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DESIGNING A CLOTHING SUPPLY CHAIN NETWORK CONSIDERING PRICING AND DEMAND SENSITIVITY TO DISCOUNTS AND ADVERTISEMENT

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Abstract. These days, clothing companies are becoming more and more developed around the world. Due to the rapid development of these companies, designing an efficient clothing supply chain network can be highly beneficial, especially with the remarkable increase in demand and uncertainties in both supply and demand. In this study, a bi-objective stochastic mixed-integer linear programming model is proposed for designing the supply chain of the clothing industry. The first objective function maximizes total profit and the second one minimizes downside risk. In the presented network, the initial demand and price are uncertain and are incorporated into the model through a set of scenarios. To solve the bi-objective model, weighted normalized goal programming is applied. Besides, a real case study for the clothing industry in Iran is proposed to validate the presented model and developed method. The obtained results showed the validity and efficiency of the current study. Also, sensitivity analyses are conducted to evaluate the effect of several important parameters, such as discount and advertisement, on the supply chain. The results indicate that considering the optimal amount for discount parameter can conceivably enhance total profit by about 20% compared to the time without this discount scheme. When the optimized parameter is taken into account for advertisement, 12% is obtained as total profit.

Mathematics Subject Classification. 90C11, 90C90, 90C29.

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1. Introduction

Expanding an effective business requires designing an integrated supply chain [7, 14]. A supply chain is described as the sequence of processes concerned with the procurement of raw materials, production and then distribution of the products to customers. Some activities must be simultaneously coordinated by most of the supply chain actors including suppliers, manufacturers, retailers and customers. These activities can comprise designing the supply chain network, choosing the proper suppliers, deciding the production rate and distributing finished products to customers [1]. Many scholars designed supply chain network models based on real case

Keywords. Clothing supply chain, downside risk, discount-sensitive demand, advertising-sensitive demand, pricing.

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studies. Some of the investigated products in the previous researches are engine oil [38], polyethylene terephthalate bottles [36], blood supply chain [22], tire [59], evaporative cooler [6], automobile part manufacturing industry [45], automotive industry [56], self-healing polymers [46], food supply chain [63], textile [54] electronic products [55].

One of the oldest and most important manufacturing industries in the world is the clothing industry. In the 21st century, this industry has reached wider markets and set up selling masses of clothes to a wider range of people. Also, many clothing manufacturing companies obeyed to the globalization trend and extended their business around the world. The clothing industry plays a significant role in expanding economic performance of some countries. For example, according to an annual report released by Ministry of Textiles (the Government of India, 2010–2011), the clothing industry provides 14% of industrial manufacturing, 4% of the GDP and 17% to the country's export incomes. It also creates more than 35 million direct jobs for its population [26]. Also, statistics of Fashion United[1] indicate that the global value of fashion apparel market reached three trillion US dollars, 2% of GDP, 115.6 million job opportunities around the world by 2014 registering a 69% of growth since 1990 [57].

Because the markets competitiveness, risks, uncertainties and increased customer expectations to newer products with higher quality and reasonable price as well as faster response time, many industries are under pressure to manage their supply chains. The clothing industry is no exception. In fact, due to the changing customers' preferences, the life cycle of the products in clothing industry has been shortened and the uncertainties have been significantly increased [27]. There are several uncertainties in the clothing industry. The amount of demand and price are the two most important factors which have a major influence on clothing supply chain. Demand and price can be randomly increased or decreased during the planning horizon. Both lost sales and unsatisfied customers are the results of under-estimation of overall demand. Needless to say that over-estimation of demand could potentially end in high production and inventory costs [17]. The companies attempt to improve the performance of their manufacturing operations to meet demand with the minimum costs [21]. Selling price of the products depends on many factors like the raw material price and customer demand. Mostly, these factors are uncertain and this uncertainty affects the supply chain efficiency. Estimated price over the optimums leads to decreasing demand and thus reducing profit. However, price under-estimation results in decreasing the profit too. In this industry, proper pricing is an important issue due to increasing net profit and decreasing risk of having a low net profit. Moreover, because of the increase in the raw material price in the production and transportation costs, and also, the decrease in the selling price, the clothing industry is suffering [11]. Designing an efficient clothing supply chain network as a powerful tool can conceivably overcome these issues and help the managers to see a big picture to make insightful decisions [8].

This study addresses a multi-item, multi-period, bi-objective supply chain network comprising suppliers, manufacturing centers, retailers and outlet retailers. In the proposed network, quality products are directly sent to retailers and sold at reasonable price whereas the damaged, low-quality, and unsold retailers' products are transferred to outlet retailers. In these centers, products are sold at a lower price concerning retailers. To increase the total profit of the clothing network, two promoting factors namely advertising and discount play integral roles. In fact, demand rate is sensitive to them. These two factors were taken into consideration to lead to the better performance of the model. Besides this, this model was formulated based on scenarios due to the uncertainty in demand and selling price which aimed to maximize total profit and minimize the financial risk.

The rest of this paper is organized as follows. The literature review is discussed in Section 2; the network description and the problem formulation are provided in Section 3; the solution approach is presented in Section 4; a case study is proposed in Section 5; and finally, conclusions and future study suggestions are given in Section 6.

[1]https://fashionunited.com/global-fashion-industry-statistics.

2. Literature review

In recent years, different aspects of the clothing industry have been investigated. For instance, Safra [42] proposed an integrated method in both tactical and operational planning for manufacturing and distributing of clothing products. In their research, two mathematical models were expanded to solve the problem with the goal of minimizing the total costs and meeting customer demand on time. Jakhar [27] considered a sustainable supply chain in the apparel industry. Survey data from 278 business organizations of the Indian clothing supply chain networks were applied and an integrated approach of structural equation modeling, fuzzy analytical hierarchy process and fuzzy multi-objective linear programming were presented. Felfel *et al.* [16] proposed a multi-product multi-site supply chain model for textile and apparel industry in Tunisian. They presented a multi-objective optimization model to minimize the total costs and maximize the goods quality level simultaneously. More recently, Liu *et al.* [29] developed a nonlinear programming model that defines several attributes of the distribution networks while minimizing the annual operational costs. All the articles mentioned above assumed deterministic modeling approaches and all parameters have a certain amount known in advance. In practice, the clothing supply chain models are defined with some uncertain parameters. Customer demand and selling price are the two most important among these parameters. Only few papers in the clothing industry have considered one stochastic parameter or more in their network ([3, 17, 31]. See also [10]).

In order to get closer to the real world, considering a set of probabilistic scenarios is extremely helpful. According to the condition of each scenario, the decision-maker (DM) can take the optimal decision as the output of the decision-making model [15]. Some authors proposed novel metrics to decrease financial risk under uncertain situations. Downside risk (DRisk) is an efficient method that manages uncertainty and minimizes the probability of achieving a low net profit. This attractive method is defined as a deviation between the total profit value of scenario and the target profit. The choice of adopting the DRisk measure has been based on the findings of the works of You *et al.* [60] who discussed several risk measures within a supply chain design and reached the conclusion that the downside risk model is effective from the modeling viewpoint and in the same time the most efficient one to control the risk in a stochastic setting [32]. This same conclusion has been confirmed recently by Felfel *et al.* [16] who successfully applied the DRisk measure even in the context of textile supply chain design. Ramezani *et al.* [40] considered the general logistics network quantity, DRisk and profit as the objective functions. Fathollahi-Fard *et al.* [14] provided a stochastic closed-loop supply chain model and optimized DRisk and total costs. Some test problems related to the food industry are reported. Pavão *et al.* [35] proposed a two-level multi-objective optimization model for heat exchanger networks. They applied the DRisk for managing financial risks controlling the costs. Fathollahi-Fard *et al.* [15] designed a stochastic mixed-integer programming model (MILP) considering three objective functions, DRisk, economical aspects and social objectives. Felfel *et al.* [17] presented a multi-product multi-period supply chain model under demand and price uncertainties. They considered two objective functions, maximizing the expected profit and minimizing the financial risk measured. Their model was evaluated by a case study for textile and apparel industry in the south of Tunisia. In this research, similar procedures in Iran are performed with the exception that we consider, moreover, discount and advertising factors.

Likewise, pricing is another important subject in clothing industry. In the presented study, price and demand are considered as decision variables that depend on discount and advertising. Some articles consider a fixed or random demand during the planning horizon. In the majority of studies, the impact of dependent variables on the demand function is not considered. Some recent research assume that demand is price-sensitive. For instance, Adeinat and Ventura [1] considered a serial supply chain with multiple suppliers and price-sensitive demand. Jadidi *et al.* [25] developed a single period mathematical model and examined a joint pricing and inventory decision problem. In their model, product demand is stochastic and price-dependent. Taleizadeh and Noori-Daryan [50] proposed a three-level supply chain comprising a supplier, a manufacturer and several retailers. The purpose of their study was to minimize the total costs of the supply chain network under price-sensitive demand. Salehi *et al.* [44] designed a mixed-integer non-linear programming model with stochastic price-sensitive demands. Focused on Internet-based business, their model considered location, allocation, order quantities, pricing and refund price decisions to optimize the total profit. Giri and Sharma [18] presented a two-level supply chain including one manufacturer and two competing retailers with advertising cost dependent demand. Both retailers compete with each other for advertisements with different sales expenses. Seyed Esfahani *et al.* [48] and Xie and Wei [58] considered a particular status of supply chain. Their study includes one manufacturer and one retailer for which demand is dependent on both price and advertisement. They applied a game-theoretic approach to get optimal decisions and reach maximum profit while the current study is designed for a general supply chain network with a manufacturer and several retailers. Moreover, the uncertainty in demand and price is considered due to the importance of these factors. As well as, some other issues such as pricing, advertising-sensitive demand and a newly-coined expression "discount-sensitive demand" are considered. Discount and advertising are two important issues that have a significant influence on demand rate directly. None of the previous studies has investigated these two factors at the same time. Demand rate also indirectly is influenced by price. To illustrate the reliability and applicability of the proposed model, a real case study of the clothing industry in Iran is presented to maximize the total profit and minimize the DRisk which have not been considered in any of the prior clothing case studies simultaneously. Some studies considered different concepts of clothing supply chain in Iran. For instance, Karami *et al.* [28] presented a three-step integrated approach to face with the supplier selection and evaluation problem in the garment supply chain. Due to the importance of customer satisfaction and quick-response, their model is designed considering the raw material suppliers' performance to increase the efficiency of garment supply chain model. Amindoust and Saghafinia [5] proposed a sustainable network for textile and clothing industry. They focused on sustainability aspects in supplier selection and applied a modular fuzzy inference system method in order to solve it. However, none of the Iranian clothing industry investigated pricing, discount, advertisement and risk, simultaneously.

Nowadays the pricing problem has attracted many companies' attention due to the greatest impact on supply chain profits, on enterprises' revenues and on demand rate [62]. In some studies, supply chain members had been investigated through various pricing policies [33]. Shi *et al.* [49] presented a multi-product newsvendor problem. They considered retailers' pricing policies and supplier quantity discount. The goal of their study was to maximize the retailers' expected profit as well as determining the ordering quantities and selling prices of the products. Maiti and Giri [30] proposed two-period pricing and decision strategies supply chain with price-dependent demand. The demand rate is related to the selling prices during the current and previous periods. Dey *et al.* [13] considered a non-linear model with a constraint problem. In their model, demand is price- and quality-sensitive together in a smart production system. Their model was optimized and evaluated with a numerical example.

2.1. Research gap

This study is focused on one of the prestigious clothing companies in Iran. According to this company, a comprehensive framework for a four-level, multi-product, multi-period, bi-objective supply chain model is designed. The members of the proposed network include a set of suppliers, manufacturing centers, retailers and outlet retailers. In the presented model, the demand rate is calculated based on two factors, advertising-sensitive demand and discount-sensitive demand. Since, advertising and discount schemes have profound influence on demand rate, planning out for their budget seems to be vital. The selling price of the products is considered as a decision variable which depends on the discount scheme in addition to the initial price uncertainty. It should be noted that the initial price of the products is determined based on the demands and supply chain costs such as raw material price, transportation, inventory cost and so on. A scenario-based stochastic programming model under demand and selling price uncertainty is presented to maximize the expected profit. Also, DRisk is incorporated into the presented model to minimize the probability of achieving a low profit. To clarify the differences of this study concerning previous ones, a brief review of articles published in the recent decade is presented in Table 1. In this table, articles are classified and compared in terms of assumptions and concepts such as items, periods, objective functions, uncertainty, pricing, risk, discount, advertisement, solution methods and case study. Some of the assumptions and concepts considered in these articles are indicated with the sign

TABLE 1. A brief review of related papers to demonstrate research gaps.

