Design of Multi-Echelon Supply Chain based on Pricing Strategy and Sales Contract Approach

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Abstract

This paper evaluates the design of a supply chain with a multi-echelon distribution channel based on the pricing strategy and a sales contract approach where pricing decision-making is simultaneously performed in retailing and wholesale channels. The proposed network consists of the main manufacturer, a set of distribution centers, retailers, and wholesalers. The objective is to maximize the supply chain profit. The main decisions include the allocation of retailers and wholesalers to distribution centers, the order size for each distribution center, and the product price in retailing and wholesale channels for different payment mode. A mathematical mixed-integer nonlinear model was formulated and validated by a sensitivity analysis approach. It was found that the proposed model had good performance in terms of the objective function value and execution time, even for large-scale problems.

Keywords: *Multi-Echelon Supply Chain, Pricing Strategy, Sales Contract*

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1. Introduction

Considering ever-increasing information technology (IT) developments and market competitiveness, organizations need to make significant efforts to provide, produce, and distribute products. To succeed in such a competitive space and possess a larger share of the market, manufacturing organizations should offer a variety of products to customers based on customer requirements and implement activities such as raw material provision, production planning, demand and supply planning, distribution, and product delivery in the form of a supply chain.

These activities can be integrated into a supply chain using supply chain management methodologies to improve the efficiency of the organization to succeed in the market.
Supply chain management tools enable organizations to develop their business relations by optimizing information exchange with business partners, such as raw material suppliers, product distributors, and commodity transportation contractors. Therefore, a business institution can supply its products to the market in a much shorter time, accelerate production, and save costs. Today, organizations recognize that they should consider not only intra-organizational aspects but also their entire supply chain to improve efficiency.
Additionally, to coordinate a supply chain, one can consider the contract type, information sharing (circulation) level, IT, and inventory management type – i.e., vendor-managed inventory (VMI) or collaborative planning, forecasting, and replenishment (CPFR). Supply chain coordination through contract design mechanisms is a crucial topic in the supply chain management literature. Since confidential information on the contract is typically unavailable but important, the design of a contract for members of different supply chain levels under information asymmetry conditions has become essential. These conditions refer to a situation where one of the parties possesses a larger amount of information or more complete information than the other contract parties.
Furthermore, the pricing approach adopted in supply chain decision-making significantly impacts the total profit of the supply chain. It is even more important to adopt an efficient pricing strategy in supply chains with more than one distribution and sales channel since such supply chains typically involve a price competition between the sales channels. Thus, pricing is a crucial aspect. The product and service prices are a demand determinant. The products and services should be priced by considering internal conditions, and market conditions, and competitors. Moreover, prices should be determined such that demand is not transferred between the channels, and the channels compete with other organizations rather than competing with each other.

2. Literature review

The literature can be divided into a few groups. The first group of studies is focused on location-inventory decisions. In inventory location problems, the locations of suppliers are assumed to be known, and the objective is finding the optimal number and locations of distribution centers, allocating them to demand points, and determining the optimal inventory levels in the centers (Cortinhal et al., 2019; Escalona et al., 2018). Numerous studies have been conducted on location-inventory problems. Daskin et al. (2002) solved an inventory-location problem using the Lagrangian relaxation (LR) method. Shu et al. (2005) studied a stochastic transportation-inventory supply chain problem consisting of one supplier and several retailers with unknown customer demand. Their objective was minimizing distribution center location costs, inventory costs, and transportation costs. They introduced a heuristic method based on the column generation algorithm to solve the formulated problems. The computational results demonstrated the efficiency of their solution for a wide range of retailer numbers.

Shu (2010) assumed a multi-echelon inventory system in which warehouses and retailers coordinated their inventory complementation activities to minimize collected costs. They proposed a greedy heuristic search algorithm to solve the model and demonstrated the performance of the solution methodology. Snyder et al. (2007) introduced a stochastic location model with risk integration under discrete scenarios for facility location and inventory decisions. They formulated the problem in the form of a mixed-integer nonlinear programming (MINLP) and solved it using LR. Nasiri et al. (2010) addressed the DND problem in a multi-product supply chain with stochastic customer demand. The model decisions included distribution center location with multi-capacity levels, allocation, and inventory policy decisions. The LR method and a heuristic were used to solve the model. Mousavi et al. (2015) developed a model for the multi-period location-allocation-inventory problem. They solved the model using modified fruit fly optimization, particle swarm optimization (PSO), and simulated annealing algorithms. Ahmadi et al. (2016) addressed a multi-level DND problem for seasonal and non-seasonal problems, including facility location and inventory decisions with transportation between distribution centers. They introduced a bi-objective model to maximize the total profit and minimize customer dissatisfaction. Production and improper demand constraints were imposed, and an interactive method was employed to solve the problem.

