پژوهش‌های نوین در تصمیم‌گیری

دوره ۱۰، شماره ۵، زمستان ۱٤۰٤، صص ۱٦۹-۱۹۱

نوع مقاله: پژوهشی

رفع بحران نقدینگی در زنجیره تأمین دارویی ایران با اعتبار فروش به‌عنوان ابزار هماهنگی بهینه در شرایط قیمت ثابت

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تاریخ دریافت: ۱٤۰٤/۰۳/۲۳ تاریخ پذیرش: ۱٤۰٤/۰۹/۰٦

چکیده

در صنعت داروسازی ایران، توزیع‌کنندگان از اعتبار فروش به‌عنوان اصلی‌ترین ابزار مدیریت تقاضا و حفظ سهم بازار استفاده می‌کنند. با این حال، استفاده بی‌برنامه و بیش از حد اعتبار تجاری (فروش)، عامل عمده بحران نقدینگی داروخانه‌ها، کاهش شدید حجم سفارش، گاهی ورشکستگی‌های کامل و در نتیجه کاهش دسترسی بیماران به داروهای ضروری شده است. این پژوهش یک مدل هماهنگی بهینه مبتنی بر اعتبار فروش ارائه می‌دهد و نشان می‌دهد که همین ابزار رایج صنعت، در صورت تنظیم علمی دوره اعتبار، قادر است بحران مالی را به‌طور قابل توجهی کاهش دهد. مدل پیشنهادی در چارچوب بازی استکلبرگ پیشرو-پیرو فرموله شده و زوال وابسته به دما (توزیع وایبول) را برای رعایت محدودیت‌های زنجیره سرد دارویی در نظر می‌گیرد. با به‌کارگیری برنامه‌ریزی کسری مقعر، شبه‌مقعر بودن تابع سود سالانه اثبات شده و وجود جواب بهینه یکتا و سراسری برای هر ترکیب پارامترهای قراردادی تضمین می‌گردد. روش حل ترکیبی از الگوریتم جستجوی تکراری کارآمد با اعتبارسنجی جامع بروت‌فورس در پایتون است. رویکرد پیشنهادی بدون نیاز به منابع مالی اضافی یا تغییر مقرراتی، بلافاصله قابل اجراست و از رویه‌های موجود صنعت استفاده می‌کند. نتایج عددی نشان‌دهنده بهبود تا ۱۹.۷٪ سود و افزایش بیش از سه برابری حجم سفارش نسبت به حالت نامتمرکز است. این پژوهش چارچوبی عملی و کم‌هزینه در اختیار توزیع‌کنندگان و داروخانه‌ها (خرده‌فروشان) قرار می‌دهد تا رایج‌ترین ابزار مدیریت تقاضای خود را به مکانیزمی مؤثر برای هماهنگی تبدیل کنند و به‌طور همزمان سودآوری، پایداری جریان نقدی و دسترسی بیماران به داروها را بهبود بخشند.

کلیدواژه‌ها: هماهنگی زنجیره تأمین، بازار دارویی تنظیم شده، اعتبار تجاری- فروش، اعتبار سنجی جستجوی جامع (بروت فورس)، زبان برنامه‌نویسی پایتون.

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Alleviating Cash-Flow Crises in the Iranian Pharmaceutical Supply Chain through Optimal Trade-Credit Coordination under Fixed Pricing

Abstract

In the Iranian pharmaceutical industry, distributors widely rely on trade credit as the primary demand-management instrument to preserve market share. However, unplanned and excessive extensions of credit periods have become a major source of pharmacy liquidity crises, sharp reductions in order volumes, occasional bankruptcies, and, ultimately, diminished patient access to essential medicines. This study develops an optimal trade-credit coordination model and demonstrates that scientifically calibrating the credit duration, using this prevalent industry practice, can substantially alleviate financial distress. The model is formulated within a Stackelberg leader–follower framework and incorporates temperature-dependent Weibull deterioration to capture the cold-chain constraints of pharmaceutical products. Concave fractional programming is employed to establish that the annual total profit function is strictly pseudo-concave, thereby guaranteeing the existence and uniqueness of a global optimal solution for feasible contract parameters. The solution methodology combines an efficient iterative search algorithm with exhaustive brute-force validation implemented in Python. The proposed approach requires no additional financial resources or regulatory changes and can be readily implemented using existing industry practices. Numerical results indicate profit improvements of up to 19.7% and more than a threefold increase in order quantity relative to the decentralized baseline. Overall, the framework provides distributors and pharmacies (retailers) with a practical, cost-free means of transforming a common demand-management instrument into an effective coordination mechanism that enhances profitability, cash-flow stability, and patient access to medicines.

Keyword: Supply chain coordination, Regulated pharmaceutical markets, Trade credit, Brute-force validation, Python.

1- Introduction

The pharmaceutical supply chain is fundamental to ensuring equitable access to essential medicines and maintaining a continuous flow of products from production to patients [1]. In regulated markets such as Canada, Japan, and Iran, price ceilings and subsidy mechanisms are implemented to enhance affordability and accessibility [2]. Regulatory authorities determine fixed selling prices at each stage, from manufacturer to distributor, distributor to pharmacy, and pharmacy to consumer, thereby eliminating price-based competition across the supply chain [3]. To safeguard product availability, multiple distributors are licensed to supply identical generic medicines, shifting competition toward non-price instruments such as quantity discounts and promotional credit terms [4].

However, this regulatory structure generates systemic distortions [5]. Fixed pricing compresses margins, pushing distributors toward aggressive trade-credit promotions, while multi-licensing intensifies volume-based competition and amplifies cash-flow pressures. In Iran, these forces have led to severe liquidity crises: pharmacies delay replenishment—thereby increasing spoilage risk—distributors face erratic ordering patterns, and manufacturers experience funding shortfalls. Collectively, these effects have resulted in bankruptcies and impaired patient access to temperature-sensitive medicines [6].

While prior studies predominantly focus on operational aspects such as cold-chain logistics or deterioration control [7, 8], the financial dimension of pharmaceutical supply chains, particularly under regulated pricing regimes, remains largely understudied. For temperature-sensitive medicines, Weibull-based deterioration further exacerbates supply-chain fragility [9]. Empirical evidence from Iran indicates that, due to fixed retail margins, pharmacy demand is driven primarily by trade-credit parameters rather than prices, with pharmacies responding mainly to credit-based incentives [10]. This misalignment between regulatory pricing structures and financial constraints heightens bankruptcy risk and supply instability, underscoring the need for more effective coordination mechanisms.