Researcher	Year	Multi-item	Multi-period	Objective function	Type of uncertainty	Pricing	Risk	Discount	Advertisement	Solution method	Case study
Taleizadeh *et al.*	2016			Maximizing total profit	Scenario-based	*		*		Game-theoretic approach	
Pavão *et al.*	2017			Minimizing total cost Minimizing downside risk	Scenario-based		*			ε-constraint Meta-heuristic approaches	Heat exchanger
Zabihi and Bafruei	2017			Optimal price Optimal discount time		*		*		Heuristic algorithm	
Nourmohamadi Shalke *et al.*	2018	*	*	Minimizing total cost Maximize the total economic qualitative score Maximize the total environmental score Maximize the total social score				*		Goal programming	Packaging food products
Rahimi *et al.*	2018	*	*	Maximizing total profit Maximize the new brands' sales	Robust			*		LP-metrics	Food
Felfel *et al.*	2018	*	*	Maximizing total profit Minimizing financial risk	Robust		*			ε-constraint	Textile and apparel
Dey *et al.*	2019			Maximizing total profit		*				Analytical model	
Bhuniya *et al.*	2019	*		Maximizing total profit		*			*	Iterative method	
Taleizadeh *et al.*	2020			Maximizing total profit	Fuzzy	*			*	Stackelberg game model	
Alizadeh *et al.*	2020	*		Maximizing total profit Minimizing biological risks			*			Bounded De Novo programming	Medical waste
Sarkar *et al.*	2020		*	Maximizing total profit	Fuzzy	*			*	Sequential quadratic programming	
Rezaei *et al.*	2020	*	*	Maximizing total profit Maximizes the production of new products Maximizes the value of CRM cost	Robust				*	Goal programming	Desktop gas and stove ovens
This study	2020	*	*	Maximizing total profit Minimizing downside risk	Scenario-based	*	*	*	*	Weighted normalized goal programming	Clothing

"*" along with the objective functions, uncertainty and solution methods explained in the table. What stands out from the table is the following:

(1) Some authors designed and solved their models by numerical examples whilst others considered a real case study and solved real-world issues.
(2) The planning horizon of models can be considered as a single-period or multi-period model. A single period is performed for constant and similar conditions with negligible parameter fluctuations whereas multi-period ones are implemented for long-term planning horizons with parameter turbulent.
(3) Some models are concentrated on single-item while others stress on multi-item to meet the needs of the world in reality.
(4) Some models are designed as a single-objective function while others considered a multi-objective function. In multi-objectives, different goals are optimized simultaneously. Therefore, these models are more realistic.
(5) Some research applied different concepts including pricing, risk, discount and advertisement in their models, but none of them investigated all these concepts simultaneously.

The precise analysis of Table 1 determines some gaps, indicating the importance of this study. The integral purposes of this paper are as follows:

– This study optimizes total profit and DRisk simultaneously in a stochastic programming framework.
– Controlling uncertainties of the problem by means of the DRisk approach is one of the major concerns of the proposed study.
– The initial demand and price are uncertain and are defined based on scenarios.
– The final price as a decision variable depends on a binary variable representing the discount.
– Actual demand as a decision variable depends on two integral factors, discount and advertising.
– A real case study for the clothing industry with the corresponding sensitivity analyses is conducted in Iran to illustrate the validity and efficiency of the proposed model.

3. Network description and problem formulation

The proposed supply chain network comprises a set of suppliers, manufacturing center, retailers and outlet retailers. The structure of the bi-objective, multi-period, multi-product, supply chain network has been demonstrated in Figure 1. In this network, the raw materials are transported from the suppliers to the manufacturing center. Afterward, the products are produced at the manufacturing center and are transported to the retailers. Some products are damaged during the production, warehousing and transportation processes. Also, some of the products are produced with lower quality. These products are transported to the outlet retailers and are sold at a lower price. The retailers and outlet retailers sell the products to the final customers. If the retailers could not sell the products during three consecutive periods, then the products would be transferred to the outlet retailers.

3.1. Assumptions

According to Figure 1, a multi-level supply chain model including suppliers, manufacturer, retailers and outlet retailers are designed The following assumptions are considered in the presented mathematical model.

– The supply chain network is designed as a multi-item model and the proposed model is considered to have two objective functions.
– There are several suppliers and one manufacturing center in the proposed model. Moreover, two types of retailers are defined in the proposed supply chain network; retailers and outlet retailers. A quality of each product is transported to retailers and sold at a reasonable price. Low quality and defective products (which are identified during the quality inspection phase inside the manufacturing center) as well as retailers' unsold products at the end of each season are sent to one of the outlet retailers and sold at a lower price.
– The locations of all facilities are known.

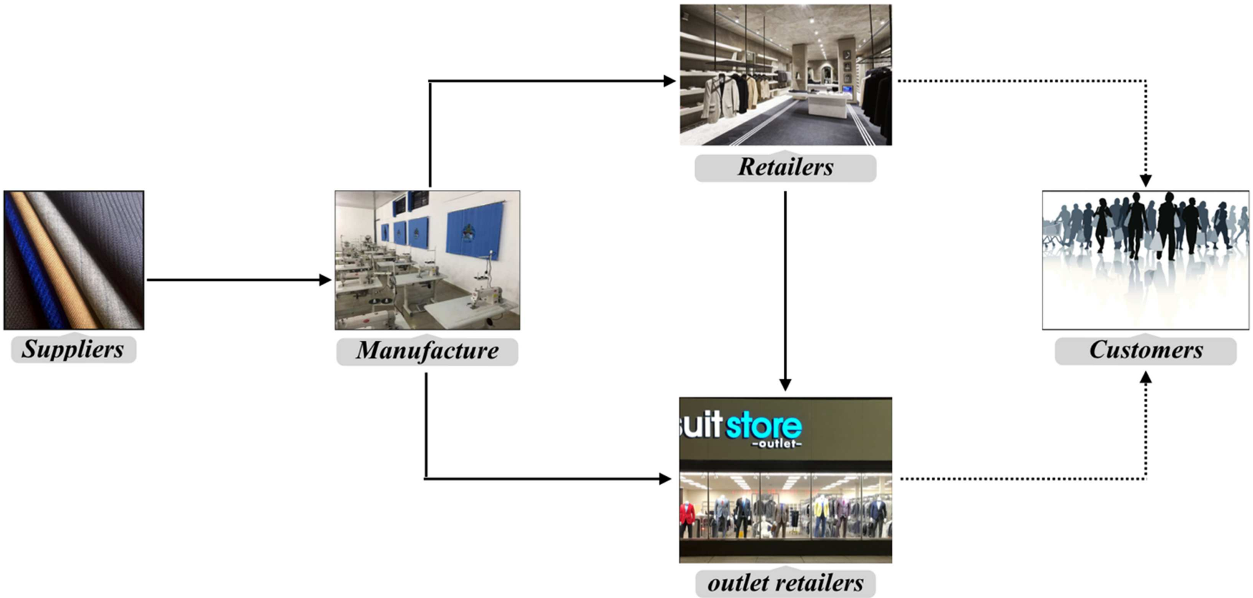


FIGURE 1. The proposed supply chain network.

- The planning horizon of the presented model is designed for a year (twelve months).
- The unfulfillment demand in a period won't be transferred to the next period and it is considered as a lost sale.
- The capacity of suppliers, manufacturing center, retailers and outlet retailers is limited.
- The proportion of products which transported from the manufacturing center to outlet retailers (defective products) is predetermined and obtained based on historical data from the factory.
- The demand is uncertain and directly dependent on advertisement and discount parameters and indirectly is influenced by price.
- The rest parameters *e.g.* transportation cost, inventory cost, lost sale cost and so on are known and fixed.
- The model is a case-based forward supply chain network. This model is designed for the clothing industry in Iran. However, without any changes in overall, throughout minor revisions, it can be applied in other industries.

3.2. Mathematical modeling

The proposed network is formulated as a MILP model. Indices, parameters and decision variables are defined as follows

Constants

S Number of suppliers.
R Number of retailers.
O Number of outlet retailers.
M Number of raw materials.
J Number of products types.
K Number of discounts.
C Number of scenarios.
T Number of periods.

Indices

s	Index of suppliers $(1, \ldots, S)$.
r	Index of retailers $(1, \ldots, R)$.
o	Index of outlet retailers $(1, \ldots, O)$.
m	Index of raw materials $(1, \ldots, M)$.
j	Index of products types $(1, \ldots, J)$.
k	Index of discounts $(1, \ldots, K)$.
c	Index of scenarios $(1, \ldots, C)$.
$t = t' \cup t''$	Index of periods $(1, \ldots, T)$.

Parameters

d_{jrct}	Initial demand for product j at retailer r under scenario c before considering discounts and advertising in period t *(in items or numbers)*.
d'_{joct}	Initial demand for product j at outlet retailers under scenario c before considering discounts and advertising in period t *(in items or numbers)*.
p_{mst}	Price of raw material m supplied by supplier s during period t *(dollars)*.
tm_{ms}	Transportation cost per unit of raw material m transported from supplier s to the manufacturing center *(dollars)*.
tr_{jr}	Transportation cost per unit of product j transported from the manufacturing center to retailer r *(dollars)*.
to_{jo}	Transportation cost per unit of product j transported from the manufacturing center to outlet retailers *(dollars)*.
tj_{jro}	Transportation cost per unit of product j transported from retailer r to outlet retailers *(dollars)*.
p'_j	Production cost per unit of product j produced in the manufacturing center *(dollars)*.
i_{mt}	Inventory holding cost per unit of raw material m held in the manufacturing center in period t *(dollars)*.
im_{jt}	Inventory holding cost per unit of product j held in the manufacturing center in period t *(dollars)*.
ic_{jrt}	Inventory holding cost per unit of product j held in retailer r in period t *(dollars)*.
ic'_{jot}	Inventory holding cost per unit of product j held in outlet retailer o in period t *(dollars)*.
l_{jt}	Lost sales cost per unit of product j in the retailers in period t *(dollars)*.
l'_{jt}	Lost sales cost per unit of product j in the outlet retailers in period t *(dollars)*.
pr_{jct}	Selling price per unit of product j sold by the retailers to the customers under scenario c before applying the discount in period t *(dollars)*.
po_{jct}	Selling price per unit of product j sold by the outlet retailers to the customers under scenario c before applying the discount in period t *(dollars)*.
cs_{ms}	Capacity of supplier s for raw material m *(meter or number)*.
cm_m	Capacity of the manufacturing center for raw material m *(meter or number)*.
cp_{jt}	Capacity of the manufacturing center for product j *(number)*.
cr_{jr}	Capacity of retailer r for product j *(number)*.
co_{jo}	Capacity of outlet retailer $o$for product j *(number)*.
b_{jm}	Raw material m required for producing one unit of product j (bill of material) *(meter or number)*.
β_{jt}	Fraction of product j transferred from the manufacturing center to the outlet retailers in period t *(number)*.
δ_{kjt}	Discount rate k for product j in period t *(as %)*.
α	Discount sensitivity index for demand *(as %)*.
λ	Advertising sensitivity index for demand *(as %)*.
δ_t	Maximum advertising cost in period t *(dollars)*.
f	A percentage of the supply chain profit as the share of retailers and outlet retailers *(as %)*.
ir_{jr}	Initial inventory of product j for retailer r *(number)*.
io_{jo}	Initial inventory of product j for outlet retailer o *(number)*.
δ_c	Occurrence probability of scenario c where $\sum_c \rho_c = 1$.
η	A large positive number.

Decision variables

Z_c	Value of total profit of scenario c *(dollars)*.
QS_{mst}	Quantity of raw material m purchased from supplier s by the manufacturing center in period t *(number)*.
QM_{jt}	Quantity of product j produced in the manufacturing center in period t *(number)*.
QR_{jrt}	Quantity of product j transported from the manufacturing center to retailer r in period . t *(number)*
QO_{jot}	Quantity of product j transported from the manufacturing center to outlet retailer o in period t *(number)*.
Q_{jroct}	Quantity of product j transported from retailer r to outlet retailer o under scenario c in period t *(number)*.
QQ_{jrct}	Quantity of product j sold by retailer r to the customers under scenario c in period t *(number)*.
QQ'_{joct}	Quantity of product j sold by outlet retailer o to the customers under scenario c in period t *(number)*.
MV_{mt}	Inventory of raw material m in the warehouse of manufacturing center at the end of period t *(meter or number)*.
JV_{jt}	Inventory of product j in the warehouse of manufacturing center at the end of period t *(meter or number)*.
RV_{jrct}	Inventory of product j in warehouse of retailer r under scenario c at the end of period t *(meter or number)*.
OV_{joct}	Inventory of product j in warehouse of outlet retailer o under scenario c at the end of period t *(meter or number)*.
DD_{jrct}	Demand of retailer r for product j under scenario c in period t *(number)*.
DD'_{joct}	Demand of outlet retailer o for product j under scenario c in period t *(number)*.
LS_{jrct}	Lost sales of product j in retailer r under scenario c in period t *(number)*.
LS'_{joct}	Lost sales of product j in outlet retailer o under scenario c in period t *(number)*.
PP_{jct}	Selling price per unit of product j by the retailers under scenario c in period t *(dollars)*.
PP'_{jct}	Selling price per unit of product j by the outlet retailers under scenario c in period t *(dollars)*.
Pk_{kct}	Equal 1 if discount k is considered under scenario c in period t, and equal 0 otherwise.
VR_{rct}	Share of retailer r under scenario c in period t *(dollars)*.
VO_{oct}	Share of outlet retailer o under scenario c in period t *(dollars)*.
γ'_t	Advertising cost in period t *(dollars)*.

Clearly, some of the above-mentioned variables are scenario-based decision variables, such as those related to retailer and outlet-retailer sales and inventories, because of the random nature due to the uncertainty characterizing the demand and price in these centers.