Wang et al. (2020) formulated a green integrated supply network problem with uncertainty and carbon-trading decisions under emission-trading regulation. They developed a stochastic model with features based on the unknown market demand scenario and unstable carbon prices. They proposed a new framework for the design of green supply networks with emissions and highlighted demand uncertainty effects on distribution facilities and regulator perspectives.

The second group of studies in the literature included pricing decisions in other supply chain decisions. Ghomi-Avili et al. (2018) proposed a bi-level fuzzy pricing model to design closed-loop supply chains with price-sensitive demands and random disruptions at the supplier level. Gao et al. (2016) studied a closed-loop supply chain with one manufacturer and one retailer, in which the manufacturer regulated the rework process for products used in the main manufacturing system. The remanufactured products were assumed to be similar to the new products that could be sold at the same price in the market. They examined collection and sales efforts and pricing decisions for various channel power structures. Taleizadeh and Noori-Daryan (2016) proposed a tri-level supply chain with a supplier, a manufacturer, and a few retailers, in which the supplier price, manufacturer price, and the number of shipments were the decision variables. Demand was assumed to be linearly dependent on the price, and no shortage was allowed. The objective was to minimize the total cost for the supplier, manufacturer, and retailers. Hajipour et al. (2016) focused on a bi-objective location pricing problem in the queuing framework, where the main decision was launching a facility in a region. The problem consisted of two networks and was solved using multi-objective vibration-damping optimization. User utility was a function of the product/service price and facility-customer distance. Alfares and Ghaithan (2016) developed a model to simultaneously optimize the inventory and pricing under price-sensitive demands, time-dependent inventory maintenance costs, and quantitative discounts. Demand diversity, maintenance costs, and purchase costs were considered. Tavakkoli-Moghaddam et al. (2017) introduced a model for facility location and the pricing problem by assuming that immobilized service facilities were compacted by demands following M/M/m/k queues. They solved the model using a multi-objective metaheuristic algorithm. Darestani and Pourasadollah (2019) investigated a closed-loop supply chain design problem with financial objectives for customers to return used products. Since the residual value of used products is the main purchase motive of the manufacturer, a dynamic pricing model was proposed to determine the purchase price of such products. Matsui (2020) compared retail and wholesale decisions. They studied a dual-channel supply chain to determine efficient timing for a manufacturer to bargain with a retailer on the wholesale price.

Duan et al. (2021) explored the effects of sales effort and payment mode on a multi-echelon supply chain. The sales channels included a sales manager, a retailer, and an agent that managed both the wholesale and retail markets. Moreover, equilibrium decisions were compared in three different scenarios, particularly the sales amount and payment mode.

The third group of studies focused on location-inventory-pricing problems (Nasiri et al., 2021). Ahmadi-Javid and Hoseinpour (2015a) proposed a location-inventory-pricing problem for multi-product supply chains through continuous inventory checks and price-sensitive demand with and without facility capacity constraints. They utilized markup levels for product pricing and solved the problem using the LR method. Ahmadi-Javid and Hoseinipour (2015b) proposed a location-inventory-pricing model for DND with price-sensitive demands and facility capacity constraints and solved it using an LR algorithm. Kaya and Urek (2016) developed a location-inventory-pricing model in a closed-loop supply chain. The model was solved using a heuristic method. Their model integrated the reverse flow of used products with the distribution flow of new products.

A review of the literature suggests that multiple distribution channels, supply chain sales contracts, and pricing strategy were not discussed in previous studies, The present study investigates a multi-period single-product supply chain network with one manufacturer, a set of distribution centers, and a set of wholesalers and retailers. The objective is the maximization of the total profit in the supply chain by considering the product price in retail and wholesale channels for different payment models. The novelty of the present study lies in:

(1) Developing a supply chain model with multiple distribution channels at the manufacturer level and
(2) Considering the pricing strategy and sales contract approach in the developed model.

The remainder of the study is organized as follows: Section 3 describes the developed model; Section 4 evaluates the developed model using a real-life case study in GAMS and performs a sensitivity analysis; Section 5 discusses the results; and, Section 6 concludes the work.

3. Description of the developed model

As mentioned, the present work analyzes a multi-period single-product supply chain network with a manufacturer, a set of distribution centers, and a set of wholesalers and retailers. The objective is to maximize the total profit of the supply chain by considering the product price in wholesale and retail channels under different modes of payment.

An efficient pricing strategy significantly contributes to the profitability of an organization. In particular, pricing is even more important in organizations with more than one channel to sell and distribute products. Fig. 1 illustrates a schematic of the developed supply chain network.