Motivated by these challenges, this study develops an optimization model for a two-echelon pharmaceutical supply chain consisting of a distributor (Stackelberg leader) and multiple pharmacies (retailers/followers) operating under fixed pricing, temperature-dependent Weibull deterioration, and trade credit as a prevalent coordination and demand-management mechanism. The proposed framework integrates fixed retail pricing with trade-credit decisions in a manner that reflects the practical constraints observed in regulated pharmaceutical markets and demonstrates how appropriate calibration of the credit period can substantially mitigate liquidity pressures along the supply chain (see Figure 1).

In addition, the demand structure incorporates the effects of a firm's own credit terms, competing credit offers, and credit duration, thereby capturing competitive credit-based interactions at the pharmacy (retailer) level. Product deterioration is modeled using a temperature-dependent two-parameter Weibull distribution, enabling a more realistic representation of pharmaceutical shelf-life behavior within a trade-credit coordination setting. From a methodological perspective, the analysis establishes the pseudo-concavity of the profit function and the uniqueness of the global optimum using concave fractional programming techniques. The robustness of the optimal solution is validated through extensive global optimality checks based on a grid search implemented in Python across a wide range of realistic scenarios, complemented by a practical Excel-based decision-support tool.

The remainder of the paper is organized as follows. Section 2 reviews the related literature, Section 3 formulates the problem and develops the mathematical model, Section 4 presents the proposed solution methodology, Section 5 reports numerical experiments, sensitivity analyses, and managerial insights, and Section 6 concludes the study and outlines directions for future research.

2- Literature Review

Fixed pricing and regulatory constraints in pharmaceutical markets

Regulated markets (e.g., Canada, Japan, and Iran) impose fixed retail pricing to ensure affordability and access to essential medicines [2]. By eliminating price competition, such pricing ceilings force firms to rely on non-price mechanisms; however, existing supply-chain coordination models rarely incorporate this critical regulatory constraint [3-5].

Deterioration modeling and temperature-sensitive pharmaceuticals

Most studies on pharmaceutical perishability focus on cold-chain logistics or generic deterioration functions [7, 8, 11]. Despite its strong relevance for biologics and temperature-sensitive medicines, temperature-dependent Weibull deterioration remains largely unexplored in coordination and financial-optimization models and has not been explicitly linked to cash-flow constraints or trade-credit incentives [9].

Trade-credit-based demand and incentive mechanisms

Trade credit has been widely examined as a demand-stimulation and coordination instrument; however, most existing models assume the presence of price competition. In fixed-price markets, pharmacy demand depends primarily on the attractiveness of own and competitors' credit terms—a critical feature supported by empirical evidence from Iran [10] but largely absent from the existing literature.

Coordination of perishable-goods supply chains

A variety of coordination contracts for perishable-goods supply chains have been proposed, including trade credit [۱۲], quantity discounts [۱۳], cost and revenue sharing [۱۴], two-part tariffs [۱۵], revenue-sharing and discount schemes [۱٦].

Table 1 Comparison of the present study with related literature on coordination of perishable goods supply chains

Reference	Fixed pricing	Weibull deterioration (Temp-dep.)	Demand (Credit-Sensitive)	Type of demand	Supply chain structure	Coordination mechanism
[۱۲]	No	No	No	Price & Credit -sensitive	2	Trade Credit+ optimal markdown time
[۱۷]	No	No	No	Deterministic demand	2	Trade Credit
[۱۳]	No	No	No	Price-sensitive	2	Quantity Discount
[۱۴]	No	No	No	Price-sensitive	2	Cost & Revenue Sharing
[۱۸]	No	No	No	Price & freshness sensitive	2	Revenue Sharing
[۱۵]	No	No	No	Price & freshness sensitive	2	Two-Part Tariffs
[۱۶]	No	No	No	Price-sensitive	2	Revenue Sharing + Quantity Discount
[۱۹]	No	No	No	Price & Credit sensitive	2	Partial Trade Credit
[20]	No	No	No	Price & freshness sensitive	2	Wholesale price; cost-sharing; revenue-sharing; transfer payment
[21]	No	No	No	Price & freshness sensitive	2	cost-sharing

Reference	Fixed pricing	Weibull deterioration (Temp-dep.)	Demand (Credit-Sensitive)	Type of demand	Supply chain structure	Coordination mechanism
[22]	No	No	No	freshness sensitive	2	Revenue + freshness-investment sharing
[23]	No	No	No	Price & freshness sensitive	2	Wholesale price; revenue-sharing
[24]	No	No	No	Price & freshness sensitive	3	Advance–cash–credit
Present study	**Yes**	**Yes**	**Yes**	**Credit-Based Demand (Own & Competitors**	**2**	**Trade Credit**

As shown in Table (1), previous studies on perishable-goods coordination have largely emphasized quantity discounts, revenue sharing, or partial trade credit, typically assuming simpler deterioration structures (fixed or time-dependent rates) and demand functions sensitive to price or freshness. Very few studies incorporate competitors' credit offers into demand modeling or adopt temperature-dependent Weibull deterioration to capture cold-chain realities. Notably, no prior work simultaneously treats fixed retail pricing and trade credit as core structural constraints in regulated pharmaceutical markets. This study addresses this gap by proposing a trade-credit-centric coordination framework tailored to pharmaceutical supply chains operating under regulatory pricing and reimbursement delays, thereby offering a more realistic and practically applicable approach to mitigating liquidity crises and improving medicine accessibility.

3- Problem Description and Formulation

This study examines a two-echelon pharmaceutical supply chain in Iran, consisting of a distributor (leader) and pharmacies as retailers (followers), operating under a fixed-pricing regime. With price competition eliminated, trade credit becomes the sole effective instrument for stimulating demand. However, unplanned or improperly designed credit extension can lead to severe liquidity shortages and reduced access to essential medicines. This paper demonstrates that a scientifically calibrated trade-credit duration can effectively address these challenges while maximizing overall supply chain profit under temperature-dependent Weibull deterioration.