Objective function

$$\operatorname{Max} E\ (Z) = \sum_c \rho_c Z_c \tag{3.1}$$

$$Z_c = \mathrm{Revenue}_c - \mathrm{Costs}_c \tag{3.2}$$

$$\mathrm{Revenue}_c = \sum_j \sum_r \sum_t \mathrm{PP}_{jct}\mathrm{QQ}_{jrct} + \sum_j \sum_o \sum_t \mathrm{PP}'_{jct}\mathrm{QQ}'_{joct} \tag{3.3}$$

$$\begin{aligned}\mathrm{Costs}_c = {} & \sum_m \sum_s \sum_t (p_{mst} + tm_{ms})\,\mathrm{QS}_{mst} + \sum_j \sum_t p'_j \mathrm{QM}_{jt} + \sum_j \sum_r \sum_t tr_{jr}\mathrm{QR}_{jrt} \\ & + \sum_j \sum_o \sum_t to_{jo}\mathrm{QO}_{jot} + \sum_j \sum_r \sum_o \sum_t tj_{jro}Q_{jroct} + \sum_m \sum_t i_{mt}\mathrm{MV}_{mt}\end{aligned}$$

$$+\sum_j\sum_t im_{jt}\mathrm{JV}_{jt}+\sum_j\sum_r\sum_t ic_{jrt}\mathrm{RV}_{jrct}+\sum_j\sum_o\sum_t ic'_{jot}\mathrm{OV}_{joct}+\sum_r\sum_t \mathrm{VR}_{rct}$$
$$+\sum_o\sum_t \mathrm{VO}_{oct}+\sum_t\gamma'_t+\sum_j\sum_r\sum_t l_{jt}\mathrm{LS}_{jrct}+\sum_j\sum_o\sum_t l'_{jt}\mathrm{LS}'_{joct}. \tag{3.4}$$

Constraints

$$\mathrm{QS}_{mst}\le cs_{ms} \qquad \forall m,s,t \tag{3.5}$$
$$\mathrm{MV}_{mt}\le cm_m \qquad \forall m,t \tag{3.6}$$
$$\mathrm{JV}_{jt}\le cp_{jt} \qquad \forall j,t \tag{3.7}$$
$$\mathrm{RV}_{jrct-1}\le cr_{jr} \qquad \forall j,r,c,t \tag{3.8}$$
$$\mathrm{OV}_{joct-1}\le co_{jo} \qquad \forall j,o,c,t \tag{3.9}$$
$$\mathrm{MV}_{mt}+\sum_j b_{jm}\mathrm{QM}_{jt}=\sum_s \mathrm{QS}_{mst}+\mathrm{MV}_{mt-1} \qquad \forall m,t \tag{3.10}$$
$$\mathrm{JV}_{jt-1}+\mathrm{QM}_{jt}=\mathrm{JV}_{jt}+\sum_r \mathrm{QR}_{jrt}+\sum_o \mathrm{QO}_{jot} \qquad \forall j,t \tag{3.11}$$
$$\sum_o \mathrm{QO}_{jot}\le \beta_{jt}\mathrm{QM}_{jt} \qquad \forall j,t \tag{3.12}$$
$$\mathrm{QR}_{jrt}+\mathrm{RV}_{jrct-1}=\mathrm{RV}_{jrct}+\sum_o Q_{jroct}+\mathrm{QQ}_{jrct} \qquad \forall j,r,c,t \tag{3.13}$$
$$\mathrm{QO}_{jot}+\sum_r Q_{jroct}+\mathrm{OV}_{joct-1}=\mathrm{OV}_{joct}+\mathrm{QQ}'_{joct} \qquad \forall j,o,c,t \tag{3.14}$$
$$\sum_o Q_{jroct}=\mathrm{RV}_{jrct-1} \qquad \forall j,r,c,t\in t \tag{3.15}$$
$$Q_{jroct}=0 \qquad \forall t\in t \tag{3.16}$$
$$\mathrm{RV}_{jrct}=ir_{jr} \qquad \forall j,r,c,t=0 \tag{3.17}$$
$$\mathrm{OV}_{joct}=io_{jo} \qquad \forall j,o,c,t=0 \tag{3.18}$$
$$\mathrm{DD}_{jrct}=d_{jrct}\left(1+\alpha\sum_k \mathrm{PK}_{kct}\delta_{kjt}\right)\left(1+\lambda\frac{\gamma_t}{\gamma'_t}\right) \qquad \forall j,r,c,t \tag{3.19}$$
$$\mathrm{DD}'_{joct}=d'_{joct}\left(1+\alpha\sum_k \mathrm{PK}_{kct}\delta_{kjt}\right)\left(1+\lambda\frac{\gamma_t}{\gamma'_t}\right) \qquad \forall j,o,c,t \tag{3.20}$$
$$\mathrm{QQ}_{jrct}=\mathrm{DD}_{jrct}-\mathrm{LS}_{jrct} \qquad \forall j,r,c,t \tag{3.21}$$
$$\mathrm{QQ}'_{joct}=\mathrm{DD}'_{joct}-\mathrm{LS}'_{joct} \qquad \forall j,o,c,t \tag{3.22}$$
$$\mathrm{PP}_{jct}=pr_{jct}-\left[\sum_k \mathrm{PK}_{kct}\delta_{kjt}pr_{jct}\right] \qquad \forall j,c,t \tag{3.23}$$
$$\mathrm{PP}'_{jct}=po_{jct}-\left[\sum_k \mathrm{PK}_{kct}\delta_{kjt}pr_{jct}\right] \qquad \forall j,c,t \tag{3.24}$$
$$\mathrm{VR}_{rct}=f\sum_j \mathrm{PP}_{jct}\mathrm{QQ}_{jrct} \qquad \forall r,c,t \tag{3.25}$$
$$\mathrm{VO}_{oct}=f\sum_j \mathrm{PP}'_{jct}\mathrm{QQ}'_{joct} \qquad \forall o,c,t \tag{3.26}$$

$$\gamma_t \leq \gamma'_t \qquad \forall t \tag{3.27}$$

$$\mathrm{PK}_{kct} \leq \eta \times \delta_{kjt} \qquad \forall k, j, c, t \tag{3.28}$$

$$\sum_k \mathrm{PK}_{kct} \leq 1 \qquad \forall c, t \tag{3.29}$$

$$\mathrm{PK}_{kct} \in \{0, 1\} \qquad \forall k, c, t \tag{3.30}$$

$$\begin{aligned}&\mathrm{PP}_{jct}, \mathrm{PP}'_{jct}, \mathrm{JV}_{jt}, \mathrm{RV}_{jrct}, \mathrm{OV}_{joct}, \mathrm{MV}_{mt}, \gamma_t,\\ &\mathrm{QQ}_{jrct}, \mathrm{QQ}'_{joct} \geq 0, \mathit{Integer}\end{aligned} \qquad \forall m, j, r, o, c, t \tag{3.31}$$

$$\begin{aligned}&\mathrm{QS}_{mst}, \mathrm{QM}_{jt}, \mathrm{QR}_{jrt}, \mathrm{QO}_{jot}, Q_{jroct}, \mathrm{PK}_{kct}, \mathrm{VR}_{rct}, \mathrm{VO}_{oct},\\ &\mathrm{DD}_{njrct}, \mathrm{DD}'_{joct}, \mathrm{LS}_{jrct}, \mathrm{LS}'_{joct} \geq 0\end{aligned} \qquad \forall m, j, r, o, k, s, c, t. \tag{3.32}$$

The first objective function of the proposed model is to maximize the expected value of the total profit over all scenarios defined as revenue minus costs. The revenue consists of retailers and outlet retailers' sales. Costs comprise purchasing cost of raw material, transportation, production, inventory holding, advertising and retailers' and outlet retailers' share. The value of the first objective function is defined according to equations (3.1)–(3.4). The second objective function will be introduced in Section 3.1.

The model constraints are represented in equations (3.5)–(3.32). Constraints (3.5)–(3.9) are the warehouse capacity constraints for the raw materials of the suppliers and manufacturing center, the products of the manufacturing center, retailers and outlet retailers, respectively. Constraints (3.10)–(3.16) are the flow balance equations between facilities. Constraints (3.17) and (3.18) show the initial inventory of the retailers and outlet retailers, respectively. In constraints (3.19) and (3.20) the demand functions of the model expressed in terms of the initial demand, as well as the amount of discount and advertising. In these equations, the impact of discounts and advertisements on increasing demand are taken into account. α and λ are discount and advertising sensitivity factors, respectively. Increasing the value of parameter α indicates more impact of a discount on the demand. Likewise, increasing the λ value, advertising will more affect the demand. Constraints (3.21) and (3.22) ensure that the number of products sold by the retailers and outlet retailers are equal to the demand minus shortage. Constraints (3.23) and (3.24) show the selling price of the products considering the discount rate in each period. The price variables must have integer values. Considering the discount, the final price would be with a decimal. So, in these equations, the floor function is used. In constraints (3.25) and (3.26) the percentage of total profit is considered as the share of the retailers and outlet retailers. Constraint (3.27) indicates the maximum cost amount allowed for advertising. Constraints (3.28)–(3.30) are related to discounts. Constraint (3.28) determines which discount plan can be considered for each product and in each period. Constraint (3.29) ensures that, for each product and in each period, there is at most one type of discounts. Constraint (3.30) ensures the binary constraint on the corresponding discount variables. Domains of the decision variables are expressed by means of constraints (3.31) and (3.32).

Model (3.1)–(3.32) results to be a mixed-integer non-linear model whose size increases with the number of actors involved in the supply chain, the number of raw materials, products, discount rates, scenarios and number of periods. In the proposed model, demand constraints (constraints (3.19) and (3.20)), price constraints (constraints (3.23) and (3.24)) and constraints related to share of retailers (constraints (3.25) and (3.26)) are causing the non-linearity. The linearization of the model will be discussed in Appendix A.

For a better understanding of the effect of changing the proportion of α (discount sensitivity index for demand) and λ (advertising sensitivity index for demand) on increasing demand, an illustrative example with one retailer, one product, one scenario and one period is brought in Table 2. What stands out from the table is that the demand rate increments with the increase of both discount and advertising.

Table 2. Illustrative example showing the impact of discount and advertising on the demand function.

	$\alpha\,(\%)$	$\lambda\,(\%)$	$\mathrm{DD}_{jrt}\,(number)$
	0	0.2	204
$\gamma_t = \$10\,000\,000$	0.3	0	212
$\gamma_t = \$100\,000\,000$	0	0	200
$d_{jrct} = 200\,(numbers)$	0.3	0.2	216
$\delta_{kjt} = 0.2\,(\%)$	1	0	240
	0	1	220
	1	1	264

4. Solution approach

According to the objective function and constraints mentioned above and in order to deal with uncertainty and unfavorable scenarios, the risk management approach is applied. DRisk is considered as an effective method to manage the uncertainty and is incorporated into the model as a second objective function. To solve the resulting bi-objective model, the weighted normalized goal programming method is utilized.

4.1. Downside risk management

Risk management is one of the most important issues when designing a stochastic programming model to manage natural uncertainties, unpleasant and low-profit scenarios. The DRisk management approach has been adopted to help the DMs. So, it is considered as the second objective function in the mathematical model. The new objective function minimizes the risk of having low total profit, where Ω is the minimum quantity for the expected profit and φ_c is considered the deviation between the profit value of scenario c and the target profit Ω. In fact, the DRisk is the expected value of the positive variable φ_c. The DRisk management model can be formulated as follows.

$$\text{Min Risk} = \sum_c p_c \varphi_c \tag{4.1}$$

$$\varphi_c \geq \Omega - Z_c \qquad \forall c \tag{4.2}$$

$$\varphi_c \geq 0 \qquad \forall c. \tag{4.3}$$

4.2. Weighted normalized goal programming

A multi-objective model includes two or more objective functions which are usually in conflict with each other. This means that optimizing one of them leads to worsening the other goals and all of the objectives cannot be optimized simultaneously. So, the best solution regarding the priority of the objectives and the optimal balance between them should be identified. For this purpose, multi-objective optimization methods are used. In this research, the bi-objective model turns into a single one. The weighted normalized goal programming model is one of the most important multi-objective solution approaches [22]. In this method, undesirable deviations between the actual results and their aspiration levels are minimized. Some values are determined as the expectation level for objective functions of the problems in goal programming. Afterward, the sum of deviations from these levels is minimized. Goal programming problems are formulated based on three concepts as follow [2, 37].

– Deviation variables: values that targets are achieved less or more than their desired quantity are deviations. d_σ^+ and d_σ^- are positive and negative deviation from of the goal σ, respectively.
– Priority factors: optimize the goals of the model considering their priorities and importance.

– Weighting deviation variables at the same level of priority: deviation variables are weighted according to their priority level. The basic structure of weighted normalized goal programming model is as follows:

$$\min = \sum_{\sigma} W_{\sigma}\left(\frac{d_{\sigma}^{+}+d_{\sigma}^{-}}{g_{\sigma}}\right)$$
$$h_u(X) = (\leq \text{ or } \geq)\, 0 \qquad \forall u$$
$$Z_{\sigma}(X) - d_{\sigma}^{+} + d_{\sigma}^{-} = g_{\sigma} \qquad \forall \sigma$$
$$d_{\sigma}^{+}, d_{\sigma}^{-} \geq 0 \qquad \forall \sigma$$

where $h_u(X)$: the u-th constraint of the system, $Z_{\sigma}(X)$: the σ-th objective function, g_{σ}: the σ-th objective function aspiration level, d_{σ}^{+}, d_{σ}^{-}: over-achievement and under-achievement of the aspiration level g_{σ}, respectively, W_{σ}: the positive weighting coefficients of the σ-th goal determined by the DM and $\sum_{\sigma} W_{\sigma} = 1$.

It should be noted that negative deviations should be minimized in the profit objective functions and positive deviation in the cost objective functions.

$$d_{\sigma}^{+} = \begin{cases} Z_{\sigma}(X) - g_{\sigma} & \text{if } Z_{\sigma}(X) > g_{\sigma} \\ 0 & \text{otherwise} \end{cases}$$
$$d_{\sigma}^{-} = \begin{cases} g_{\sigma} - Z_{\sigma}(X) & \text{if } Z_{\sigma}(X) < g_{\sigma} \\ 0 & \text{otherwise} \end{cases}.$$

One of the major concerns in using goal programming method is incommensurability. In goal programming incommensurability happens when deviational variables measured in different units are summed directly. This problem may lead to incorrect or misleading results. In order to tackle this problem, the goal programming method was developed by normalization techniques [53].

5. Case study

To show the efficiency of the proposed model, a real case study of the clothing industry is utilized. The computational results for this case are presented to illustrate the performance of the proposed model and the developed approach.

