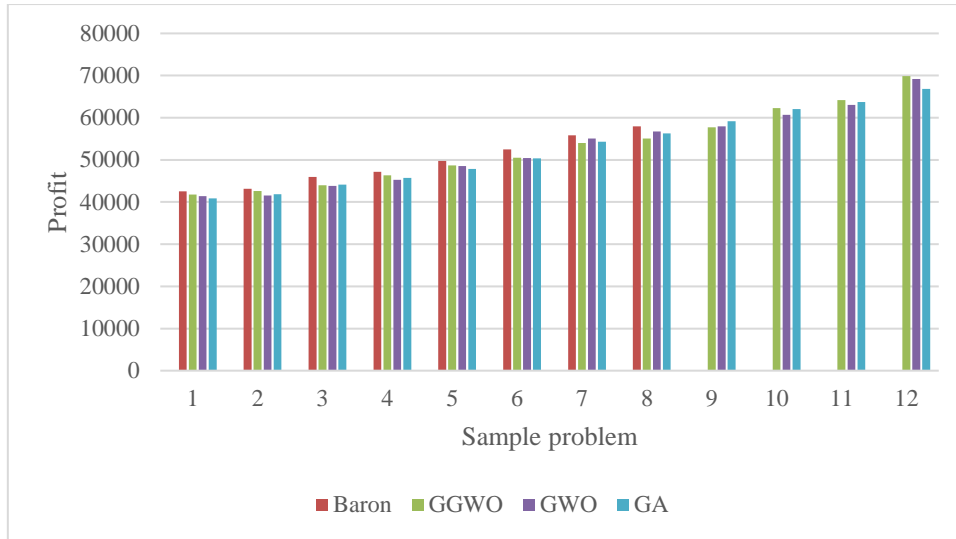


Figure 6. The best profit obtained in solving sample problems with different solution methods

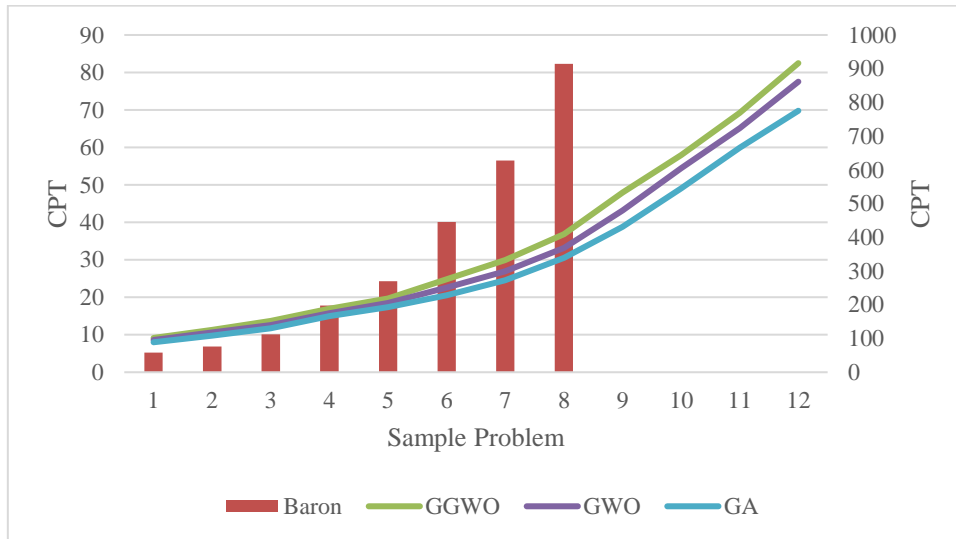


Figure 7. The best profit obtained in solving sample problems with different solution methods

The results of examining Figures 6 and 7 show that with the increase in the size of the sample problems, the time to solve the problem increased due to the complexity of the problem. However, the time to solve sample problems with meta-heuristic algorithms is less than Baron. Achieving the near-optimal solution by the proposed algorithms for the first sample problem is demonstrated in Figure 8. In this figure, the convergence of GGWO, GWO, and GA algorithms is shown in 200 iterations.