Notation and indices

The following notations are used throughout the paper:

Indices

Nu	Set of pharmacies indexed *i*
J	Set of substitute products indexed *j*

Parameters

$I(t)$	Inventory level at time *t*.
$I_i(t)$	Inventory level of the *i-th* pharmacy (retailer) at time *t*
$\theta(t)$	Time-varying deterioration rate at time *t*, where $0 \leq \theta(t) \leq 1$.
φ	Temperature-dependent coefficient (scale parameter)
τ	Temperature-dependent coefficient (shape parameter)
D_i	Demand function of *i-th* pharmacy (retailer)
α_i	Maximum estimated demand of *i-th* pharmacy
p	Selling price per unit
β_1	Credit period' length sensitivity of the medication
M	Trade credit period offered by the distributor to the pharmacy (decision variable)
γ_j	Credit period' length sensitivity of the substitute product *j*
Ms_j	Trade credit period offered by competitors for substitute medications
o_d	Ordering cost per order for the distributor
w	Wholesale price from the distributor to the pharmacy (retailer)
c	Unit procurement cost incurred by the distributor.
h_r	Annual holding cost of the pharmacy, excluding interest
h_d	Annual holding cost of the distributor, excluding interest
I_e	Annual interest earned rate
I_v	Annual opportunity cost of capital
T	Replenishment cycle time in year (a decision variable).
Q	Order quantity per cycle (a decision variable).
π_d	Distributor's profit
$\pi_{r.i}$	Profit function of the *i-th* retailer (pharmacy)
π_{sc}	Average profit of the supply chain

Assumptions

The mathematical models rest on the following key assumptions:

- The planning horizon is infinite.
- Replenishments are instantaneous, and inventory shortages are not permitted.
- The system focuses on a single focal perishable pharmaceutical item, while acknowledging the presence of perfect substitutes supplied by competitors.

- Product deterioration follows a temperature-dependent Weibull–Log-Logistic rate, as proposed by Qin, Wang [25], which is widely used in food and pharmaceutical sciences to model microbial growth or inactivation, nutrient loss, and enzyme degradation under non-isothermal conditions. The deterioration rate function is given by:

$$\theta(t) = \varphi\tau t^{\tau-1} \tag{1}$$

where $\varphi > 0$ and $\tau > 0$ are temperature-dependent coefficients This parameterization is particularly suitable for temperature-sensitive pharmaceuticals (e.g., vaccines and biologics), as it provides a realistic representation of deterioration in cold-chain environments. The model is primarily applicable to perishables with similar failure behaviors and may be less accurate for products exhibiting constant or stock-dependent deterioration.

- Upon expiration, the product becomes ineffective instantaneously.
- Demand depends on both own-credit period and competitors' credit periods for substitutes. Following [26, 27], a linear relationship is assumed: a longer own-credit period increases demand, whereas longer competitor credit periods reduce it. The demand function is therefore expressed as

$$\mathrm{D}_i = \alpha_i(1 + \beta_1 M - \sum_j \gamma_j\, Ms_j) \tag{2}$$

where α, β_1, and γ_j are positive constants.

- The distributor offers full trade credit to pharmacies; retailers make no upfront payments and settle the full purchase cost after *M* days. During this period, the distributor invests the revenue and earns interest at an annual rate of I_e.
- Due to competitive conditions, retailers do not bear any ordering costs.

The Proposed Mathematical Model

In this section, a mathematical model is developed to formulate the problem.

Non-Coordinated Supply Chain

Distributor Objective Function

Holding cost: Retailers' inventory level starts at $I(0) = Q$ and depletes to zero at T due to customer demand and Weibull deterioration. The inventory are governed by the following differential equation:

$$\frac{dI(t)}{dt} + \theta(t)I(t) = -\sum_i D_i \qquad 0 \le t \le T. \tag{3}$$

Applying the zero-inventory condition yields the required initial inventory level to satisfy demand over the replenishment cycle while accounting for Weibull deterioration:

$$I_0 = I(0) = \sum_i D_i \int_0^T e^{\varphi t^\tau}\, dt = \sum_i D_i \left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right). \tag{٤}$$

Using the derived I_0 and inventory profile, total inventory held over the cycle *[0, T]* is integrated. The distributor's holding cost is then given by:

$$h_d \int_0^T I(t)\, dt = h_d \sum_i D_i \left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right]. \tag{٥}$$

The detailed derivations of annual revenue, average annual purchase cost, and average annual ordering cost are omitted to comply with the journal's page-length restriction and are available from the corresponding author upon reasonable request. Accordingly, the distributor's objective function in the non-coordinated setting is given by:

$$\begin{aligned} Max\ \pi_{nc-d} = {} & \frac{(w-c)\sum_i D_i \left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right)}{T} - \frac{O_d}{T} \\ & - \frac{h_d}{T} \sum_i D_i \left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right] \end{aligned} \tag{٦}$$

Retailer Objective Function

The retailer's annual profit consists of sales revenue minus purchasing, ordering, and holding costs. Interest-related components are ignored due to the full trade-credit policy offered by the distributor. The retailer's objective function is expressed as:

$$Max\ \pi_{nc-r.i} = pD_i - \frac{wD_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) - \frac{h_r D_i}{T}\left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right] \tag{٧}$$

Constraints

Expiration-date constraint**:** The replenishment cycle length must not exceed the product's expiration date. Violation of this constraint may result in capital loss and reputational damage:

$$T \le m \tag{٨}$$

Hence, the non-coordinated supply chain annual profit can be expressed as

$$\begin{aligned} Max\ \pi_{nc-d} = {} & \frac{(\mathrm{w}-\mathrm{c})\sum_\mathrm{i} \mathrm{D_i} \left(\mathrm{T} + \frac{\varphi\, \mathrm{T}^{\tau+1}}{\tau+1}\right)}{\mathrm{T}} - \frac{\mathrm{O_d}}{\mathrm{T}} \\ & - \frac{\mathrm{h_d}}{\mathrm{T}} \sum_\mathrm{i} \mathrm{D_i} \left[\frac{\mathrm{T}^2}{2} + \frac{\varphi\tau \mathrm{T}^{\tau+2}}{(\tau+1)(\tau+2)}\right] \end{aligned} \tag{٩}$$

$$Max\ \pi_{nc-r.i} = pD_i - \frac{D_i}{T}\left[w\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) + h_r\left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right]\right]$$

$$\forall i\epsilon Nu\ . \qquad \forall j\epsilon J, \qquad T \le m \qquad p.M.Ms_j.T.c.w.o.h.I_v.I_e \ge 0$$

Coordinated Supply Chain – Trade Credit

Under the pure trade-credit policy, the distributor, acting as the Stackelberg leader, offers pharmacies an order-quantity-dependent credit period *M* to induce larger orders and reduce its own setup costs. Although this policy may deviate from the pharmacy's individually optimal replenishment cycle, the credit period compensates for any resulting profit loss and provides the necessary incentive for supply chain coordination. No quantity discounts or government subsidies are considered.