5.1. Case description

The proposed model in this research is validated by a real case study for the clothing industry in Iran. The model belongs to a four-level supply chain network including suppliers, manufacturing center, retailers and outlet retailers. There are six suppliers, one manufacturer, eighteen retailers and two outlet retailers in the network under exam. The number and location of all the facilities are fixed. In Figure 2, the location of the manufacturing center, retailers and outlet retailers are shown. Four main product types are produced in this network comprising suit, coat, shirt and trousers. In order to produce these products, nine types of raw materials are used, which are described as follows. In sewing and tailoring, a lining is an inner layer of textile inserted into clothing. Linings provide a neat inside finish and cover interfacing, layers, the raw edges of seams, and other sewing details. The canvas is an extra layer of clothing that sits between the outer fabric and inner lining. Although this layer is never seen or touched in clothing, but it plays a significant role when is fitted in body. The canvas will adapt to the shape of body and causing a better fit. Wigan is a roll of premade, some of fabric to bridge the gap and often is used to interface sleeve cuffs or collar lapel or pocket flap. The wigan holds the shaping without adding a lot of bulk, it is really nice crisp thin fabric. Buckram is a stiff fabric, made of cotton, and still sometimes linen or horse hair, which is used to stiffen parts of clothing such as collar, sleeves and pockets. The first product of this network is suit, which is made from nine different types of raw materials including fabric, lining, canvas, wigan, buckram, button, thread, hook and eyes and zip. The second product is coat, which is produced from seven types of raw materials containing fabric, lining, canvas, wigan, buckram,

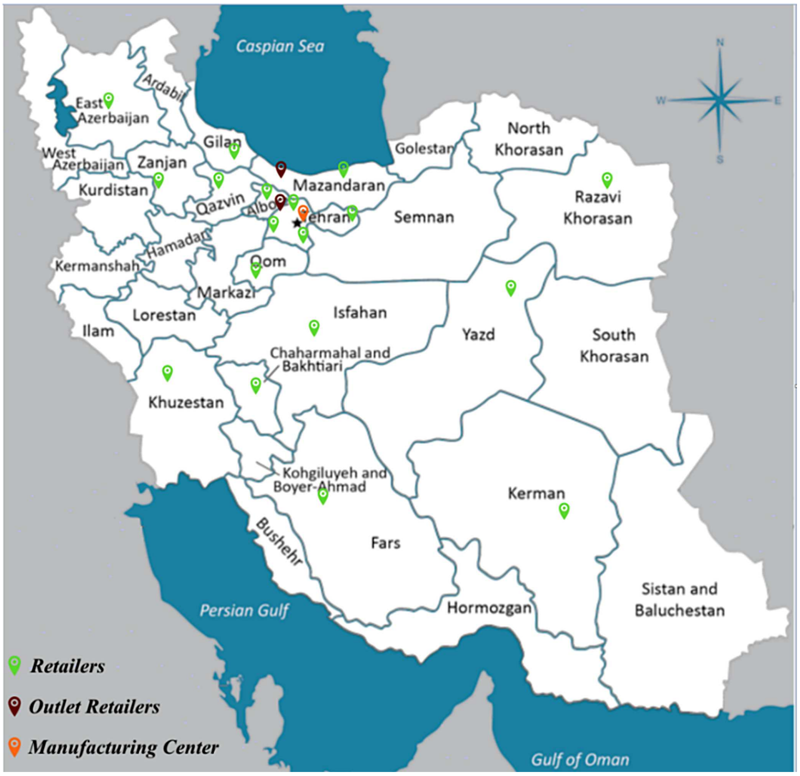


FIGURE 2. Location of facilities in the case study.

TABLE 3. Bill of material (BOM).

b_{jm}		Raw material								
		Fabric (m)	Lining (m)	Canvas (m)	Wigan (m)	Buckram (m)	Button ($number$)	Thread ($number$)	Hook and eyes ($number$)	Zip ($number$)
Product	1 – Suit	3	2	1	0.7	0.6	14	2	1	1
	2 – Coat	2	1.5	1	0.4	0.6	13	1	–	–
	3 – Shirt	1.6	–	–	0.4	–	13	1	–	–
	4 – Trousers	1.4	0.5	–	0.3	–	1	1	1	1

button and thread. The third product is shirt which is produced using four types of raw materials including fabric, wigan, button and thread. The last product is trousers which is made from seven types of raw materials comprising fabric, lining, wigan, button, thread, hook and eyes and zip. The quantity of raw materials required to produce each product (bill of material) is shown in Table 3. The first five raw materials are expressed in meter and the rest of them are given in number. The planning horizon is one year and monthly periods are considered as time intervals.

The required raw materials are purchased from the suppliers. After being transferred to the manufacturing center, the products are produced according to the demand and are distributed to the retailers. Sometimes, the products identified with defects are transferred to the outlet retailers and are sold at a lower price. The same applies to those that have not been sold in retailers after a certain number of periods or are damaged during

TABLE 4. Initial demand for the products for the first retailer under the second scenario.

d_{jrct} *(number)*			Period											
			1	2	3	4	5	6	7	8	9	10	11	12
Product	1	The first retailer	483	420	364	364	413	364	364	357	364	350	434	385
	2		504	644	595	616	385	434	525	427	476	392	609	651
	3		602	672	420	665	455	434	469	469	441	609	441	644
	4		630	511	602	602	497	602	399	434	371	511	630	511

transportation, they are transferred to the outlet retailers. In order to be more realistic, uncertain parameters, namely the initial price and demand, in the stochastic programming model are categorized *via* three possible scenarios. Each scenario occurs with a specified probability.

– First scenario: the pessimistic situation in which the amount of initial price and demand are low.
– Second scenario: the moderate situation in which the amount of initial price and demand are medium.
– Third scenario: the optimistic situation in which the amount of initial price and demand are high.

It is assumed here that the price and demand in the first and third scenarios are 15 percent lower than the second scenario and 20 percent higher than their initial values, respectively. Also, the probability of each scenario is 0.5, 0.3 and 0.2, respectively.

5.2. Input parameters

Some of input parameters based on the second scenario are given in Tables 4–8. More specifically, the demand for the first retailer and outlet retailers is given in Tables 4 and 5, respectively. The presented values in these tables are related to the initial demand, regardless of the impact of discounts and advertising. The selling prices of the products sold by retailers and outlet retailers without considering discounts are presented in Tables 6 and 7. There are four types of discounts and only one of them can be considered for selling each product in each period. The discount rates are shown in Table 8. Costs-related parameters are described in Tables B.1–B.13. In detail, production cost per unit of product j produced in the manufacturing center is shown in Table B.1. Maximum advertising cost in period t is portrayed in Table B.2. Transportation costs are illustrated in Tables B.3–B.6. Inventory holding costs are indicated in Tables B.7–B.10. Lost sales costs are given in Tables B.11 and B.12 and the price of raw material m supplied by supplier s during period t is described in Table B.13. These rates are determined by DMs based not only on the events and seasons, but also based on historical data and DMs experience.

The discount and advertising sensitivity index are equal to 2.75 and 0.4, respectively. The maximum cost of advertising is equal to 1 000 000. Five percent of revenue is considered as retailers and outlet retailers shares.

Whenever is needed, preliminary analyses of the available statistical data have been carried out and also intensive expertise exchange with the company managers in order to ensure an efficient tuning of the governing parameters and to select the most suitable input values.

5.3. Results

The proposed model is a bi-objective problem, the first objective function is maximizing the total profit and the second one is minimizing the risk of having a low net profit. These objective functions are conflicting. So, they should balance according to their priority. For this purpose, the model was reformulated in order to suit the weighted normalized goal programming approach. The proposed MILP model is implemented by using LINGO 9 software on PC equipped with AMD Ryzen 7 2700 Eight-Core processor @3.2 GHz and 16.00 GB RAM @3000 MHz. According to the general structure mentioned in Section 4.2, the application of weighted

TABLE 5. Initial demand for the products for the outlet retailers under the second scenario.

d'_{joct} *(number)*				Period											
				1	2	3	4	5	6	7	8	9	10	11	12
Product	1	Outlet retailer	1	112	196	210	168	210	266	189	182	252	224	224	154
			2	70	168	189	154	175	217	224	231	168	147	161	252
	2		1	133	175	168	231	245	476	434	329	413	462	364	441
			2	105	98	238	175	301	441	406	469	350	448	287	406
	3		1	119	119	224	175	259	322	343	301	322	476	287	315
			2	112	133	175	273	280	357	385	350	385	413	301	455
	4		1	77	161	182	154	308	336	336	434	476	385	371	280
			2	126	91	189	245	413	350	322	476	483	315	427	455

TABLE 6. Initial selling price of the products at the retailers.

pr_{jt} (\$)		Period											
		1	2	3	4	5	6	7	8	9	10	11	12
Product	1	450	450	450	465	460	470	480	480	490	495	500	520
	2	320	320	325	330	330	335	335	335	340	340	345	350
	3	210	210	215	215	220	220	225	225	230	230	235	240
	4	195	195	200	200	205	210	210	210	215	215	220	225

TABLE 7. Initial selling price of the products at the outlet retailers.

po_{jt}(\$)		Period											
		1	2	3	4	5	6	7	8	9	10	11	12
Product	1	320	320	320	325	330	340	345	350	350	355	360	370
	2	225	230	235	235	240	240	240	245	245	250	250	255
	3	150	155	155	160	160	160	165	165	165	170	170	175
	4	135	135	140	140	145	150	150	150	155	160	160	165

normalized goal programming method for the proposed bi-objective mathematical model is as follows.

$$\min = W_1\left(\frac{d_1^+ + d_1^-}{g_1}\right) + W_2\left(\frac{d_2^+ + d_2^-}{g_2}\right).$$

Subject to equations (3.5)–(3.18), (3.21), (3.22), (3.27)–(3.32), (A.3)–(A.9), (A.14), (A.16)–(A.21), (A.26), (A.28)–(A.32), (A.34), (A.35), (A.37), (A.38), (A.40)–(A.44), (4.2), (4.3) and

$$\sum_c p_c Z_c - d_1^+ + d_1^- = g_1$$

$$\sum_c p_c \varphi_c - d_2^+ + d_2^- = g_2$$

$$d_1^+, d_1^-, d_2^+, d_2^- \geq 0$$

where W_1 is a positive weighting coefficient of the first objective function; W_2 is a positive weighting coefficient of the second objective function; d_1^+ is the over-achievement of the aspiration level g_1; d_1^- is the under-achievement

TABLE 8. Discount rates for each product.

$\delta_{kjt}(\%)$				Period											
				1	2	3	4	5	6	7	8	9	10	11	12
Discount	1	Product	1			0.10						0.10			
			2			0.10						0.10			
			3			0.15						0.15			
			4			0.15						0.15			
	2		1						0.10					0.10	
			2						0.10					0.20	
			3						0.15					0.20	
			4						0.15					0.15	
	3		1			0.10									
			2			0.20									
			3			0.15									
			4			0.20									
	4		1						0.10			0.10			
			2						0.10			0.10			
			3						0.15			0.15			
			4						0.15			0.15			

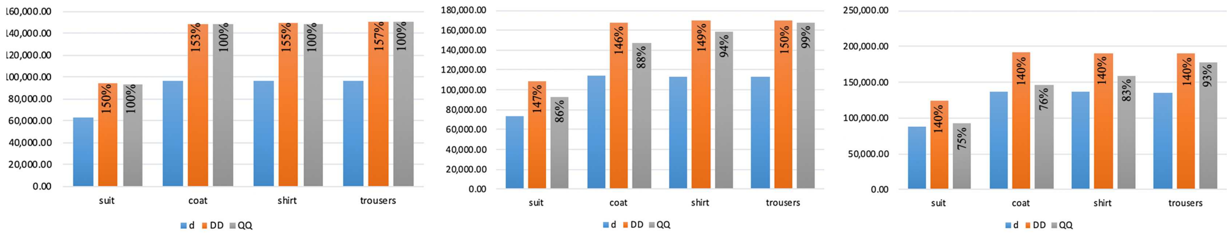
of the aspiration level g_1; d_2^+ is the over-achievement of the aspiration level g_2; d_2^- is the under−achievement of the aspiration level g_2; g_1, the first objective function aspiration level; g_2, the second objective function aspiration level. In order to obtain, g_1 and g_2, two sub-problems with individual objective function should be solved. g_1 is obtained by solving Max $E(Z)$ and g_2 is obtained by solving Min Risk. The values of the first and second goals (g_1 and g_2) resulted to be 59 700 000 and 3 000 000, respectively with the CPU time of 17 h and 24 min and 35 s. The weights of the objective functions are determined according to their priority and DM recognition. The weights 0.7 (for W_1) and 0.3 (for W_2) for the first and second objective functions, respectively are used. Also, it is assumed that the minimum quantity for the expected profit (Ω) is 50 000 000. The presented model is solved applying the weighted normalized goal programming approach and the results are reported as follows:

With respect to the goals, the value of the first objective function achieved 22.788 percent decrease and the second one is 30.149 percent increase. In Figures 3 and 4 the initial demand, actual demand and the quantity of sale products of retailers and outlet retailers are shown, respectively. In Figure 3, a. scenario 1, the first product (suit), the initial demand is equal to 62 741. Considering discount and advertisement, the quantity of demand increased to 94 068 which means the discount and advertising have strong affected on the demand that reaches 150%. Moreover, the whole new demand has been responded. Some results of the optimal solution are presented in Tables 9 and 10. Table 9 represents the number of products produced in the manufacturing center. Table 10 shows which discount plan has been employed in each period. When this variable is equal one, discount k-th under scenario c-th is applied, otherwise it is zero. In all periods, the maximum amount of advertising cost is considered.

As a final consideration, Figure 5 portrays the total profits for each scenario over all periods. The figure shows how more profit is achieved for periods with discounts. For instance, in scenario 2, the discount scheme is employed for some products in periods 6 and 9 (as per the results of Tab. 10). Figure 5 clearly shows that during these two periods the company gained more profits compared to the remaining period of the year.