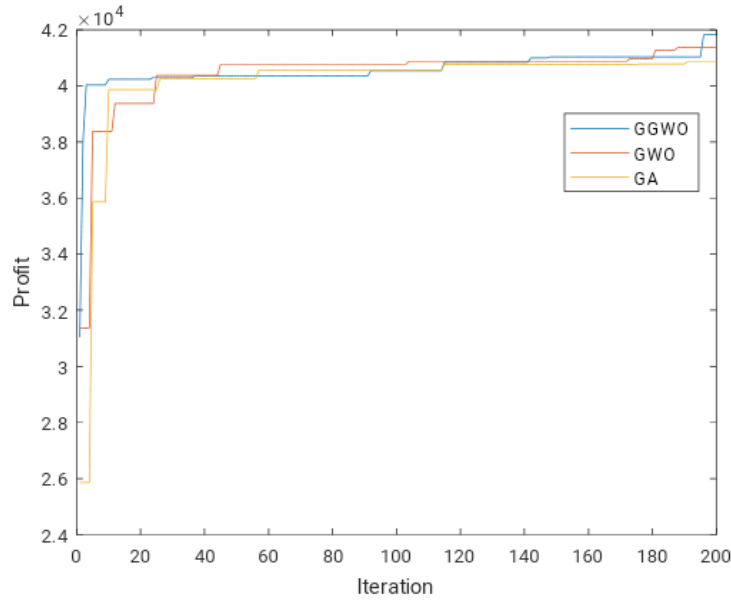


Figure 8. Convergence of meta-heuristic algorithms in solving sample problem (1)

By examining Figure 8, it can be seen that GGWO has reached convergence faster than other algorithms. This shows that the search for the justified space of the pricing problem in the SSC is higher in GGWO. These analyses indicate that GGWO has a higher efficiency than GA and GWO, while GA has a lower solution time than GWO and GGWO.

By analyzing this numerical example, the actual demand of customers for different products in each scenario is shown in Table 5.

Table 5. Actual customer demand in direct and indirect channel

Customer	Product	Direct Channel		Indirect Channel	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
1	1	256.67	264.33	183.67	192.33
2		294.00	321.67	196.00	181.33
3		287.00	309.33	214.00	207.00
4		258.67	300.00	204.00	210.00
5		328.33	333.33	172.67	196.00
1	2	324.67	283.67	204.67	228.33
2		269.00	273.00	201.33	183.00
3		306.00	323.00	218.00	182.00
4		316.67	255.33	233.00	195.67
5		298.00	277.67	183.00	205.00

Also, the product price for each time period and each product are according to Table 6. According to the results of Table 6, it can be seen that the average product price in the direct channel is lower than the average price in the indirect channel due to the lack of distribution centers.

Table 6. The average price of products in direct and indirect channels

Product	Direct Channel		Indirect Channel	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
1	275.11	253.44	313.66	319.33
2	249.55	263.78	312.31	329.55

After the analysis of different sample problems, the sensitivity analysis of the problem is discussed. These analyses show how sensitive the value of the objective function is to changes in the parameters of the problem. The most important parameters affecting the profit of the SSCN are the parameters of price elasticity of substitute products and price elasticity of demand

in direct and indirect channels. In Table 7, the sensitivity analysis of the profit of the SCN for the changes of the stated parameters is discussed.

Table 7. Profit changes of the SCN in different values of product price elasticity

Parameter	Changes	Profit	Demand in direct channel	Demand in indirect channel	Price in direct channel	Price in indirect channel
α'	-10%	42069.02	295.46	252.08	266.46	322.61
	0 %	42563.95	293.13	261.56	270.87	321.19
	+10%	42860.91	284.97	267.82	285.27	317.21
	+20%	43256.85	274.87	274.17	301.87	315.07
α	-10%	41871.05	287.37	267.11	286.31	319.07
	0 %	42563.95	293.13	261.56	270.87	321.19
	+10%	43355.84	298.10	254.86	259.43	325.50
	+20%	44048.74	307.51	249.46	255.78	328.32
β'	-10%	42365.98	288.78	265.88	281.72	315.00
	0 %	42563.95	293.13	261.56	270.87	321.19
	+10%	42761.92	299.05	256.08	266.50	325.21
	+20%	43157.87	303.83	249.22	235.54	328.33
β	-10%	41871.05	299.00	256.26	260.94	322.41
	0 %	42563.95	293.13	261.56	270.87	321.19
	+10%	43058.88	287.49	266.27	277.54	314.66
	+20%	43652.80	282.56	270.46	283.89	311.30