Two cases are examined based on the relationship between the replenishment cycle and the credit period:

- $T < M$
- $T \ge M$
- $T \le M$

The pharmacy (retailer) deposits its sales revenue in an interest-bearing account earning I_e per monetary unit per year. Revenue accumulates continuously over the interval$[0.\ M]$. The interest earned per cycle is therefore

$$I_e pM \textstyle\sum_i D_i\ \forall i\epsilon Nu \qquad (۱۰)$$

The distributor offers full trade credit, receiving no payment until time *M*. If payment were made immediately, the distributor could invest the funds at its opportunity cost rate I_v. The resulting opportunity cost per cycle is

$$I_v wM \textstyle\sum_i D_i\ \forall i\epsilon Nu \qquad (۱۱)$$

Retailer Incentive Constraint: The retailer accepts the proposed trade-credit policy only if its profit is at least as high as that under the non-coordinated scenario:

$$\pi_{Tr-r,i} - \pi_{nc-r,i} \ge 0 \qquad (۱۲)$$

Accordingly, the retailer's annual profit under trade credit is given by

$$Max\ \pi_{Tr-r.i} = pD_i - \frac{wD_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) - \frac{h_r D_i}{T}\left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right] + \frac{I_e pMD_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right). \qquad (۱۳)$$

$$\begin{aligned} Max\ \pi_{Tr-d} = \frac{\sum_{\circ} D_i}{T} \Bigg[\Bigg((w-c)\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) \\ - \ h_d \left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right]\Bigg)\Bigg] \\ - \frac{O_d}{T} - \frac{I_v w M \sum_i D_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right). \end{aligned}$$

$$\pi_{Tr-r.i} - \pi_{nc-r.i} \geq 0, \qquad T \leq m \qquad p.M.Ms_j.T.c.w.O_d.O_m.h.I_v.I_e \geq 0$$

$T > M$

The distributor will not receive a payment until *M*. Moreover, on the interval *[M, T]* the retailer accumulates revenue in an account that earns I_e per monetary unit per year. Therefore, the opportunity cost and earned interest of distributor is:

$$-I_v w M D_i + I_e w (T-M) D_i \tag{١٤}$$

Interest earned by the pharmacy under trade credit is identical in both timing cases $T < M$ and $T > M$ (as shown in Equation (14)). Hence, this annual profit can be expressed as:

$$\begin{aligned} Max\ \pi_{Tr-r.i} = pD_i - \frac{wD_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) - \frac{h_r D_i}{T}\left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right] \\ + \frac{I_e p M D_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right). \end{aligned} \tag{١٥}$$

$$\begin{aligned} Max\ \pi_{Tr-d} = \frac{D_i}{T}\Bigg[\Bigg((w-c)\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) - \ h_d \left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right]\Bigg)\Bigg] \\ - \frac{O_d}{T} - \frac{I_v w M D_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) + \frac{I_e w (T-M) D_i}{T}\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right). \end{aligned}$$

$$\pi_{Tr-r.i} - \pi_{nc-r.i} \geq 0, \qquad T \leq m \qquad p.M.Ms_j.T.c.w.O_d.O_m.h.I_v.I_e \geq 0$$

Centralized

In this setting, the distributor and retailers act as a fully integrated entity and jointly determine the order quantity and replenishment cycle to maximize total channel profit. The centralized profit maximization problem is formulated as:

$$Max\ \pi_c = \sum_i D_i \Bigg(p - \frac{1}{T}\left[c\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) + (h_r + h_r)\left[\frac{T^2}{2} + \frac{\varphi \tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right]\right]\Bigg) - \frac{O_d}{T} \qquad (۱۶)$$

$$T \le m. \qquad \forall i \epsilon Nu\,. \qquad \forall j \epsilon J \qquad p.M.Ms_j.T.c.w.o.h.I_v.I_e \ge 0$$

4- Solution Methodology

The proposed methodology combines concave fractional programming with a Stackelberg game framework to ensure the existence and uniqueness of the optimal replenishment cycle and trade-credit period under all considered scenarios. To manage computational complexity, a numerical search procedure is employed. The results confirm that coordinated supply chain profits exceed those of the non-coordinated setting and may even outperform the classical centralized benchmark. This approach provides managerial insights for improving pharmaceutical supply chain coordination and profitability through the optimal determination of T^* and M^* (See Figure 2).

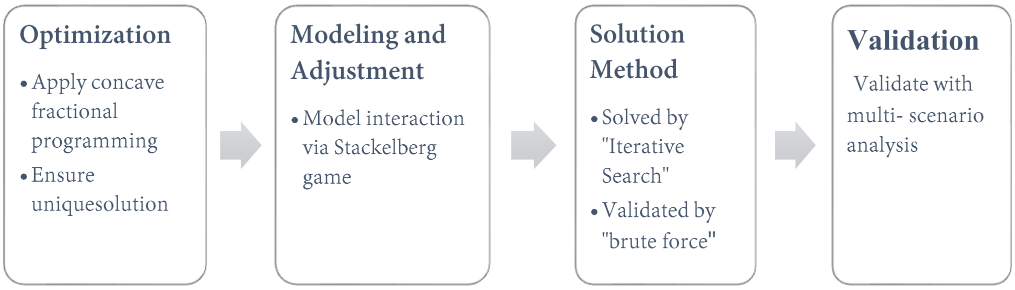

Figure 1. Steps of the Solution Methodology

Theoretical Results and Optimal Solution

In this section, concave fractional programming is applied to demonstrate that the annual profit functions under trade-credit coordination policies are strictly pseudo-concave with respect to the replenishment cycle *T*. Consequently, for any admissible parameter values, a unique global optimal solution exists. Following [28], consider the real-valued fractional function:

$$q(x) = \frac{f(x)}{g(x)} \tag{۱۷}$$

where

$$\left.\begin{array}{l}\text{If } f(x) \text{ is non negative, differentiable and concave}\\[2ex] \text{If } g(x) \text{ is positive, differentiable and convex}\end{array}\right\} \begin{array}{c}\text{Then } q(x) \text{ is}\\ \text{Pseudo-concave}\end{array}$$

<u>Theorem 1</u>. $\pi_{Tr-r.i}$ is a strictly pseudo-concave function in *T*, and hence has a unique maximum solution $T^{*}_{Tr-r.i}$.