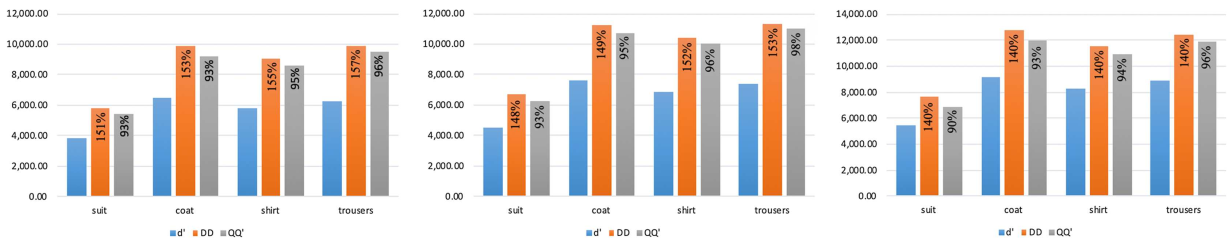
5.4. Sensitivity analyses

One of the most important issues in the clothing industry is assessing the profitability of the supply chain. For this purpose, an efficient model should be designed with the goal of maximizing the total profit. Also, the



(a) *(b)* *(c)*

FIGURE 3. Comparison between initial demand, actual demand and the amount of sale products of retailers. (a) Scenario 1. (b) Scenario 2. (c) Scenario 3.



(a) *(b)* *(c)*

FIGURE 4. Comparison between initial demand, actual demand and the amount of sale products of outlet retailers. (a) Scenario 1. (b) Scenario 2. (c) Scenario 3.

TABLE 9. Amount of production.

$\mathrm{QM}_{jt}(number)$		Period											
		1	2	3	4	5	6	7	8	9	10	11	12
Product	1	7251	7402	28 348	5308	6005	8317	5856	5559	7437	5880	6077	5958
	2	12 245	11 300	48 100	8961	8169	11 136	9722	8475	11 615	9008	9173	9612
	3	11 346	13 700	56 300	9212	8804	13 510	8122	9236	11 318	8906	9045	9518
	4	10 400	62 835	14 765	8702	8648	13 687	8608	9588	12 325	10 251	20 738	8804

risk of having low net profit should be minimized as much as possible. In this section, some sensitivity analyses are performed to increase the total profit and decrease DRisk. Three major parameters (α, λ, Ω) with different levels are investigated in order to have a clear view of the impact of data variation and to compare the relative values of their effects. The aim is to help DMs in taking insightful decisions.

5.4.1. Discount sensitivity index (α)

Defining the proper amount for the discount parameter leads to an increase in demand that would result in an increase in the total profit. To determine the appropriate value for this parameter, nine different values are examined. The values of the parameter and the results of this analysis are given in Figure 6. The results show that, by increasing the value of parameter α, at first, the amount of total profit will increase as demand increases and then it will decrease due to the capacity constraints and unanswered demand.

TABLE 10. Discount scheme.

PK_{kct}				Period		
				3	6	9
Discount	1	Scenario	1			
			2			1
			3			
	2		1		1	
			2		1	
			3			
	3		1	1		
			2			
			3			
	4		1			1
			2			
			3			

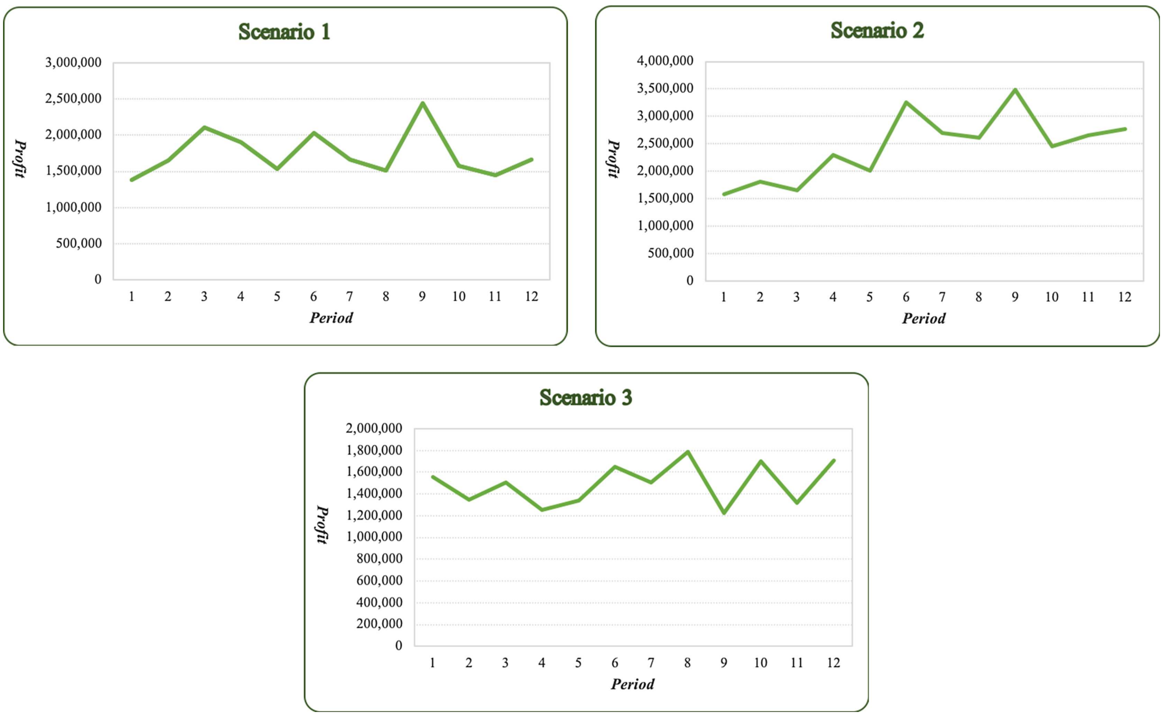


FIGURE 5. The total profit of each scenario in each period.

5.4.2. Advertising sensitivity index (λ)

Another important subject that significantly influences the demand rate is the advertisement. Therefore, considering the proper amount for the advertising parameter is very essential. For this purpose, nine levels are discussed. The results presented in Figure 7 show that, by increasing the value of parameter λ, the demand will increase and will result in the increase of the total profit as the demand is satisfied. Again, the total profit starts to decrease after reaching the threshold value of $\lambda = 0.5$, due to the unsatisfied demand after this level.

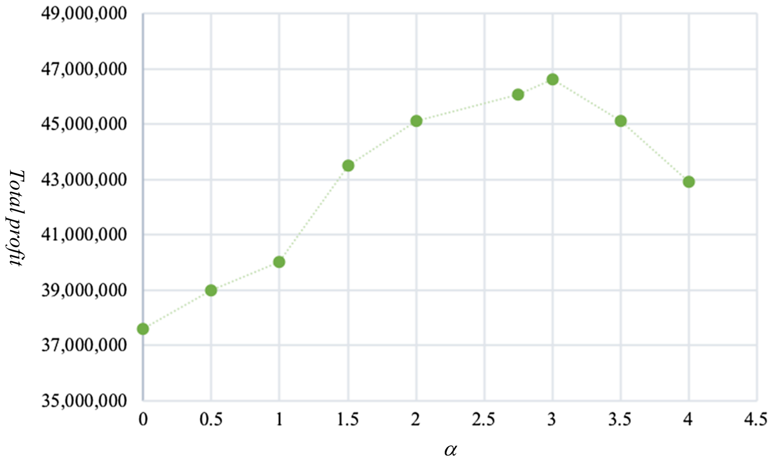


FIGURE 6. The results of sensitivity analysis on discount parameter.

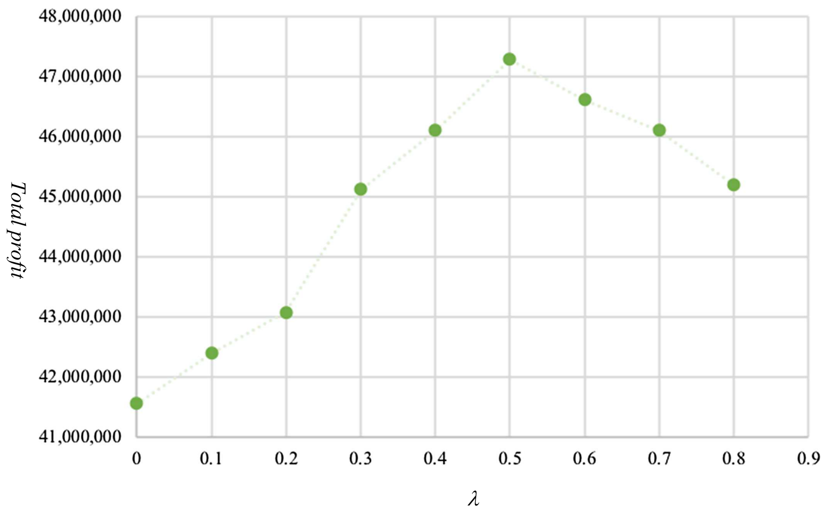


FIGURE 7. The results of sensitivity analysis on advertising parameter.

What stands out from Figures 6 and 7 is that in the absence of discount scheme, the total amount of profit is equal to 37 609 148 whereas without considering advertisement this amount is equal to 41 551 901. Considering the discount scheme, the total profit sees its peak at 46 621 902, which is incremented by 19% whereas this amount considering advertisement has increased to $47 280 315 (12% growth).

5.4.3. Minimum quantity for expected profit (Ω)

In the proposed model, different scenarios are considered. Determining the lowest expected profit value is an important issue that should be studied. In order to explore how the expected profit influences the objectives, seven sub-problems with different expected profit values (Ω) were solved. The various values considered for Ω and the corresponding solutions are presented in Figure 8. According to Figure 8, by increasing the expected profit value (Ω), the amount of total profit and risk are increased, simultaneously.

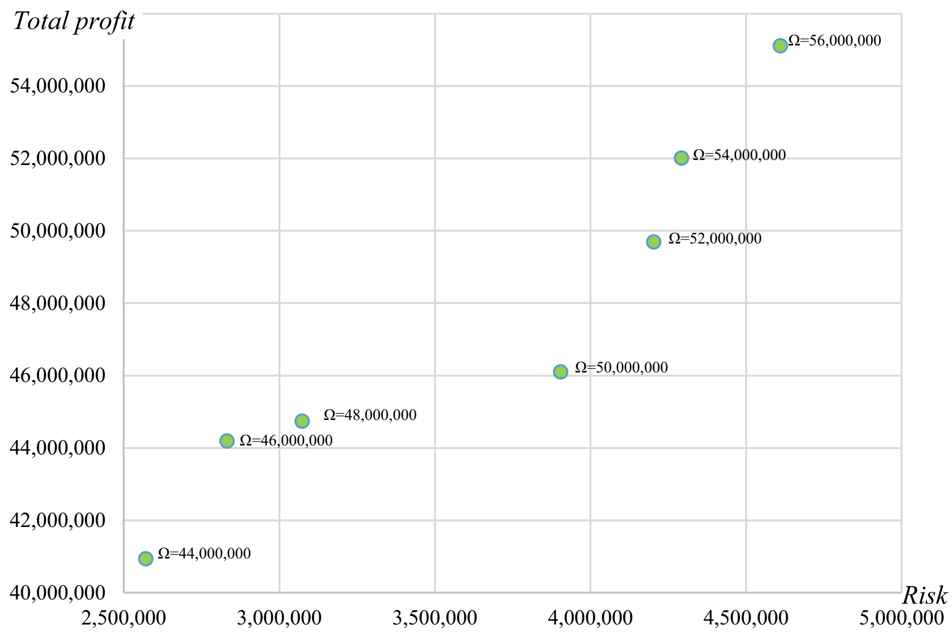


FIGURE 8. The results of sensitivity analysis on minimum quantity for the expected profit.

TABLE 11. Impact of the most effective parameters on total profit.

Discount parameter (α)	Total profit (1000 \$)	Advertisement parameter (λ)	Total profit (1000 \$)	Minimum expected profit (Ω)	Total profit (1000 \$)
0	37 609	0	41 552	44 000 000	40 938
0.5	38 984	0.1	42 390	46 000 000	44 190
1	40 010	0.2	43 071	48 000 000	44 737
1.5	43 521	0.3	45 120	50 000 000	46 095
2	45 117	0.4	46 095	52 000 000	49 690
2.75	46 095	0.5	47 280	54 000 000	52 008
3	46 621	0.6	46 610	56 000 000	55 106
3.5	451 143	0.7	46 095	–	–
4	42 906	0.8	45 193	–	–

In order to compare the influence of the most important parameters on the total profit more vividly, Table 11 is presented. This table visualizes the interaction between the total profit and the parameters (α, λ, Ω).

5.5. Managerial insights

In many countries, clothing companies have faced some challenges. Determining proper suppliers, production planning, pricing policy, discount and advertising schemes, flow between facilities and demand uncertainty are vital issues for clothing companies. Many clothing companies in Iran are suffering from the above-mentioned issues as well. In fact, due to the competitive environment, extravagant prices including raw materials and even inventory transportation, planning out for the production rate precisely bring advantages for them. Designing an efficient supply chain network triggers implementing these goals and consequently improving the companies' performance and enhance their profits. This model offers some beneficial managerial insights for clothing industry managers based on the computational results and sensitivity analyses on important parameters that were carried out.