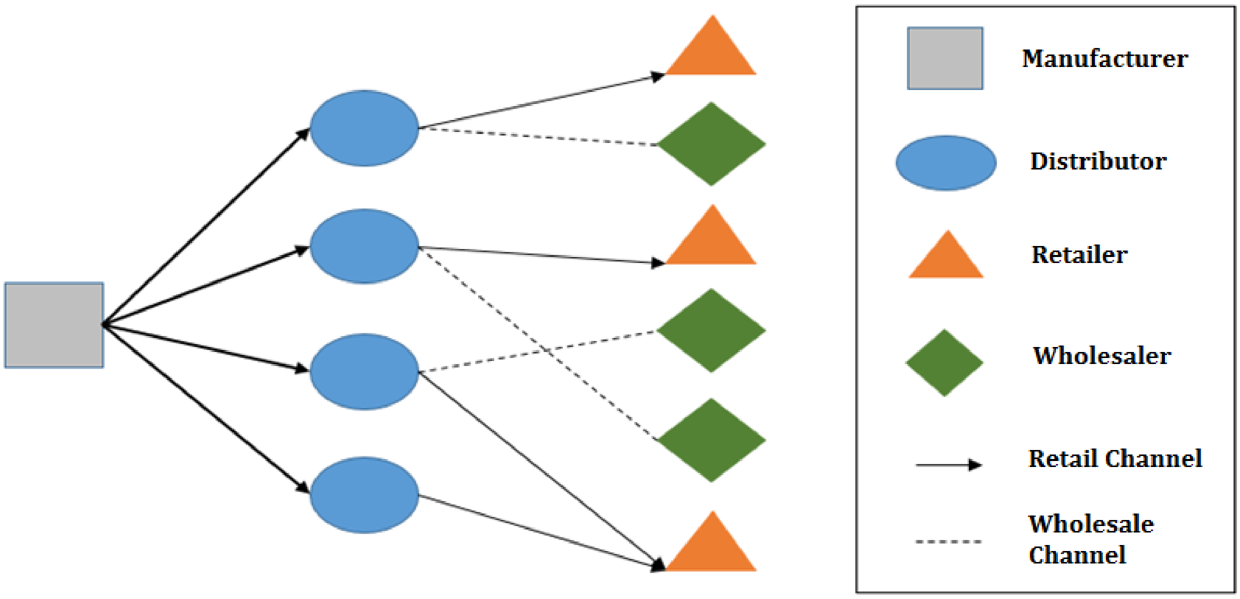


Fig 1. Schematic of the developed supply chain network

The assumptions, indices, parameters, and decision variables of the developed model are described below.

3.1. Assumptions

The assumptions included:

(1) The supply chain consists of retail and wholesale channels and distribution centers
(2) A multi-period supply chain problem
(3) Shortages are not allowed in the retail and wholesale channels
(4) A single-product supply chain problem
(5) Uncertain and price-sensitive demands

3.2. Indices

The indices included:

i: set of retailers (i=1, 2, …I)

j: set of candidate distribution center locations (j=1, 2,… J)

H: set of available capacities at level h for the distributor

W: set of wholesalers
T: set of periods for payment

3.3. Parameters

The parameters of the model were:
$TC1_{ji}$: Transportation cost per unit product between the manufacturer, distributor *j*, and retailer *i*
$TC2_{jw}$: Transportation cost per unit product between the manufacturer, distributor *j*, and wholesaler *w*
F_{jh}: Launching cost of distributor *j* at level *h*
m_1: Sensitivity coefficient of retainer demand from the manufacturer at the retail price in the retail channel
m_2: Sensitivity coefficient of retainer demand from the manufacturer at the wholesale price in the wholesale channel
m_3: Sensitivity coefficient of wholesaler demand from the manufacturer at the wholesale price
l_j: Process completion time for distribution center *j*
r_j: Re-order point for distribution center *j*
σ_{it}^2: Demand variance of retailer *i* with payment period *t*
σ_{wt}^2: Demand variance of wholesaler *w* with payment period *t*
$z_{1-\alpha}$: Z-value in the normal distribution function, in which $1-\alpha$ denotes the service level of the distribution network
CH_j: Maintenance cost per unit in distribution center *j*
CS_j: Constant cost of ordering from the manufacturer for distribution center *j*
cap_{jh}: Capacity of distribution center *j* at level *h*
$Pop1_i$: Average population in retailer *i*
$Pop2_w$: Average population in wholesaler *w*
ε_1: Lower bound of the allowed price difference percentage between the retail and wholesale channels, which is determined by marketing policies
ε_2: Upper bound of the allowed price difference percentage between the retail and wholesale channels, which is determined by marketing policies
γ: Demand leak rate (the rate of demands transferred from the higher-price channel to the lower-price one)
pr_t^{LB}: Lower bound of the price product in the retail channel with payment period *t*
pr_t^{UB}: Upper bound of the price product in the retail channel with payment period *t*
pw_t^{LB}: Lower bound of the price product in the wholesale channel with payment period *t*
pw_t^{UB}: Upper bound of the price product in the wholesale channel with payment period *t*
PH: Time horizon
ss_i: Safety stock in distribution center *j*
S: Space per unit product in each distribution center
λ_w: Excess profit deduction of wholesaler *w* to the manufacturer ($0 < \lambda_w < 1$)