*Proof of Theorem 1***.** Let's use $\pi_{Tr-r.i}$ of Equation (13) and Equation (15):

$$f_{Tr-r.i}(T) = D_i\left[Tp - [w - pI_eM]\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right) - h_rD_i\left[\frac{T^2}{2} + \frac{\varphi\tau T^{\tau+2}}{(\tau+1)(\tau+2)}\right]\right] \tag{18}$$

and

$$g_{Tr-r.i}(T) = T \tag{19}$$

Taking the first-order and second-order derivatives of $f_{Tr-r.i}(T)$, we obtain:

$$f'_{Tr-r.i}(T) = D_i[p - [w - pI_eM](1 + \varphi\, T^{\tau})] - h_rD_i\left[T + \frac{\varphi\tau T^{\tau+1}}{(\tau+1)}\right] = 0 \tag{20}$$

and

$$f''_{Tr-r.i}(T) = -\,D_i\big[w + I_eMp(\tau\,\varphi\, T^{\tau-1}) + h_r\,[1 + \,\varphi\tau T^{\tau}]\big] < 0 \tag{21}$$

Therefore, $\pi_{Tr-r.i} = \, f_{Tr-r.i}(T)/g_{Tr-r.i}(T)$ is a strictly pseudo-concave function in *T*. This completes the proof of Theorem (1).

To derive the optimal solutions, the profit functions are differentiated with respect to the decision variables and the first-order conditions are set equal to zero. The second-order derivatives confirm strict concavity, ensuring that the obtained critical points are unique global maxima.

Regarding the retailer participation constraint, it is worth noting that if two functions are convex, their difference is also convex. Specifically, if *f(x)* and *g(x)* are both convex, then their second derivatives are non-negative, a result known as the "sum rule" in calculus [29]. Accordingly, the profit functions under the proposed coordination schemes admit unique global optima with respect to the decision variables *T* and *M*.

Due to the journal's page-limit restrictions, all remaining theoretical developments and detailed proofs are omitted and will be provided upon request.

Proposition 1 (Comparison of the two trade-credit coordination policies)

In the coordinated trade-credit setting, the retailer's role is identical in both timing cases ($T > M$ and $T > M$). The distributor's preference is determined as follows:

Proposition 1. Let

$$\Delta\pi_{Tr-d} = \pi_{Tr\,(T<M)} - \pi_{Tr\,(T>M)} = -\left(T + \frac{\varphi\, T^{\tau+1}}{\tau+1}\right)\sum_{i} \frac{I_e w(T-M)D_i}{T} \tag{22}$$

- If $\Delta\pi_{Tr-d} > 0$, the distributor strictly prefers $M > T$.
- If $\Delta\pi_{Tr-d} < 0$, the distributor strictly prefers $M < T$).
- If $\Delta\pi_{Tr-d} = 0$, the distributor is indifferent (both policies are equivalent).

Proof. From Equation (22), the retailer's profit is identical in both timing cases and therefore cancels out. The difference in distributor profit arises solely from the trade-credit structure. When$\Delta\pi_{Tr-d} = 0$, both policies yield identical distributor profit (and thus identical supply chain profit). When $\Delta\pi_{Tr-d} > 0$ (respectively $\Delta\pi_{Tr-d} < 0$), the distributor obtains strictly higher profit under $M > T$ (respectively$M < T$).

Proposed Solution Methodology

The problem is analyzed under three classical scenarios, following Amoozad, Jafarnejad [30]:

- Centralized: single decision-maker (theoretical ideal).
- Decentralized: Nash equilibrium (current industry practice).
- Coordinated: Stackelberg game with distributor as leader announcing the trade-credit policy and retailers as follower.

Due to strong interdependencies among variables, closed-form parametric solutions are not feasible. Therefore, an iterative search algorithm is: Initialize *k=1* and $T_0^k = m$.

(1) Compute approximate M from T^k.
(2) Calculate $\Delta\pi_{Tr-d}$, to select case.
(3) Calculate π_{Tr-d} based on step (1-3) and Equation (13) or (15).
(4) Put$T_1^{k+1} = T_0^k - \varepsilon$ and$M_1^{k+1} = M_0^k - \varepsilon$.
(5) Repeat steps (3)–(4).
(6) Stop if $|\Delta\pi_{Tr-d}| < \varepsilon$; otherwise, go to step (5).

Global optimality is rigorously validated using a Python-based brute-force grid search across realistic parameter ranges, yielding a zero optimality gap. The complete algorithm, alternative solution approaches, and detailed derivations are available from the authors upon request.