- The company should prepare a suitable plan for discount in different periods. What stands out from the results is that the company should plan for some discount scheme in some determined period. Planned discount scheme is suggested at the end of some seasons $(3, 6, 9)$, bearing in mind the sale and profit and inventory.
- Many clothing industries such as the case studied in this paper, often ignore uncertainties. So, this will result in facing overstock or shortage which means cost increases. In this research, the production rate is obtained according to historical data considering some integral factors affecting the demand to achieve an optimal amount for production and decrease costs such as inventory holding and lost sale cost.
- Sensitivity analysis of the advertising parameter portrayed that allocating part of the revenue budget to advertisement is effectively essential for the company to promote their brands and products and gaining more profits. The company should determine a proper advertising budget in each period. It is clear from Figures 3 and 4, that by proposing the appropriate budget for advertisement, the demand rate increases significantly, reaching over 140% over all scenarios and centers.
- Due to the low selling price of the products in outlet retailers and the satisfaction of royal customers and also, comparing the demand rates of retailers and outlet retailers (Tabs. 4 and 5 compared with Figs. 3 and 4), establishing new outlet retailers can potentially increase the profit of the supply chain. In fact, based on the results of Figures 3 and 4, the demand for the products of outlet centers is high. Furthermore, geographically, outlet retailers are currently present in only two cities (and their location is not convenient for the customers of many regions) while the numbers for retailers are eighteen centers located at the reach of approximately all regions in Iran. Thus, it is clearly advantageous to the company to take effective policy in order to establish new outlet retailers.
- Company should investigate how much demand and price depend on the amount of discount. They should determine the impact of discount and advertising amount on the profitability of the supply chain and perform the best policy for both advertising and discount.
- the obtained results prove that by considering the uncertainty in demand and price based on scenarios in the proposed network, the model becomes closer to the real world. As a result, the quality of the solutions will be better. The presented model helped in producing better solution quality and, for instance, determined the optimal selling price which helps in increasing the profitability of the company.

6. Conclusion and future study

In this paper, a bi-objective stochastic MILP model for the clothing industry has been proposed with the aim of maximizing the total profit and minimizing the DRisk. It is assumed that the initial price and demand are uncertain and are determined based on a set of scenarios. Three scenarios are provided to consider different realistic situations. Moreover, pricing, advertising-sensitive demand and discount-sensitive demand are considered given their importance in this industry. Weighted normalized goal programming is utilized for solving the bi-objective model using LINGO software. The results of these three scenarios indicate that considering the optimal amount for discount and advertisement, aside from the type of products, the demand rate has increased by approximately 1.5-fold than the initial demand in both retailers and outlet retailers, with over 75% of actual demand being fulfilled in all scenarios. Also, some sensitivity analyses study is performed to investigate the effect of some parameters on the results. The results of the presented study offered useful managerial insights for clothing industry managers. Several interesting findings are highlighted in this study including the optimal production rate, optimal flow between facilities, the amount of discount and advertising, the final price of the products and estimating the demand based on discount and advertising.

For future research, large-scale problems can be considered and their time complexity should be discussed. It may be necessary to use meta-heuristic algorithms or tailored exact methods to solve large-scale problems.

Developing large-scale problems can be not only the result of dealing with a more sophisticated and widely spread supply chain, but also the result of considering a much higher number of possible scenarios to characterize the uncertainty. In this case, advanced stochastic optimization techniques, such as scenario aggregation and reduction, should be used in order to solve the resulting instances. Also, the model developed within this research can be applied to solve other case studies.

Investigating the impact of fashion on demand rate as one of the most important and influential issues in the clothing industry can be tremendously helpful. Another issue that may significantly affect the profitability of the clothing supply chain is enriching the distribution channels by the online retail trading [24]. Nowadays the number of industries which use this channel are on the rise. So, designing an online-retail network and, consequently, adapt the supply chain design for the new distribution channel and to any possible demand patterns that can be generated can be very beneficial. Finally, since more and more manufacturers are seeking in recent years to produce goods with lower resource consumption and using recyclable and environmentally friendly raw materials, considering environmental issues is useful [26]. Green transportation is one of these issues that can be considered to reduce emissions and harmful pollutions.

Appendix A. Linearization of the proposed model

Constraints (3.19) and (3.20) of the original mathematical model are non-linear due to the existence of multiple decision variables. Therefore, auxiliary variables and additional constraints were added to linearize these non-linear constraints [6, 43]. Equation (3.19) can be written as follows.

$$\mathrm{DD}_{jrct} = d_{jrct} + \lambda d_{jrct}\frac{\gamma_t}{\gamma'_t} + \alpha d_{jrct}\sum_k \mathrm{PK}_{kt}\delta_{kjt} + \alpha\lambda d_{jrct}\frac{\gamma_t}{\gamma'_t}\sum_k \mathrm{PK}_{kt}\delta_{kjt}. \tag{A.1}$$

A set of new variables, namely X_{kct}, is defined with the following equation.

$$X_{kct} = \mathrm{PK}_{kct}\gamma_t. \tag{A.2}$$

According to equation (A.2), the following additional constraints are added to the main proposed model.

$$X_{kct} \geq \gamma_t - \eta\,(1 - \mathrm{PK}_{kct}) \qquad \forall k, c, t \tag{A.3}$$

$$X_{kct} \leq \gamma_t + \eta\,(1 - \mathrm{PK}_{kct}) \qquad \forall k, c, t \tag{A.4}$$

$$X_{kct} \leq \eta \times \mathrm{PK}_{kct} \qquad \forall k, c, t \tag{A.5}$$

$$X_{kct} \geq 0, \mathrm{Integer} \qquad \forall k, c, t \tag{A.6}$$

Therefore, the linearized constraint (A.7) should replace constraint (3.19) into the model (3.1)–(3.32).

$$\mathrm{DD}_{jrct} = d_{jrct} + \lambda d_{jrct}\frac{\gamma_t}{\gamma'_t} + \alpha d_{jrct}\sum_k \mathrm{PK}_{kct}\delta_{kjt} + \frac{\alpha\lambda d_{jrct}}{\gamma'_t}\sum_k X_{kct}\delta_{kjt} \quad \forall j, r, c, t. \tag{A.7}$$

Similar to constraint (3.19), constraint (3.20) is linearized as follows.

$$\mathrm{DD}_{joct} = d'_{joct} + \lambda d'_{joct}\frac{\gamma_t}{\gamma'_t} + \alpha d'_{joct}\sum_k \mathrm{PK}_{kct}\delta_{kjt} + \frac{\alpha\lambda d'_{joct}}{\gamma'_t}\sum_k X_{kct}\delta_{kjt} \quad \forall j, o, c, t. \tag{A.8}$$

and the linearized constraint (A.8) replaces constraint (3.20).

Moreover, the first part of the objective function (Eq. (3.3)) representing the revenue involves the multiplication of two integer variables. In order to linearize it, an integer variable should be transformed into sum of binary variables [19, 23]. Consequently, Prd_{jct} variable is converted into sum of the binary variables.

$$\mathrm{PP}_{jct} = \sum_{i=1}^{N+1} 2^{i-1} Y_{ijct} \qquad \forall j, c, t \tag{A.9}$$

where Y_{ijct} is a binary variable and N is the minimum number of binary variables required. In order to determine the value of N, an upper bound was considered for the corresponding integer variable. The value of N is calculated according to equations (A.10) and (A.11).

$$\mathrm{PP}_{jct} \leq \max\{pr_{jct}\} \qquad \forall j,c,t \tag{A.10}$$
$$\max\{pr_{jct}\} < 2^{N+1} \qquad \forall j,c,t. \tag{A.11}$$

In order to complete the linearization, a new auxiliary integer variable, QY_{jrct} is defined as follows.

$$\mathrm{QY}_{jrct} = \mathrm{PP}_{jct}\mathrm{QQ}_{jrct} \qquad \forall j,r,c,t \tag{A.12}$$
$$\mathrm{QY}_{jrct} = \sum_{i=1}^{N+1} 2^{i-1} Y_{ijct}\mathrm{QQ}_{jrct} \qquad \forall j,r,c,t \tag{A.13}$$
$$\mathrm{QY}_{jrct} \geq 0, \mathrm{Integer} \qquad \forall j,r,c,t. \tag{A.14}$$

Equation (A.13) is non-linear, due to the multiplication of integer and binary variables. In order to linearize this equation, an additional variable, namely QH_{ijrct} is defined.

$$\mathrm{QH}_{ijrct} = Y_{ijct}\mathrm{QQ}_{jrct} \qquad \forall i,j,r,c,t. \tag{A.15}$$

Therefore, equation (A.13) is rewritten as:

$$\mathrm{QY}_{jrct} = \sum_{i=1}^{N+1} 2^{i-1}\mathrm{QH}_{ijrct} \qquad \forall j,r,c,t. \tag{A.16}$$

According to this equation, the following additional constraints are added to the main model.

$$\mathrm{QH}_{ijrct} \geq \mathrm{QQ}_{jrct} - \eta\,(1 - Y_{ijct}) \qquad \forall i,j,r,c,t \tag{A.17}$$
$$\mathrm{QH}_{ijrct} \leq \mathrm{QQ}_{jrct} + \eta\,(1 - Y_{ijct}) \qquad \forall i,j,r,c,t. \tag{A.18}$$
$$\mathrm{QH}_{ijrct} \leq \eta \times Y_{ijct} \qquad \forall i,j,r,c,t \tag{A.19}$$
$$\mathrm{QH}_{ijrct} \geq 0, \mathrm{Integer} \qquad \forall i,j,r,c,t. \tag{A.20}$$

The second part of the revenue function (Eq. (3.3)) is nonlinear as well and is linearized as follows.

$$\mathrm{PP}'_{jct} = \sum_{e=1}^{N+1} 2^{e-1} Z_{ejct} \qquad \forall j,c,t \tag{A.21}$$
$$\mathrm{PP}'_{jct} \leq \max\{po_{jct}\} \qquad \forall j,c,t \tag{A.22}$$
$$\max\{po_{jct}\} < 2^{N+1} \qquad \forall j,c,t \tag{A.23}$$

where Z_{ijct} is a binary variable. An auxiliary variable namely QZ_{joct} is defined as follows.

$$\mathrm{QZ}_{joct} = \mathrm{PP}'_{jct}\mathrm{QQ}'_{joct} \qquad \forall j,o,c,t \tag{A.24}$$
$$\mathrm{QZ}_{joct} = \sum_{e=1}^{N+1} 2^{e-1} Z_{ejct}\mathrm{QQ}'_{joct} \qquad \forall j,o,c,t \tag{A.25}$$
$$\mathrm{QZ}_{joct} \geq 0, \mathrm{Integer} \qquad \forall j,o,c,t. \tag{A.26}$$

Even equation (A.25) contains the multiplication of binary and integer variables therefore, in order to linearize this non-linear equation, a new variable QH'_{ejoct} is defined.

$$\mathrm{QH}'_{ejoct} = Z_{ejct}\mathrm{QQ}'_{joct} \qquad \forall e,j,o,c,t. \tag{A.27}$$

So, equation (A.25) should be rewritten as:

$$\mathrm{QZ}_{joct} = \sum_{e=1}^{N+1} 2^{e-1}\mathrm{QH}'_{ejoct} \qquad \forall j, o, c, t. \tag{A.28}$$

According to this equation, the following additional constraints are added to the main model.

$$\mathrm{QH}'_{ejoct} \geq \mathrm{QQ}'_{joct} - \eta\,(1 - Z_{ejct}) \qquad \forall e, j, o, c, t \tag{A.29}$$

$$\mathrm{QH}'_{ejoct} \leq \mathrm{QQ}'_{joct} + \eta\,(1 - Z_{ejct}) \qquad \forall e, j, o, c, t \tag{A.30}$$

$$\mathrm{QH}'_{ejoct} \leq \eta \times Z_{ejct} \qquad \forall e, j, o, c, t \tag{A.31}$$

$$\mathrm{QH}'_{ejoct} \geq 0, \text{Integer} \qquad \forall e, j, o, c, t. \tag{A.32}$$

Therefore, the linearize equation (A.33) should replace equation (3.3).

$$\text{Revenue}_c = \sum_j \sum_r \sum_t \mathrm{QY}_{jrct} + \sum_j \sum_o \sum_t \mathrm{QZ}_{joct}. \tag{A.33}$$

Moreover, equations (A.34) and (A.35) will replace constraints (3.25) and (3.26).

$$\mathrm{VR}_{rct} = f \sum_j \mathrm{QY}_{jrct} \qquad \forall r, c, t \tag{A.34}$$

$$\mathrm{VO}_{oct} = f \sum_j \mathrm{QZ}_{joct} \qquad \forall o, c, t. \tag{A.35}$$

Finally, constraints (3.23) and (3.24) of the original proposed model are non-linear because of the existent floor function. In order to linearize these constraints, two auxiliary positive integer variables namely YY_{jct} and ZZ_{jct} are defined. The quantity of floor function has been limited between two consecutive integer numbers that are explained in equations (A.37), (A.38), (A.40) and (A.41). So, these equations are added to the main model as additional constraints [20].

$$\mathrm{YY}_{jct} = \left\lfloor \sum_k \mathrm{PK}_{kt}\delta_{kjt} pr_{jct} \right\rfloor \qquad \forall j, c, t \tag{A.36}$$

$$\mathrm{YY}_{jct} \leq \sum_k \mathrm{PK}_{kt}\delta_{kjt} pr_{jct} \qquad \forall j, c, t \tag{A.37}$$

$$\mathrm{YY}_{jct} > \left(\sum_k \mathrm{PK}_{kt}\delta_{kjt} pr_{jct} \right) - 1 \qquad \forall j, c, t \tag{A.38}$$

$$\mathrm{ZZ}_{jct} = \left\lfloor \sum_k \mathrm{PK}_{kt}\delta_{kjt} po_{jct} \right\rfloor \qquad \forall j, c, t \tag{A.39}$$

$$\mathrm{ZZ}_{jct} \leq \sum_k \mathrm{PK}_{kt}\delta_{kjt} po_{jct} \qquad \forall j, c, t \tag{A.40}$$

$$\mathrm{ZZ}_{jct} > \left(\sum_k \mathrm{PK}_{kt}\delta_{kjt} po_{jct} \right) - 1 \qquad \forall j, c, t \tag{A.41}$$

$$\mathrm{YY}_{jct}, \mathrm{ZZ}_{jct} \geq 0, \text{Integer} \qquad \forall j, c, t. \tag{A.42}$$

Therefore, the linearized constraints (A.43) and (A.44) should replace constraints (3.23) and (3.24), respectively.

$$\mathrm{PP}_{jct} = pr_{jct} - \mathrm{YY}_{jct} \qquad \forall j, c, t \tag{A.43}$$

$$\mathrm{PP}'_{jct} = po_{jct} - \mathrm{ZZ}_{jct} \qquad \forall j, c, t. \tag{A.44}$$

Appendix B. Input parameters (costs)

Table B.1. Production cost.