β_w: Minimum guaranteed profit of wholesaler *w*

π_w: Excess profit of wholesaler *w* ($\pi_w \geq 0$)

ρ_{it} : Profit of retailer *i*

μco_w : Average demand of the end consumer from wholesaler *w*

3.3. Decision variables

$P3_{wt}$: Final product price soled by wholesaler *w* to the end consumer

$P2_{wt}$: Minimum price determined by the manufacturer for sales from wholesaler *w* to the end consumer

X_{jh}: Binary variable, which is 1 if distribution center *j* is established at capacity level *h*; otherwise, it is zero.

Y_{jh}: Binary variable, which is 1 if retailer *i* is allocated to distribution center *j;* otherwise, it is zero.

Y'_{jh}: Binary variable, which is 1 if wholesaler *i* is allocated to distribution center *j;* otherwise, it is zero.

pr_{it}: Product price offered by the distribution center to the retail channel with payment period *t*

pw_{wt}: Product price offered by the distribution center to the wholesale channel with payment period *t*

Q_j: Order quantity in distribution center *j*

D_j: Mean of the allocated demand in distribution center *j*

V_j: Variance of the allocated demand in distribution center *j*

μ_{jit}: Mean demand of retailer *i* from distribution center *j* with payment period *t*

μ'_{jwt}: Mean demand of wholesaler *w* from distribution center *j* with payment period *t*

3.4. Mathematical modeling

$\text{Max } Z = \sum_{w=1}^{W} \lambda_w \mu co_{wt}(p3_{wt} - p2_{wt}) + \sum_{j\in J}\sum_{i\in I}\sum_{t\in T}^{I} PH.\, pr_{it}.\ \mu_{jit} + \sum_{j\in J}\sum_{w\in W}\sum_{t\in T}^{I} PH.\, pw_{wt}\ \mu' - \sum_{j\in J}\sum_{i\in I}\sum_{t\in T}^{I} PH.\, TC1_{ji}.\ \mu_{jit} - \sum_{j\in J}\sum_{w\in W}\sum_{t\in T}^{I} PH.\, TC2_{jw}\ \mu'_{jwt} - \sum_{j\in J}\sum_{h\in H} X_{jh}.\, F_{jh} - \sum_{j\in J} CH_j.\sqrt{D_j} - \sum_{j\in J} CS_j.\sqrt{V_j}$	(1)
S.t:	
$\sum_{i=1}^{I} Y_{ji} = 1 \qquad \forall i$	(2)
(2) $\sum_{j=1}^{J} Y'_{jw} = 1 \qquad \forall w$	(3)

(3) $D_j . s \le \sum_{h \epsilon H}^{H} cap_{jh} . X_{jh} = 1 \qquad \forall j$	(4)
(4) $\sum_{h=1}^{H} X_{jh} = 1 \qquad \forall j$	(5)
(5) $\mu_{jit} = [pop1_i - m_1 pr_{it} + m_2 pw_{wt} - \gamma\,(pr_{it} - pw_{wt})] . Y_{ji} \qquad \forall j, i, t$	(6)
(6) $\mu'_{jwt} = [pop2_w - m_3 pw_{wt} + \gamma\,(pr_{it} - pw_{wt})] . Y'_{jw} \qquad \forall j, w, t$	(7)
(7) $\sum_{i}^{I} \sum_{t} \mu_{jit} . Y_{ji} + \sum_{w}^{I} \sum_{t} \mu'_{jwt} . Y'_{jw} = D_j \qquad \forall j$	(8)
(8) $\sum_{i}^{I} \sum_{t} \sigma_{it}^2 . Y_{ji} + \sum_{w}^{I} \sum_{t} \sigma_{wt}^2 . Y'_{jw} = V_j \qquad \forall j$	(9)
(9) $\varepsilon_1 \le \frac{pr_{it} - pw_{wt}}{pr_{it}} \le \varepsilon_2 \qquad \forall t$	(10)
(9) $\varepsilon_1 \le \frac{pr_{it} - pw_{wt}}{pr_{it}} \le \varepsilon_2 \qquad \forall t$	(11)
(10) $pr_t^{LB} \le pr_{it} \le pr_t^{UB}$	(12)
(11) $pw_t^{LB} \le pw_{wt} \le pw_t^{UB}$	(13)
$(1 + \rho_{it})\, pr_{it} = pco_t$	(14)
(13) $(1 + \beta_w)\, pw_{wt} = P2_{wt}$	(15)
(14) $(1 + \pi_w)\, P2_{wt} = P3_{wt}$	(16)
$pr . pc . p2_c . p3_c . pco . R_j . \mu_i . \mu_c . \mu co_c . Q_{ckj} . V . D \ge 0,$	(17)

The objective function is profit maximization. The first and second terms represent the income of sales from the manufacturer to wholesale and retail channels, respectively in the programmed time horizon. The third term stands for the income of the revenue-sharing contract with the wholesale channel. The fourth and fifth terms represent the costs of transportation from the manufacturer to the retail and wholesale channels, respectively. Finally, the sixth term denotes the cost of chain channel discounts.