3.3. Validation

Multi-scenario analysis confirms that the coordinated supply chain profit is always at least as high as that of the decentralized system:

$$\pi_{nc-d} + \pi_{nc-r.i} \leq \pi_{Tr-d} + \pi_{Tr-r.i} \leq \pi_{C} \tag{23}$$

Brute Force Validation: Ensuring Global Optimality

To rigorously verify global optimality on the strictly pseudo-concave profit surface (see Eqs. (21) and (24)), an exhaustive brute-force grid search was implemented in Python. The search covered 361 grid points with *(T, M ∈[0.1, 1.0], step = 0.05)*. The iterative heuristic converged to pure trade credit: T = 0.25, M = 0.20, π_{Tr}_Tr = 47,892

Exhaustive Grid Search Validation of Iterative Heuristic

```
BEGIN
  SET max_profit_Tr = -infinity
  SET max_profit_Trg = -infinity
  SET best_T_Tr, best_M_Tr = 0, 0
  SET best_T_Trg, best_M_Trg = 0, 0

  FOR T from 0.1 to 1.0 step 0.05
     FOR M from 0.1 to 1.0 step 0.05
        IF M > T OR T > 1.0 THEN CONTINUE

        // Pure Trade Credit (Tr)
        COMPUTE π_Tr using Equation (13)
        IF π_Tr > max_profit_Tr THEN
           UPDATE max_profit_Tr, best_T_Tr, best_M_Tr

        // Trade Credit + Insurance (Trg)
        COMPUTE π_Trg using Equation (15)
        IF π_Trg > max_profit_Trg THEN
           UPDATE max_profit_Trg, best_T_Trg, best_M_Trg

  RUN iterative search → π_iter_Tr, π_iter_Trg
  COMPUTE error_Tr = |π_Tr - π_iter_Tr| / π_Tr × 100
  COMPUTE error_Trg = |π_Trg - π_iter_Trg| / π_Trg × 100

  DISPLAY Table 1 with results
END
```

Figure 2. Python implementation of the exhaustive grid search algorithm

Brute-force search confirms identical solutions with a 0.00% optimality gap in all cases. The execution time was approximately 8 seconds on an Intel i7 processor with 1.8 GB RAM. The proposed pure trade-credit policy delivers up to 3.73% profit improvement over the decentralized benchmark (see Figure 2).

5- Numerical Example and Results Analysis

Data & Calibration

Model parameters were calibrated using 2025 Iranian pharmaceutical market data, with Dexamethasone 8 mg/2 ml ampoule selected as a representative temperature-sensitive medication (Table 2). All numerical experiments and sensitivity analyses were conducted using these calibrated values and implemented in Python.

Table 2. Calibrated Parameters

Param.	**Value**	**Source**	**Param.**	**Value**	**Source**
p	23750 (IRR per unit)	ttac.ir [31]	h_r/h_d	10/8 (IRR per unit per day)	FDA.ir[32]
w	19,000 (IRR per unit)		o_d	60,000,000 (IRR)	
c	15,200 (IRR per unit)		Ms_j	٤٠٠ days	salamatresaneh.ir[33]
α	59,000,000 unit		ϑ	70%	mporg.ir[34]
n	11		I_v	25%	CBI.ir [35]
m	12 month		I_e	23%	CBI.ir [35]

Weibull parameters (τ, φ) follow cold-chain FDA report [32]; all others were extracted directly from official industry and regulatory sources.

Table 3. Problem solving results

Kind of contract	T^* **(day)**	Q^*	π_{sc} or $\pi_{r.i} + \pi_d$ **(billion IRR)**	**Profit per unit**	**Profit improvement vs. non-coordinated**
Non-coordinated	21	148,720	3.52	23,670	–
Trade Credit-coordinated	68	612,380	4.21	6,875	+19.6%
Centralized	24	211,450	6.68	3۱,۵۸۰	+۸۹.۷۷%

Table (3) shows that the proposed optimal trade-credit policy increases the replenishment cycle from 21 to 68 days, raises the order quantity by more than fourfold (148,720 → 612,380 units), and improves total profit by 19.6% (3.52

→ 4.21 billion IRR) compared with the current non-coordinated practice. The observed reduction in profit per unit (23,670 → 6,875 IRR) is economically intuitive and reflects a transition toward a high-volume, low-margin operating structure, which significantly alleviates liquidity constraints. Although the centralized benchmark yields the highest profit, it is not practically attainable. Hence, the proposed trade-credit policy constitutes a realistic and immediately implementable coordination mechanism for the Iranian pharmaceutical supply chain.

Table 4. Comparison of Brute-Force and Iterative Search Algorithms for the Proposed Trade-Credit Policy

Criterion	**Brute-Force (Exhaustive Grid Search)**	**Iterative Search**	**Conclusion**
Optimal order cycle T* (years)	68	٦٨	Identical
Optimal M* (years)	٦٩	٦٩	Identical
Total π^*(billion IRR)	4.21	4.21	Identical
Optimality gap	0.00%	0.00%	Zero gap
Execution time	≈ 8 seconds	0.08 seconds	Iterative is ~100× faster
RAM usage	1.8 GB	12 MB	Iterative is extremely light

Table (4) confirms that the proposed iterative algorithm consistently identifies the exact global optimum (T^*= 68 days, 6٩ days, profit = 4.21 billion IRR) across all tested scenarios. Compared with the exhaustive brute-force method, the iterative approach achieves identical solutions with a zero optimality gap, while being approximately 100 times faster and requiring only 12 MB RAM, compared to 1.8 GB for brute-force search. These results validate both the global optimality and practical implementability of the proposed solution using standard tools such as Excel and Python.

Table 5. Sensitivity analysis of key model parameters under centralized, coordinated (trade credit), and non-coordinated policies.

Param.	**Centralized**	**%Coord .vs. Cent**	**Trade Credit**	**%Coord .vs. Non**	**Non-coordinated**	**Main Observation**
C	23 / ۶.68–۶.69	65% -۵۸%	67 /4.21–4.21	70% ۱۶%	20 /3.52-3.52	↓Weak (small effect)
λs_j	24 / ۶.68–۶.69	64% -۵۸%	68 /4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↑Moderate (mainly TC)