$P'j(\$)$	$j=1$	$j=2$	$j=3$	$j=4$
	30.00	20.00	15.00	15.00

Table B.2. Maximum advertising cost.

$\delta_t(\$)$	$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table B.3. Transportation cost of raw material between supplier and manufacturing center.

$tm_{ms}(\$)$	$s=1$	$s=2$	$s=3$	$s=4$	$s=5$	$s=6$
$m=1$	2.00	3.00	3.00	3.00	3.00	2.00
$m=2$	1.00	3.00	2.00	2.00	2.00	1.00
$m=3$	1.00	2.00	1.00	1.00	1.00	2.00
$m=4$	1.00	2.00	2.00	2.00	2.00	2.00
$m=5$	2.00	3.00	2.00	2.00	3.00	1.00
$m=6$	2.00	2.00	3.00	2.00	1.00	1.00
$m=7$	1.00	2.00	1.00	2.00	1.00	3.00
$m=8$	2.00	2.00	2.00	2.00	1.00	1.00
$m=9$	1.00	1.00	2.00	2.00	2.00	1.00

Table B.4. Transportation cost of products between manufacturing center and retailer.

$tr_{jr}(\$)$	$r=1$	$r=2$	$r=3$	$r=4$	$r=5$	$r=6$	$r=7$	$r=8$	$r=9$	$r=10$	$r=11$	$r=12$	$r=13$	$r=14$	$r=15$	$r=16$	$r=17$	$r=18$
$j=1$	2	1	2	1	1	2	2	1	2	1	1	1	2	2	2	2	1	1
$j=2$	2	2	1	1	2	1	1	2	2	2	2	2	2	2	1	2	2	2
$j=3$	1	2	2	1	2	1	1	2	2	1	1	2	2	2	2	2	1	1
$j=4$	2	1	1	2	2	1	2	1	1	2	2	2	2	1	2	2	2	2

Table B.5. Transportation cost of products between manufacturing center and outlet retailer.

$to_{jo}(\$)$	$o=1$	$o=2$
$j=1$	3.00	3.00
$j=2$	2.00	3.00
$j=3$	2.00	1.00
$j=4$	1.00	2.00

Table B.6. Transportation cost of products between retailer and outlet retailer.

tj_{jro}(\$)		$o = 1$	$o = 2$
$j = 1$	$r = 1$	3.00	3.00
	$r = 2$	2.00	2.00
	$r = 3$	3.00	3.00
	$r = 4$	1.00	1.00
	$r = 5$	1.00	3.00
	$r = 6$	2.00	1.00
	$r = 7$	2.00	2.00
	$r = 8$	1.00	3.00
	$r = 9$	1.00	2.00
	$r = 10$	2.00	3.00
	$r = 11$	1.00	3.00
	$r = 12$	1.00	3.00
	$r = 13$	3.00	2.00
	$r = 14$	2.00	3.00
	$r = 15$	3.00	2.00
	$r = 16$	1.00	3.00
	$r = 17$	2.00	2.00
	$r = 18$	3.00	2.00
$j = 2$	$r = 1$	1.00	2.00
	$r = 2$	2.00	3.00
	$r = 3$	1.00	3.00
	$r = 4$	3.00	1.00
	$r = 5$	2.00	3.00
	$r = 6$	2.00	3.00
	$r = 7$	2.00	3.00
	$r = 8$	1.00	2.00
	$r = 9$	2.00	1.00
	$r = 10$	2.00	2.00
	$r = 11$	2.00	3.00
	$r = 12$	1.00	3.00
	$r = 13$	1.00	3.00
	$r = 14$	2.00	2.00
	$r = 15$	2.00	1.00
	$r = 16$	3.00	3.00
	$r = 17$	3.00	2.00
	$r = 18$	3.00	2.00
$j = 3$	$r = 1$	3.00	2.00
	$r = 2$	2.00	3.00
	$r = 3$	1.00	1.00
	$r = 4$	2.00	3.00
	$r = 5$	3.00	2.00
	$r = 6$	2.00	3.00
	$r = 7$	2.00	1.00
	$r = 8$	1.00	3.00
	$r = 9$	2.00	2.00
	$r = 10$	3.00	2.00
	$r = 11$	2.00	1.00
	$r = 12$	3.00	2.00
	$r = 13$	3.00	2.00
	$r = 14$	2.00	3.00
	$r = 15$	1.00	2.00
	$r = 16$	1.00	2.00
	$r = 17$	3.00	1.00
	$r = 18$	2.00	1.00
$j = 4$	$r = 1$	1.00	3.00
	$r = 2$	3.00	3.00
	$r = 3$	3.00	3.00
	$r = 4$	1.00	2.00
	$r = 5$	1.00	2.00
	$r = 6$	2.00	1.00
	$r = 7$	3.00	1.00
	$r = 8$	3.00	1.00
	$r = 9$	2.00	1.00
	$r = 10$	1.00	2.00
	$r = 11$	3.00	1.00
	$r = 12$	2.00	2.00
	$r = 13$	2.00	2.00
	$r = 14$	2.00	2.00
	$r = 15$	2.00	3.00
	$r = 16$	1.00	1.00
	$r = 17$	2.00	2.00
	$r = 18$	3.00	1.00

Table B.7. Inventory holding cost of raw material in manufacturing center.

i_{mt}($)	$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
$m=1$	0.45	0.60	0.40	0.60	0.70	0.50	0.60	0.60	0.70	0.50	0.60	0.50
$m=2$	0.70	0.50	0.50	0.70	0.40	0.60	0.40	0.70	0.40	0.60	0.40	0.60
$m=3$	0.40	0.60	0.60	0.40	0.40	0.60	0.40	0.40	0.40	0.60	0.40	0.60
$m=4$	0.40	0.60	0.70	0.40	0.50	0.70	0.50	0.70	0.40	0.60	0.60	0.70
$m=5$	0.50	0.70	0.40	0.60	0.60	0.40	0.50	0.50	0.70	0.40	0.60	0.40
$m=6$	0.60	0.40	0.40	0.60	0.60	0.70	0.60	0.60	0.40	0.40	0.60	0.40
$m=7$	0.70	0.40	0.50	0.70	0.70	0.40	0.60	0.70	0.40	0.50	0.70	0.40
$m=8$	0.50	0.40	0.60	0.40	0.40	0.40	0.70	0.40	0.60	0.60	0.40	0.60
$m=9$	0.60	0.40	0.40	0.60	0.60	0.70	0.50	0.70	0.70	0.40	0.60	0.70

Table B.8. Inventory holding cost of product in manufacturing center.

im_{jt}($)	$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
$j=1$	0.75	0.80	0.90	0.75	0.80	0.90	0.90	0.95	0.80	0.70	0.85	0.85
$j=2$	0.60	0.70	0.90	0.60	0.70	0.90	0.93	0.80	0.70	0.60	0.90	0.90
$j=3$	0.16	0.25	0.10	0.15	0.20	0.30	0.10	0.20	0.20	0.20	0.10	0.30
$j=4$	0.40	0.50	0.50	0.40	0.50	0.50	0.40	0.40	0.40	0.50	0.40	0.30

Table B.9. Inventory holding cost of product in retailer.

ic_{jrt}($)		$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
$j=1$	$r=1$	0.75	0.80	0.90	0.75	0.90	0.90	0.90	0.95	0.80	0.70	0.85	0.90
	$r=2$	0.90	0.90	0.90	0.95	0.80	0.90	0.75	0.90	0.85	0.90	0.95	0.80
	$r=3$	0.90	0.75	1.25	0.80	0.90	0.95	0.80	0.90	0.75	0.90	0.90	0.90
	$r=4$	0.90	0.95	0.80	0.75	0.85	0.90	0.90	0.95	0.95	0.80	0.90	0.75
	$r=5$	0.75	0.80	0.90	0.95	0.80	0.90	0.75	0.90	0.75	0.75	0.80	0.90
	$r=6$	0.80	1.00	0.90	0.75	0.75	0.80	0.90	0.75	0.95	0.85	0.80	0.90
	$r=7$	0.90	0.75	1.25	0.95	0.85	0.70	0.90	0.95	0.90	0.90	0.75	0.70
	$r=8$	0.90	0.95	0.80	0.90	0.90	0.75	0.70	0.75	0.90	0.90	0.95	0.80
	$r=9$	0.75	0.80	0.90	0.75	0.75	0.80	0.90	0.95	0.80	0.70	0.80	0.85
	$r=10$	0.75	0.75	0.90	0.95	0.80	0.90	0.75	0.70	0.90	0.90	0.95	0.90
	$r=11$	0.90	0.75	0.80	0.85	0.90	0.95	0.80	0.90	0.75	0.90	0.90	0.90
	$r=12$	0.90	0.95	0.80	0.75	0.70	0.80	0.90	0.95	0.95	0.80	0.90	0.80
	$r=13$	0.75	0.80	0.90	0.95	0.80	0.90	0.75	0.70	0.75	0.75	0.80	0.60
	$r=14$	0.70	0.90	0.90	0.75	0.75	0.80	0.90	0.75	0.95	0.70	0.60	0.75
	$r=15$	0.90	0.75	0.70	0.95	0.80	0.90	0.90	0.95	0.90	0.90	0.75	0.60
	$r=16$	0.90	0.95	0.80	0.90	0.95	0.80	0.70	0.75	0.70	0.90	0.95	0.90
	$r=17$	0.70	0.70	0.90	0.80	0.80	0.90	0.95	0.95	0.80	0.75	0.90	0.95
	$r=18$	0.80	0.90	0.75	0.80	0.90	0.75	0.80	0.75	0.75	0.80	0.75	0.80
$j=2$	$r=1$	0.60	0.60	0.60	0.90	0.90	0.70	0.60	0.60	0.60	0.90	0.90	0.90
	$r=2$	0.70	0.70	0.70	0.60	0.60	0.80	0.70	0.70	0.70	0.60	0.60	0.90
	$r=3$	0.60	0.60	0.80	0.60	0.60	0.60	0.60	0.80	0.80	0.60	0.80	0.60
	$r=4$	0.80	0.80	0.60	0.60	0.60	0.60	0.60	0.80	0.60	0.80	0.60	0.60
	$r=5$	0.90	0.90	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.90	0.70	0.70
	$r=6$	0.60	0.60	0.80	0.80	0.60	0.80	0.60	0.60	0.80	0.60	0.80	0.80
	$r=7$	0.60	0.60	0.80	0.60	0.80	0.60	0.80	0.80	0.80	0.60	0.80	0.60
	$r=8$	0.60	0.60	0.80	0.70	0.70	0.70	0.70	0.70	0.90	0.60	0.80	0.70
	$r=9$	0.70	0.70	0.70	0.80	0.60	0.80	0.60	0.60	0.60	0.70	0.70	0.80
	$r=10$	0.80	0.60	0.60	0.60	0.60	0.60	0.60	0.80	0.80	0.60	0.80	0.80
	$r=11$	0.60	0.80	0.80	0.60	0.60	0.60	0.60	0.80	0.60	0.80	0.60	0.80
	$r=12$	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.90	0.70	0.60
	$r=13$	0.80	0.60	0.60	0.80	0.60	0.80	0.60	0.60	0.80	0.60	0.80	0.60
	$r=14$	0.80	0.80	0.80	0.60	0.80	0.60	0.80	0.80	0.80	0.60	0.80	0.60

Table B.9. continued.