Constraints 1 and 2 indicate that each retailer and wholesaler should be allocated to a distribution center. Constraint 3 requires that the demand in a distribution center be proportionate to its capacity. Constraint 4 implies that the capacity of a distribution center is proportionate to its h-level capacity. Constraints 5 and 6 determine the average demand and price level for the retailer and wholesaler, respectively. Constraints 7 and 8 calculate the mean and variance of the retailer and wholesaler input demands in each distribution center, respectively. Constraint 9 stands for the pricing strategy, based on which the retail channel price should be set such that the price of sales from the wholesaler to the retailer is not lower than the offered distribution center price. Constraints 10 and 11 denote the upper and lower price bounds of the wholesale and retail channels, respectively. Constraint 12 determines the final price of sales from the retail channel to the end consumer. Also, Constraint 13 imposes the minimum price of sales from the wholesale channel to the end consumer, while Constraint 14 determines the final price of sales from the wholesale channel to the end consumer.

4. Linearization of the mathematical model

As can be seen, the objective function and constraints 5, 6, and 7 contain nonlinear terms. Thus, the nonlinear model is linearized by defining auxiliary variables and incorporating a number of additional constraints based on Pishvaei et al. (2012). For variables *x* and *y* in a nonlinear equation, auxiliary variable *z* is defined as z=xy. Then, the nonlinear constraint changes into:

$Z \geq Y - M(1-X)$	(18)
$Z \leq Y + M(1-X)$	(19)
$Z \leq MX$	(20)
$Z \in \text{integer}$	(21)

Where M is a very large positive value. Therefore, if nonlinear relations $\theta 1 = \mathrm{pr}_{it}.\ \mu_{jit}$ and $\theta 2 = \mathrm{pw}_{wt}\ \mu'_{jwt}$ hold for the objective function, the nonlinear objective function becomes:

$\text{Max Z} = \sum_{w=1}^{W} \lambda_w \mu co_{wt}(p3_{wt} - p2_{wt}) + \sum_{j\in J}\sum_{i\in I}\sum_{t\in T}^{I} \mathrm{PH}.\theta 1_{jit} + \sum_{j\in J}\sum_{w\in W}\sum_{t\in T}^{I} \mathrm{PH}.\theta 2_{jwt} - \sum_{j\in J}\sum_{i\in I}\sum_{t\in T}^{I} \mathrm{PH}.\mathrm{TC1}_{ji}.\ \mu_{jit} - \sum_{j\in J}\sum_{w\in W}\sum_{t\in T}^{I} \mathrm{PH}.\mathrm{TC2}_{jw}\ \mu'_{jwt} - \sum_{j\in J}\sum_{h\in H} X_{jh}.F_{jh} - \sum_{j\in J} \mathrm{CH}_j.\sqrt{D_j} - \sum_{j\in J} \mathrm{CS}_j.\sqrt{V_j}$	(22)
$\theta 1_{jit} \geq \mu_{jit} - M(1 - \mathrm{pr}_{it})$	(23)
$\theta 1_{jit} \leq \mu_{jit} + M(1 - \mathrm{pr}_{it})$	(24)
$\theta 1_{jit} \leq M\mathrm{pr}_{it}$	(25)
$\theta 2_{jwt} \geq \mu'_{jwt} - M(1 - \mathrm{pw}_{wt})$	(26)
$\theta 2_{jwt} \leq \mu'_{jwt} + M(1 - \mathrm{pw}_{wt})$	(27)
$\theta 2_{jwt} \leq M\mathrm{pw}_{wt}$	(28)

Moreover, if nonlinear relations $\vartheta 1 = \mathrm{pr}_{it}.\mathrm{Y}_{ji}$, $\vartheta 2 = \mathrm{pw}_{wt}.\mathrm{Y}_{ji}$, $\vartheta 3 = \mathrm{pw}_{wt}.\mathrm{Y}'_{jw}$, and $\vartheta 4 = \mathrm{pr}_{it}.\mathrm{Y}'_{jw}$ hold for Constraints 6 and 7, these nonlinear constraints change into:

$\mu_{jit} = \left[pop1_i . Y_{ji} - m_1 \vartheta1_{jit} + m_2 \vartheta2_{jiwt} - \gamma\left(\vartheta1_{jit} - \vartheta2_{jiwt}\right)\right] \quad \forall j, i, t$	(29)
$\vartheta1_{jit} \geq Y_{ji} - M(1 - pr_{it})$	(30)
$\vartheta1_{jit} \leq Y_{ji} + M(1 - pr_{it})$	(31)
$\vartheta1_{jit} \leq M pr_{it}$	(32)
$\vartheta2_{jiwt} \geq Y_{ji} - M(1 - pw_{wt})$	(33)
$\vartheta2_{jiwt} \leq Y_{ji} + M(1 - pw_{wt})$	(34)
$\vartheta2_{jiwt} \leq M pw_{wt}$	(35)
$\mu'_{jwt} = \left[pop2_w . Y'_{jw} - m_3 \vartheta3_{jwt} + \gamma\left(\vartheta4_{jwit} - \vartheta3_{jwt}\right)\right] \quad \forall j, w, t$	(36)
$\vartheta3_{jwt} \geq Y'_{jw} - M(1 - pw_{wt})$	(37)
$\vartheta3_{jwt} \leq Y'_{jw} + M(1 - pw_{wt})$	(38)
$\vartheta3_{jwt} \leq M pw_{wt}$	(39)
$\vartheta4_{jwit} \geq Y'_{jw} - M(1 - pr_{it})$	(40)
$\vartheta4_{jwit} \leq Y'_{jw} + M(1 - pr_{it})$	(41)
$\vartheta4_{jwit} \leq M pr_{it}$	(42)

Furthermore, if $\vartheta5 = \mu_{jit}. Y_{ji}$ and $\vartheta6 = \mu'_{jwt}. Y'_{jw}$ are the case with Constraint 8, the nonlinear objective function and Constraint 8 become:

$\sum_{i}^{I} \sum_{t} \vartheta5_{jit} + \sum_{w}^{I} \sum_{t} \vartheta6_{jwt} = D_j \quad \forall j$	(43)
$\vartheta5_{jit} \geq Y_{ji} - M(1 - \mu_{jit})$	(44)
$\vartheta5_{jit} \leq Y_{ji} + M(1 - \mu_{jit})$	(45)
$\vartheta5_{jit} \leq M \mu_{jit}$	(46)
$\vartheta6_{jwt} \geq Y'_{jw} - M(1 - \mu'_{jwt})$	(47)
$\vartheta6_{jwt} \leq Y'_{jw} + M(1 - \mu'_{jwt})$	(48)
$\vartheta6_{jwt} \leq M \mu'_{jwt}$	(49)

5. Results and discussion

This study developed a tri-level multi-period single-product mathematical model with a manufacturer, distributors, and several retailers and wholesalers. To maximize the profit of the proposed supply chain network, the present work adopted a methodology based on mathematical modeling, simulation, and system behavior analysis through simulation technology. Tools such as mathematical programming models, uncertain programming, and simulations could be used to solve such a problem. The proposed model was coded and solved in GAMS. The data and parameters were adopted from a numerical case study.

5.1. Numerical results

As mentioned, the proposed model was coded in GAMS V.24.1.2 and executed on a PC with a Corei7@2.3GHz CPU and 4GB RAM. The solution was obtained in shorter than 1.44 s in all the executions. The model was validated using the sensitivity analysis of a number of parameters, evaluating the performance of the model. Five scenarios (based on the number of distribution centers) were implemented to validate and solve the proposed model. The model had one objective function (i.e., profit maximization). Table 1 reports the performance of the proposed model based on the number of distribution centers. It divides the GAMS results based on the objective function value and execution time

Table 1. Performance of the proposed model based on the number of distribution centers

SOLUTION	DISTRIBUTION CENTER (J)	Gams	
		Objective function	Execution Time
TP 1	3	1063	5.157
TP 2	5	1486	27.479
TP 3	7	1705	49.607
TP 4	9	1560	101.222
TP 5	10	1529	143.017