The results of the sensitivity analysis in Table 5 show that with the increase in the price elasticity of the substitute product in the direct channel, the product price increased in the direct channel and decreased in the indirect channel. This problem has led to the market bust in the direct channel and the boom market in the indirect channel. On the other hand, a different analysis of the increase in price elasticity of the substitute product occurred in the indirect channel. In this case, the profit in the direct channel is higher than the indirect channel due to lower transportation costs. However, with the increase in demand price elasticity in the direct channel, the product price decreased and the market boost took place. Meanwhile, with the increase in demand price elasticity in the indirect channel, the product price increased and led to the market bust. These analyses suggest that the increase in price elasticity of demand in the direct channel leads to less profit than the indirect channel. Figures 9 and 10 display the trend of changes in average price and demand, as well as profit earned in the analysis of price elasticity of substitute product and price elasticity of demand in direct and indirect channels.

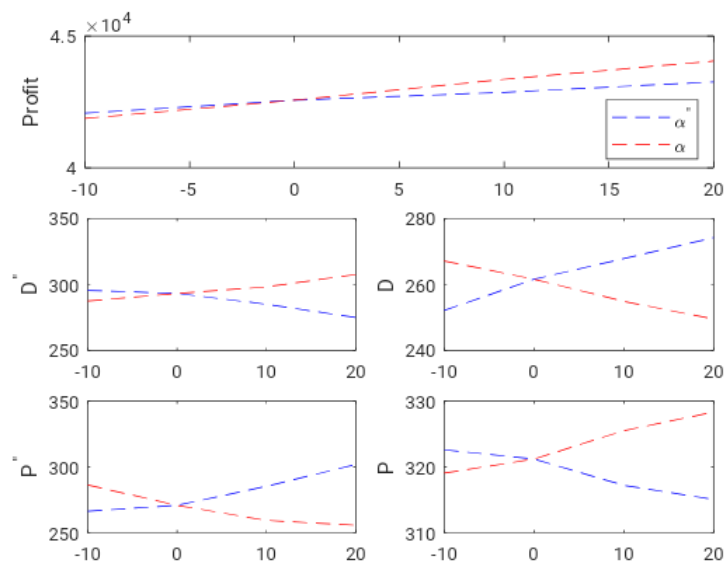


Figure 9. Trend of changes in the objective functions of the problem in the price elasticity of the substitute product

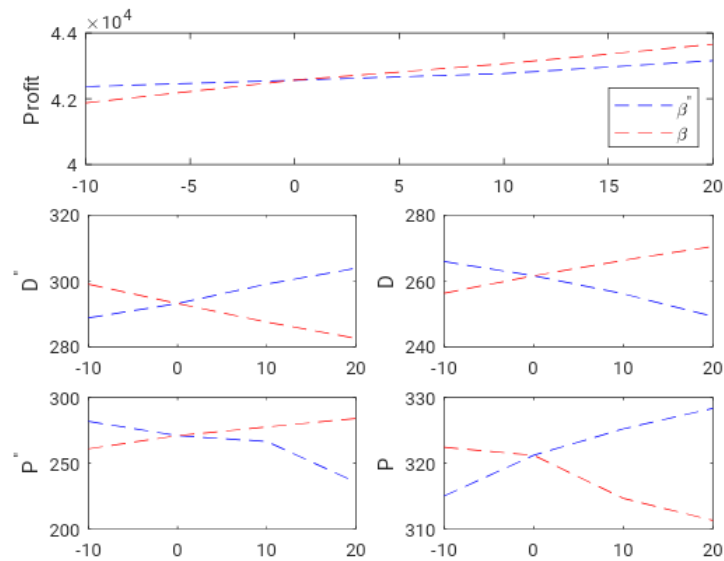


Figure 10. Trend of changes in the objective functions of the problem in price elasticity of demand