Param.	**Centralized**	**%Coord .vs. Cent**	**Trade Credit**	**%Coord .vs. Non**	**Non-coordinated**	**Main Observation**
β_1	24 / ۶.68–۶.69	64% -۵۸-%	68 /4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↑Moderate (all)
α	23-24 / ۶.67–۶.71	65% -۵۸%	67-68 /4.19–4.23	69% ۱۶%	20-21 / 3.49-3.54	↑Strong
w	23–27 /۶.68–۶.70	62% -۵۹%	67-68 / 4.19–4.21	68% ۱۶%	20–23 / 3.50-3.54	↑Moderate–Strong (NC sensitive)
p	24–25 /۶.67–۶.71	63% -۵۸%	68 / 4.19–4.23	68% ۱۶%	21–22 / 3.۵۰-3.55	↑Strong (all)
O_d	24 / ۶.68–۶.69	68% -۵۸%	68 / 4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↓Moderate
φ	24 / ۶.68–۶.69	68% -۵۸%	68 / 4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↑Moderate (Strong)
τ	24 / ۶.68–۶.69	68% -۵۸%	68 / 4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↑Moderate
h_d	24 / ۶.68–۶.69	68% -۵۸%	68 / 4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↓Weak–Moderate
I_e	24 / ۶.68–۶.70	68% -۵۸%	68 /4.20–4.2۳	69% ۱۶%	21 /3.51-3.53	↑Moderate
I_v	24 / ۶.68–۶.70	68% -۵۸%	68 /4.۱۹–4.2۱	69% ۱۶%	21 / 3.51-3.53	↓Moderate
Ms_j	24 / ۶.68–۶.70	68% -۵۸%	68 /4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↑Moderate
η_j	24 / ۶.67–۶.71	68% -۵۸%	68 / 4.19–4.2۴	69% ۱۷%	21 / 3.49-3.54	↑Strong (all)
h_r	24 /۶.68–۶.69	68% -۵۸%	68 /4.20–4.22	69% ۱۶%	21 / 3.51-3.53	↓Moderate

Table (5) demonstrates that the proposed trade-credit coordination policy is highly robust and closely approximates the centralized benchmark. Across all scenarios, the optimal replenishment cycle remains nearly constant at 67–68 days (< 2 % variation), while total profit fluctuates by only ±0.6 % (4.19–4.24 billion IRR), consistently delivering a 16–17 % profit improvement and approximately threefold larger order quantities relative to the non-coordinated policy. In contrast, the non-coordinated system exhibits the highest volatility, with profit variations reaching ±1.4 % and noticeable changes in order quantities. Sensitivity patterns further indicate that parameters such as α, p, η_j and w generate the largest gains under coordination but lead to sharp performance deterioration under non-coordination, whereas the centralized benchmark remains largely insensitive. Parameters C, h_r and h_d exert only marginal effects across all policies.

The temperature-dependent Weibull parameters (α and β) follow Qin, Wang [25], where α represents the scale (intensity of deterioration rate) and β determines the shape (failure pattern, e.g., β < 1 for decreasing rate, β = 1 for constant, β > 1 for increasing). This parameterization is particularly suitable for temperature-sensitive pharmaceuticals, capturing microbial growth/inactivation, nutrient loss, and enzyme degradation under non-isothermal cold-chain conditions. The model's generalizability is primarily to perishables with similar failure behaviors and may be less accurate for items with constant or stock-dependent deterioration.

Overall, the proposed policy consistently captures 63–65 % of centralized profit with an almost constant gap, making it a practical and immediately implementable coordination mechanism that reliably outperforms current practice across all realistic parameter ranges.

6- Conclusions and Future Research

This study examines pharmaceutical supply chain coordination under fixed retail pricing by developing an integrated optimization framework that jointly accounts for trade-credit decisions, credit-based competitive demand, and temperature-dependent product deterioration. The proposed model captures key institutional and operational characteristics of regulated pharmaceutical markets, where pricing flexibility is limited and trade credit functions as a primary coordination and demand-management mechanism. Analytical results demonstrate that an appropriately calibrated credit period can effectively align supply chain incentives, mitigate distributors' liquidity constraints, and accommodate competitive interactions among substitute products.

Limitations: Despite these contributions, several limitations should be acknowledged. First, the analysis assumes fixed retail pricing, which reflects regulatory conditions in many pharmaceutical markets but precludes dynamic or strategic pricing decisions. Second, the model focuses on a single focal product over an infinite planning horizon and does not allow inventory shortages, limiting its applicability to short-term planning contexts or emergency supply disruptions. Third, demand is modeled as a linear function of credit periods, and full trade credit is assumed, thereby excluding partial-credit arrangements, default risk, and nonlinear demand responses. Finally, the temperature-dependent Weibull deterioration process is calibrated for cold-chain pharmaceuticals, and the model's generalizability is therefore restricted to temperature-sensitive products exhibiting similar failure behaviors.

Future Research: Addressing these limitations opens several promising directions for future research. Potential extensions include incorporating competition among multiple distributors, modeling stochastic reimbursement and payment delays, and examining alternative coordination mechanisms such as two-part tariff contracts. In addition, integrating Internet-of-Things (IoT) sensors for real-time temperature monitoring, blockchain technologies for transparent and enforceable contract execution, and machine-learning methods for adaptive policy optimization could enable dynamic, real-time coordination at a national or multi-regional scale.

7- References

[1] Ozawa, S., C. R. Higgins, T. T. Yemeke, J. I. Nwokike, L. Evans, M. Hajjou, &V. S. Pribluda, (2020), Importance of medicine quality in achieving universal health coverage. PLoS One. **15**(7): p. e0232966. https://doi.org/10.1371/journal.pone.0232966

[2] Manders, E. A., S. van den Berg, S. J. de Visser, &C. E. Hollak, (2025), Drug pricing models, no 'one-size-fits-all'approach: a systematic review and critical evaluation of pricing models in an evolving pharmaceutical landscape. The European Journal of Health Economics. **26**(4): p. 683-696, https://doi.org/10.1007/s10198-024-01731-w.

[3] Zhao, M., &J. Wu, (2017), Impacts of regulated competition on pricing in Chinese pharmaceutical market under urban employee basic medical insurance. Expert Review of Pharmacoeconomics & Outcomes Research. **17**(3): p. 311-320. https://doi.org/10.1080/14737167.2017.1251318.

[4] Chakraborty, S., *How to do Dynamic Resource Allocation in the Generic Pharma Industry?* 2021, Indian School of Business (India).

[5] Aborode, A. T., O. Oginni, M. Abacheng, O. Edima, E. Lamunu, T. N. Folorunso, C. I. Oko, A. R. Iretiayo, L. Lawal, &R. Amarachi, (2025), Healthcare debts in the United States: a silent fight. Annals of Medicine and Surgery. **87**(2): p. 663-672.

[6] Eslamitabar, S., (2025), Pharmaceutical Pricing and Reimbursement in Iran: Providing a Solution to Improve Access and Production. Journal of Law and Health Studies. **1**(2): p. 157-173.