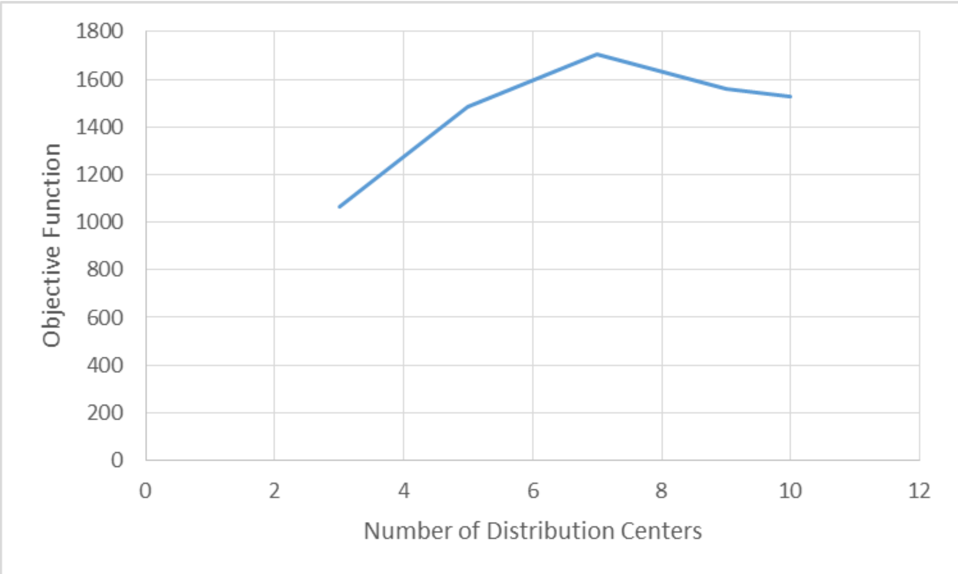


Fig. 2. First objective function versus the number of distribution centers

According to Fig. 2, the profit (objective function) increased as the number of distribution centers increased. The objective function was maximized for seven distribution centers in Scenario 3 and then began to decline at a relatively moderate rate. Fig. 2.4 plots the model execution time versus the number of distribution centers.

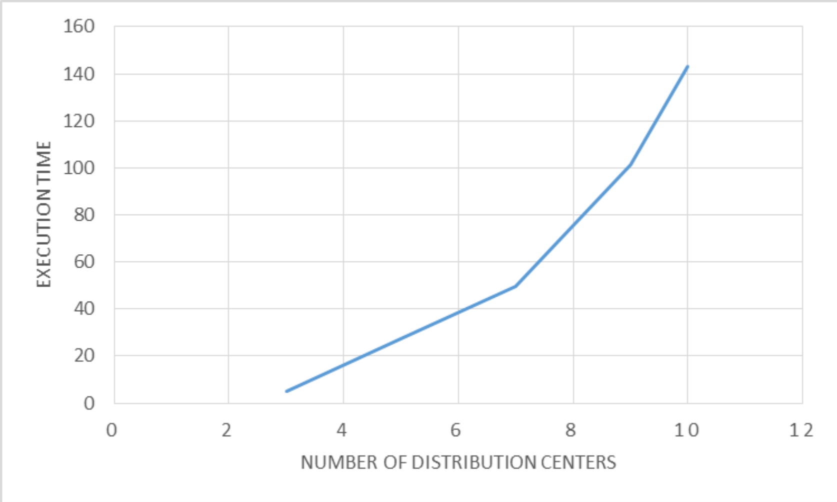


Fig. 3. Model execution time versus the number of distribution centers

According to Fig. 3, the execution time expectedly increased as distribution centers rose in number. The rising rate of the execution time elevated once the number of distribution centers rose from 5 to 7.

5.2. Sensitivity analysis

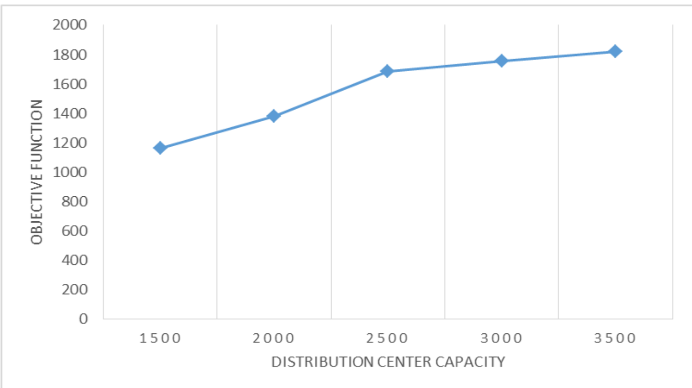
To explore the effects of different parameters on the proposed model, a sensitivity analysis was carried out on the parameters.

5.2.1. Sensitivity analysis of $cap_{j,h}$

Table 3.4 indicates the sensitivity of the objective function to the capacity of distribution center j at level h. As can be seen, the objective function rose as the distribution center capacity increased.

Table 2. Sensitivity analysis of $\boldsymbol{cap_{j,h}}$

Row	$\mathbf{cap_{j,h}}$	Obj
1	1500	1165
2	2000	1378
3	2500	1687
4	3000	1756
5	3500	1820



Fig, 4. Sensitivity of the objective function to $\boldsymbol{cap_{j,h}}$

Fig. 4 plots the sensitivity of the objective function to the distribution center capacity. According to Fig. 4, a rise in the distribution center capacity raised the objective function. In other words, the expected profit was larger at higher distribution center capacities. A further increase in the capacity led to a smaller rising rate of the objective function.