In another analysis, the probability of occurrence of market bust and boom scenarios is investigated. In these scenarios, it is assumed that the amount of demand in the SSN increased and the amount of production of products increased accordingly. In this case, the profit changes of the SSN are in accordance with Table 8. In this table, the higher the probability of the scenario occurring, the greater the demand and supply in the SSN.

Table 8. Profit changes of the SCN in the market boom and bust scenarios

Changes	Profit	Demand in direct channel	Demand in indirect channel	Price in direct channel	Price in indirect channel
0.1	40759.66	271.98	240.92	285.94	340.42
0.2	41036.84	276.98	245.48	280.06	337.26
0.3	41486.94	280.17	250.98	276.92	331.48
0.4	42015.36	286.48	258.43	273.18	326.48
0.5	42563.95	293.13	261.56	270.87	321.19
0.6	43015.94	298.68	266.41	266.48	319.27
0.7	43615.99	318.68	272.64	263.18	316.27
0.8	44248.62	328.84	279.92	260.40	311.20
0.9	44948.69	337.94	287.64	257.49	304.92

The results of Table 8 indicate that with the increase in the probability of the market boom scenario, the amount of demand increased both in the direct channel and in the indirect channel. This increase in demand has led to a decrease in sales prices. The result of this is an increase in the marginal profit from selling more products in the supply chain.

6. Conclusion and Future suggestions

In this paper, a product pricing problem in an SSC in the conditions of market boom and bust was discussed. The model designed in this paper adopted different decisions on location of facilities, determining the optimal number of transferred products, and product pricing in direct and indirect channels. To control the conditions of market boom and bust, different scenarios were considered and a two-level probabilistic programming method was used to deal with uncertain supply and demand. The designed model aims to maximize the total profit of the

supply chain, in which environmental and social issues are considered. To solve the model and obtain decision variables, the new algorithm of GGWO was used, using GA and GWO operators simultaneously. By analyzing various numerical examples, it was observed that with the increase in the price elasticity of the substitute product in the direct channel, the price of the product increased in the direct channel and decreased in the indirect channel. This problem has led to the market bust in the direct channel and the market boom in the indirect channel. On the other hand, a different analysis of the increase in price elasticity of the substitute product has occurred in the indirect channel. In this case, the profit in the direct channel is higher than the indirect channel due to lower transportation costs. On the other hand, with the increase in price elasticity of demand in the direct channel, the price of the product decreased and the demand increased. While the price elasticity of demand increased in the indirect channel, the price of the product increased and the demand decreased. These analyses indicate that the increase in price elasticity of demand in the direct channel leads to less profit than the indirect channel.

On the other hand, by analyzing different numerical examples, it was also observed that the new hybrid algorithm has reached convergence faster than other algorithms, even though the problem-solving time was longer than GA and GWO. These analyses show the efficiency of the proposed solution method compared to the existing solution methods. In this paper, in addition to considering the economic aspect, which aims to increase the total profit of the SSC, it helps managers to optimize the environmental and social aspects so that managers, in addition to considering the profit of their supply chain, can manufacture green products and increase the reliability of their products. Considering pricing helps managers to make optimal decisions to eliminate middlemen, and the results show that managers should sell their products directly in order to increase the profit of their supply chain and also increase customer satisfaction. While selling the product through sales centers would have a higher cost for customers and less profit for producers.

The presence of various limitations, including the lack of access to historical data, leads to the use of the fuzzy programming method along with the two-level probabilistic programming method as future suggestions. Also, the exponential nature of the problem-solving time in larger sizes suggests more developed hybrid algorithms for the analysis of the proposed model. Also, considering different sustainability objective functions can be proposed as another suggestion.

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