ic_{jrt}($)		$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
	$r=15$	0.80	0.90	0.90	0.70	0.70	0.70	0.70	0.70	0.90	0.60	0.80	0.70
	$r=16$	0.60	0.60	0.60	0.80	0.60	0.80	0.60	0.60	0.60	0.70	0.70	0.60
	$r=17$	0.60	0.60	0.60	0.80	0.80	0.80	0.80	0.80	0.60	0.60	0.60	0.80
	$r=18$	0.70	0.60	0.60	0.80	0.90	0.80	0.90	0.90	0.60	0.80	0.80	0.70
$j=3$	$r=1$	0.16	0.18	0.10	0.18	0.10	0.18	0.10	0.15	0.18	0.15	0.10	0.18
	$r=2$	0.17	0.18	0.15	0.18	0.15	0.18	0.15	0.18	0.30	0.18	0.15	0.18
	$r=3$	0.10	0.30	0.18	0.20	0.18	0.20	0.18	0.18	0.20	0.18	0.18	0.30
	$r=4$	0.15	0.20	0.18	0.20	0.15	0.18	0.15	0.30	0.25	0.30	0.18	0.20
	$r=5$	0.18	0.25	0.18	0.10	0.18	0.10	0.15	0.18	0.15	0.10	0.18	0.10
	$r=6$	0.18	0.24	0.18	0.15	0.18	0.15	0.18	0.30	0.18	0.15	0.18	0.15
	$r=7$	0.30	0.16	0.20	0.18	0.20	0.18	0.18	0.20	0.18	0.18	0.20	0.18
	$r=8$	0.20	0.25	0.20	0.15	0.18	0.15	0.30	0.25	0.30	0.18	0.20	0.15
	$r=9$	0.25	0.20	0.16	0.17	0.18	0.15	0.18	0.15	0.18	0.15	0.18	0.30
	$r=10$	0.24	0.16	0.16	0.10	0.30	0.18	0.20	0.18	0.20	0.18	0.18	0.20
	$r=11$	0.16	0.17	0.17	0.15	0.20	0.18	0.20	0.15	0.18	0.15	0.30	0.25
	$r=12$	0.25	0.18	0.10	0.18	0.25	0.18	0.10	0.18	0.10	0.15	0.18	0.15
	$r=13$	0.20	0.25	0.15	0.18	0.24	0.18	0.15	0.18	0.15	0.18	0.30	0.18
	$r=14$	0.16	0.24	0.18	0.30	0.16	0.20	0.18	0.20	0.18	0.18	0.20	0.18
	$r=15$	0.17	0.16	0.25	0.25	0.18	0.10	0.18	0.10	0.15	0.18	0.25	0.30
	$r=16$	0.18	0.25	0.24	0.24	0.18	0.15	0.18	0.15	0.18	0.30	0.20	0.25
	$r=17$	0.25	0.20	0.16	0.16	0.20	0.18	0.20	0.18	0.18	0.20	0.25	0.20
	$r=18$	0.20	0.16	0.25	0.25	0.20	0.15	0.18	0.15	0.30	0.25	0.24	0.16
$j=4$	$r=1$	0.40	0.40	0.50	0.40	0.40	0.50	0.40	0.40	0.50	0.50	0.40	0.40
	$r=2$	0.50	0.50	0.40	0.50	0.40	0.50	0.50	0.40	0.40	0.50	0.40	0.50
	$r=3$	0.40	0.50	0.40	0.50	0.50	0.50	0.50	0.40	0.40	0.40	0.50	0.50
	$r=4$	0.40	0.50	0.40	0.40	0.50	0.50	0.40	0.50	0.50	0.40	0.40	0.40
	$r=5$	0.40	0.40	0.40	0.40	0.40	0.50	0.50	0.50	0.50	0.40	0.40	0.50
	$r=6$	0.40	0.40	0.50	0.40	0.40	0.50	0.50	0.40	0.40	0.40	0.40	0.40
	$r=7$	0.50	0.40	0.50	0.50	0.40	0.40	0.50	0.50	0.40	0.50	0.50	0.40
	$r=8$	0.50	0.50	0.50	0.50	0.40	0.40	0.50	0.50	0.40	0.40	0.50	0.50
	$r=9$	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50
	$r=10$	0.40	0.50	0.50	0.40	0.50	0.40	0.40	0.40	0.50	0.40	0.40	0.50
	$r=11$	0.40	0.40	0.50	0.40	0.40	0.50	0.40	0.40	0.50	0.50	0.40	0.40
	$r=12$	0.40	0.40	0.50	0.50	0.50	0.50	0.50	0.40	0.40	0.50	0.50	0.40
	$r=13$	0.40	0.40	0.40	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.50	0.40
	$r=14$	0.50	0.40	0.40	0.40	0.50	0.50	0.40	0.50	0.50	0.40	0.40	0.40
	$r=15$	0.50	0.50	0.40	0.40	0.50	0.50	0.40	0.40	0.50	0.50	0.40	0.40
	$r=16$	0.40	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	0.50	0.40
	$r=17$	0.50	0.40	0.50	0.40	0.40	0.40	0.50	0.40	0.40	0.50	0.50	0.50
	$r=18$	0.40	0.50	0.50	0.50	0.40	0.40	0.50	0.50	0.40	0.40	0.50	0.40

Table B.10. Inventory holding cost of product in outlet retailer.

ic'_{jot}($)		$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
$j=1$	$o=1$	0.75	0.80	0.90	0.75	0.85	0.70	0.90	0.95	0.80	0.70	0.75	0.80
	$o=2$	1.25	0.90	0.90	0.95	0.80	0.90	0.75	0.65	0.75	0.90	0.95	0.80
$j=2$	$o=1$	0.90	0.90	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.90	0.70	0.70
	$o=2$	0.60	0.60	0.80	0.80	0.60	0.80	0.60	0.60	0.80	0.60	0.80	0.80
$j=3$	$o=1$	0.60	0.60	0.60	0.90	0.90	0.70	0.60	0.60	0.60	0.90	0.90	0.90
	$o=2$	0.70	0.70	0.70	0.60	0.60	0.80	0.70	0.70	0.70	0.60	0.60	0.90
$j=4$	$o=1$	0.40	0.40	0.40	0.40	0.40	0.50	0.50	0.50	0.50	0.40	0.40	0.50
	$o=2$	0.40	0.40	0.50	0.40	0.40	0.50	0.50	0.40	0.40	0.40	0.40	0.40

Table B.11. Lost sales cost of product in retailer.

l_{jt}($)	$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
$j=1$	35.00	30.00	32.00	34.00	35.00	34.00	35.00	30.00	35.00	35.00	35.00	35.00
$j=2$	20.00	21.00	22.00	22.00	23.00	23.00	24.00	25.00	24.00	24.00	25.00	25.00
$j=3$	15.00	15.00	15.00	16.00	16.00	17.00	17.00	17.00	18.00	18.00	18.00	19.00
$j=4$	13.00	13.00	13.00	14.00	14.00	14.00	15.00	15.00	15.00	16.00	16.00	16.00

TABLE B.12. Lost sales cost of product in outlet retailer.

l'_{jt}($)	$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$
$j=1$	980	950	950	1060	1060	1080	900	1030	1080	980	1020	1020
$j=2$	1080	900	920	1090	1060	980	1100	1010	920	1060	950	1060
$j=3$	1080	960	1010	1080	1090	1010	1090	1000	1040	1060	1020	960
$j=4$	1030	1030	1010	1080	1020	900	950	950	920	920	1090	990

TABLE B.13. Price of raw material.

p_{mst}($)		$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$	$t=13$
$m=1(m)$	$s=1$	46.00	38.00	47.00	46.00	44.00	44.00	45.00	45.00	45.00	48.00	38.00	38.00	38.00
	$s=2$	46.00	47.00	45.00	38.00	48.00	47.00	44.00	44.00	43.00	48.00	45.00	48.00	46.00
	$s=3$	43.00	45.00	40.00	44.00	45.00	41.00	42.00	45.00	42.00	43.00	45.00	43.00	39.00
	$s=4$	46.00	44.00	48.00	40.00	45.00	41.00	43.00	41.00	38.00	38.00	47.00	45.00	46.00
	$s=5$	45.00	46.00	45.00	39.00	38.00	47.00	44.00	42.00	44.00	40.00	46.00	44.00	41.00
	$s=6$	44.00	39.00	44.00	43.00	48.00	44.00	43.00	38.00	45.00	38.00	45.00	44.00	41.00
$m=2(m)$	$s=1$	6.00	7.00	6.00	8.00	7.00	8.00	8.00	7.00	7.00	6.00	7.00	7.00	7.00
	$s=2$	7.00	7.00	7.00	7.00	7.00	8.00	7.00	8.00	6.00	7.00	7.00	6.00	7.00
	$s=3$	6.00	6.00	6.00	7.00	6.00	6.00	6.00	7.00	6.00	7.00	6.00	6.00	8.00
	$s=4$	7.00	6.00	8.00	7.00	6.00	8.00	6.00	8.00	7.00	6.00	6.00	7.00	7.00
	$s=5$	8.00	7.00	8.00	6.00	6.00	6.00	8.00	8.00	6.00	6.00	7.00	7.00	7.00
	$s=6$	8.00	7.00	6.00	6.00	6.00	8.00	8.00	7.00	8.00	7.00	7.00	8.00	8.00
$m=3(m)$	$s=1$	15.00	15.00	14.00	13.00	14.00	14.00	15.00	15.00	15.00	16.00	14.00	15.00	15.00
	$s=2$	13.00	16.00	12.00	12.00	15.00	14.00	14.00	14.00	12.00	15.00	13.00	15.00	14.00
	$s=3$	14.00	14.00	14.00	12.00	14.00	13.00	15.00	14.00	16.00	14.00	13.00	13.00	13.00
	$s=4$	15.00	14.00	13.00	14.00	15.00	15.00	13.00	14.00	15.00	13.00	14.00	14.00	16.00
	$s=5$	16.00	16.00	15.00	14.00	12.00	16.00	15.00	14.00	14.00	12.00	12.00	16.00	12.00
	$s=6$	12.00	15.00	13.00	16.00	13.00	13.00	15.00	13.00	15.00	13.00	14.00	16.00	12.00
$m=4(m)$	$s=1$	8.00	7.00	6.00	9.00	6.00	7.00	6.00	8.00	9.00	8.00	5.00	8.00	9.00
	$s=2$	7.00	7.00	8.00	7.00	5.00	5.00	6.00	6.00	5.00	6.00	9.00	8.00	8.00
	$s=3$	6.00	6.00	5.00	9.00	7.00	8.00	6.00	9.00	5.00	7.00	7.00	8.00	8.00
	$s=4$	9.00	5.00	9.00	5.00	5.00	6.00	9.00	8.00	7.00	6.00	9.00	8.00	9.00
	$s=5$	6.00	8.00	7.00	6.00	5.00	5.00	5.00	8.00	7.00	9.00	8.00	8.00	5.00
	$s=6$	8.00	6.00	7.00	9.00	9.00	7.00	6.00	8.00	5.00	7.00	9.00	7.00	9.00
$m=5$	$s=1$	13.00	14.00	12.00	15.00	12.00	12.00	12.00	12.00	14.00	12.00	11.00	14.00	13.00
	$s=2$	13.00	14.00	13.00	13.00	14.00	12.00	14.00	12.00	14.00	12.00	10.00	12.00	14.00
	$s=3$	14.00	12.00	10.00	12.00	10.00	11.00	11.00	11.00	14.00	15.00	14.00	14.00	13.00
	$s=4$	12.00	11.00	11.00	14.00	10.00	15.00	13.00	10.00	13.00	14.00	13.00	14.00	11.00
	$s=5$	10.00	15.00	14.00	15.00	11.00	12.00	13.00	12.00	12.00	14.00	15.00	11.00	10.00
	$s=6$	10.00	14.00	14.00	15.00	11.00	14.00	11.00	11.00	10.00	10.00	14.00	15.00	11.00
$m=6$	$s=1$	0.42	0.47	0.42	0.47	0.47	0.42	0.42	0.47	0.47	0.47	0.47	0.47	0.42
	$s=2$	0.50	0.54	0.50	0.54	0.54	0.50	0.50	0.54	0.54	0.54	0.54	0.54	0.50
	$s=3$	0.60	0.56	0.60	0.56	0.56	0.60	0.60	0.56	0.56	0.56	0.56	0.56	0.60
	$s=4$	0.50	0.58	0.50	0.58	0.58	0.50	0.50	0.58	0.58	0.58	0.58	0.58	0.50
	$s=5$	0.45	0.59	0.45	0.59	0.59	0.45	0.45	0.59	0.59	0.59	0.59	0.59	0.45
	$s=6$	0.43	0.60	0.43	0.60	0.60	0.43	0.43	0.60	0.60	0.60	0.60	0.60	0.43
$m=7$	$s=1$	0.82	0.90	0.82	0.82	0.90	0.82	0.82	0.82	0.82	0.82	0.90	0.82	0.82
	$s=2$	0.90	0.95	0.83	0.90	0.95	0.83	0.83	0.90	0.83	0.90	0.95	0.83	0.83
	$s=3$	0.95	0.80	0.85	0.95	0.80	0.85	0.85	0.95	0.85	0.95	0.80	0.85	0.85
	$s=4$	0.85	0.90	0.90	0.85	0.90	0.90	0.90	0.85	0.90	0.85	0.90	0.90	0.90
	$s=5$	1.00	1.00	0.95	1.00	1.00	0.95	0.95	1.00	0.95	1.00	1.00	0.95	0.95
	$s=6$	1.05	0.95	0.97	1.05	0.95	0.97	0.97	1.05	0.97	1.05	0.95	0.97	0.97
$m=8$	$s=1$	1.65	1.85	1.65	1.65	1.85	1.65	1.65	1.85	1.65	1.65	1.65	1.85	1.65
	$s=2$	2.09	1.84	1.70	2.09	1.84	1.70	2.09	1.84	1.70	1.70	2.09	1.84	1.70
	$s=3$	2.00	2.00	1.75	2.00	2.00	1.75	2.00	2.00	1.75	1.75	2.00	2.00	1.75

Table B.13. continued.

p_{mst}(\$)		$t=1$	$t=2$	$t=3$	$t=4$	$t=5$	$t=6$	$t=7$	$t=8$	$t=9$	$t=10$	$t=11$	$t=12$	$t=13$
	$s=4$	2.05	2.05	1.85	2.00	2.00	1.75	2.05	2.05	1.85	1.85	2.00	2.00	1.75
	$s=5$	1.70	2.00	2.00	2.05	2.05	1.85	1.70	2.00	2.00	2.00	2.05	2.05	1.85
	$s=6$	1.80	1.85	2.05	1.70	2.00	2.00	1.80	1.85	2.05	2.05	1.70	2.00	2.00
$m=9$	$s=1$	1.65	1.65	1.85	1.80	1.85	2.05	1.65	1.65	1.85	1.85	1.80	1.85	2.05
	$s=2$	1.70	2.09	1.84	1.65	1.65	1.85	1.70	2.09	1.84	1.84	1.65	1.65	1.85
	$s=3$	1.75	2.00	2.00	1.70	2.09	1.84	1.75	2.00	2.00	2.00	1.70	2.09	1.84
	$s=4$	1.85	2.05	2.05	1.75	2.00	2.00	1.85	2.05	2.05	2.05	1.75	2.00	2.00
	$s=5$	2.00	1.70	2.00	1.85	2.05	2.05	2.00	1.70	2.00	2.00	1.85	2.05	2.05
	$s=6$	1.85	2.05	2.05	2.00	1.70	2.00	1.85	2.05	2.05	2.05	2.00	1.70	2.00

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