5.2.2. Sensitivity analysis of demand parameters m_1, m_2, and m_3

Table 3 reports the sensitivity of the objective function to demand parameters m_1, m_2, and m_3. As can be seen, the first objective function declined as the demand parameters rose.

The optimal demand parameters were found to be $m_1 = 0.75$, $m_2 = 0.002$, and $m_3 = 0.85$ after analyzing the sensitivity of the objective function to demand parameters in a range of 0.05-0.25.

Table 3. Sensitivity analysis results of the demand parameters

Raw	Range of changes (%)	$obj\ (m_1)$	$obj(m_2)$	$obj(m_3)$
1	0	1486	1486	1486
2	0.05	1395	1425	1410
3	0.10	1310	1390	1358
4	0.15	1197	1324	1267
5	0.20	965	1281	1108
6	0.25	648	1239	1059

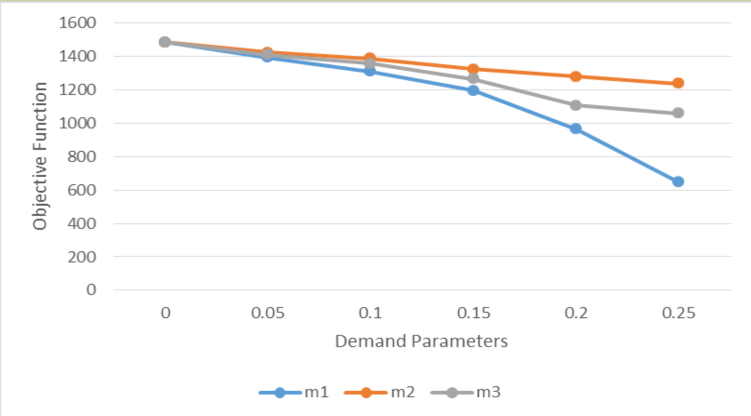


Fig. 5. Objective function versus demand parameters

Fig. 5 plots the objective function versus the demand parameters. According to Fig. 5, the objective function diminished as the demand parameters increased. Also, the objective function has the highest sensitivity to m_1 and the lowest sensitivity to m_2.

5.2.3. Sensitivity analysis of γ

Table 4 shows the sensitivity of the objective function to the demand leakage rate γ. It can be inferred that a rise in the demand leakage rate raised the objective function.

Table 4. Sensitivity analysis of γ

Row	γ(%)	Obj
1	0	1486
2	0.05	1367
3	0.10	1207
4	0.15	1167
5	0.20	953
6	0.25	725

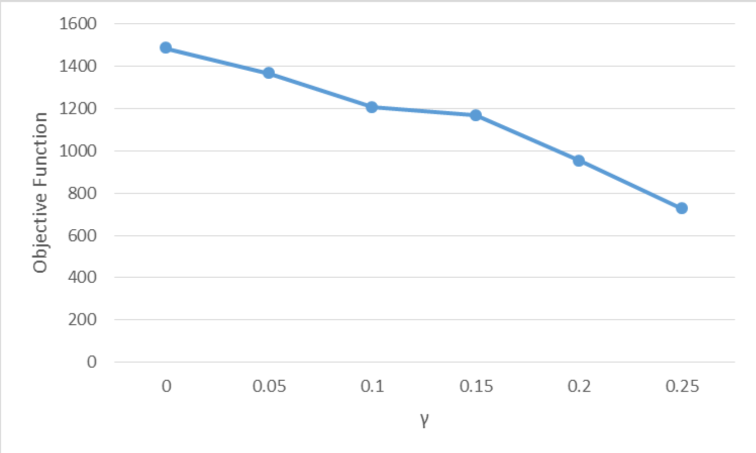


Fig. 6. Objective function versus γ

Fig. 6 plots the objective function versus the demand leakage rate. As can be seen, the objective function declined as the demand leakage rate increased. In other words, the expected profit of the supply chain was found to be lower at higher demand leakage rates.

6. Conclusion

This paper proposed a supply chain design problem with a multi-echelon distribution channel based on the pricing strategy and sales contract approach, in which pricing decisions in the wholesale and retail channels were made simultaneously. The main objective of the proposed model was supply chain profit maximization, and the main decisions included wholesaler and retailer allocation to distribution centers, order size in each distribution center, and product prices in wholesale and retail channels for different payment modes. The computational results indicated that the proposed model had good performance in terms of the objective function value and execution time, and the solution was derived in shorter than 1.44 s in all the executions. The model was validated using the sensitivity analysis of some important parameters, evaluating model performance. To validate and solve the model, five scenarios were implemented based on the number of distribution centers. The sensitivity analysis results indicated that the objective function increased as the distribution center capacity increased. Furthermore, a simultaneous rise in the demand parameters reduced the objective function.

7. Resource

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