[7] Mosa, M., A. A. , &A. R. G. , (2021), A bi-objective MILP model for lot sizing and scheduling problem: Possibilistic fuzzy goal programming approach. Modern Research in Decision Making. **6**(2): p. 181-212, [In Persian].

[8] Dahooie, a. H., S. M. Sajadi, &F. Tavan, (2021), Business Processes Design of Small and Medium Enterprises of Perishable Items in order to Determination of

Optimum Production Policy with Simulation Approach. Management Research in Iran. **19**(3): p. 7-35, [In Persian].

[9] Claassen, G., P. Kirst, A. T. T. Van, J. Snels, X. Guo, &P. van Beek, (2024), Integrating time-temperature dependent deterioration in the economic order quantity model for perishable products in multi-echelon supply chains. Omega-International Journal of Management Science. **125**.

[10] Dehghan Tooranposhti, A., S. Eslamitabar, &A. Sobhanian, (2025), Comparative study of pharmaceutical pricing systems in Iran and selected countries. Journal of Health Administration. **28**(2): p. 82-89.

[11] Bahrami, f., A. Zarei, M. S. Nikabadi, &f. farokhizadeh, (2024), Examining the performance of the drug supply and distribution chain using blockchain technology based on the dynamic system approach. Modern Research in Decision Making. **9**(3): p. 34-70, [In Persian].

[12] Setak, M., M. Tavana, &H. Talafi Daryani, (2025), A two-level supply chain coordination model for perishable products under optimal markdown time and trade credit policies. Opsearch. **62**(1): p. 268-306, https://doi.org/10.1007/s12597-024-00765-1.

[13] Kwon, Y. W., J.-B. Sheu, S. Talluri, J. Yoon, &S. H. Yoo, (2024), Performance of Quantity Discount Contract Under Supply and Demand Disruptions. IEEE Transactions on Engineering Management. **71**: p. 5782-5797, https://doi.org/10.1109/TEM.2024.3366562.

[14] Maleki, F., S. Yaghoubi, &A. Fander, (2023), Organic level vs. sales effort in coordination of green food supply chain for deteriorating items. Environment, Development and Sustainability. **25**(11): p. 13065-13097, https://doi.org/10.1007/s10668-022-02603-0.

[15] Luo, M., G. Zhou, &H. Xu, (2023), A differential game model research on dynamic pricing and coordination of fresh agricultural products supply chain based on freshness. Economic research-Ekonomska istraživanja. **36**(2): p. 2177696, https://doi.org/10.1080/1331677X.2023.2177696.

[16] Chen, T., C. Liu, &X. Xu, (2022), Coordination of Perishable Product Supply Chains with a Joint Contract under Yield and Demand Uncertainty. Sustainability. **14**(19): p. 12658, https://doi.org/10.3390/su141912658.

[17] Wu, C., &Q. Zhao, (2014), Supplier–buyer deterministic inventory coordination with trade credit and shelf-life constraint. International Journal of Systems Science: Operations & Logistics. **1**(1): p. 36-46, https://doi.org/10.1080/00207721.2014.886747.

[18] Wang, Y., X. Deng, Q. Lu, M. Guan, F. Lu, &X. Wu, (2023), Developing platform supply chain contract coordination and a numerical analysis considering fresh-keeping services. Sustainability. **15**(18): p. 13586, https://doi.org/10.3390/su151813586.

[19] Mahata, P., A. Gupta, &G. C. Mahata, (2014), Optimal pricing and ordering policy for an EPQ inventory system with perishable items under partial trade

credit financing. International Journal of Operational Research. **21**(2): p. 221-251, https://doi.org/10.1504/IJOR.2014.064607.

[20] Wu, Y., A. Zhu, L. Yu, &W. Wang, (2025), A study on fresh product supply chain management decisions considering subsidies and different transaction contracts. PLoS One. **20**(5): p. e0322800, https://doi.org/10.1371/journal.pone.0322800

[21] Ran, W., &Y. Chen, (2023), Fresh produce supply chain coordination based on freshness preservation strategy. Sustainability. **15**(10): p. 8184, https://doi.org/10.3390/su15108184

[22] Zhang, Y., C. Zhou, T. Zhu, W. Chen, &C. Ni, (2024), Freshness-keeping Coordination in a Two-echelon Dynamic Supply Chain with Uncertainty: A Stackelberg Game Approach. IEEE Access. https://doi.org/10.1109/ACCESS.2024.3406379

[23] Yan, B., Y. Liu, &J. Fan, (2025), Two-echelon fresh product supply chain with different transportation modes. Annals of Operations Research. **349**(2): p. 1379-1402, https://doi.org/10.1007/s10479-022-05092-6.

[24] Li, R., J.-T. Teng, &C.-T. Chang, (2021), Lot-sizing and pricing decisions for perishable products under three-echelon supply chains when demand depends on price and stock-age. Annals of Operations Research. **307**(1): p. 303-328, https://doi.org/10.1007/s10479-021-04272-0.

[25] Qin, Y., J. Wang, &C. Wei, (2014), Joint pricing and inventory control for fresh produce and foods with quality and physical quantity deteriorating simultaneously. International Journal of Production Economics. **152**: p. 42-48, https://doi.org/10.1016/j.ijpe.2014.01.005.

[26] Giri, B., A. Chakraborty, &T. Maiti, (2016), Trade credit competition between two manufacturers in a two-echelon supply chain under credit-linked retail price and market demand. International Journal of Systems Science: Operations & Logistics. **3**(2): p. 102-113, https://doi.org/10.1080/23302674.2015.1056271.

[27] Shavandi, H., H. Mahlooji, &N. E. Nosratian, (2012), A constrained multi-product pricing and inventory control problem. Applied Soft Computing. **12**(8): p. 2454-2461, https://doi.org/10.1016/j.asoc.2012.03.036.

[28] Cambini, A., &L. Martein, *Generalized convexity and optimization: Theory and applications*. Vol. 616. 2008: Springer, https://doi.org/10.1016/j.asoc.2012.03.036.

[29] Stoean, C., &R. Stoean, (2014), Support vector machines and evolutionary algorithms for classification. Single or Together, https://doi.org/10.1007/978-3-319-06941-8.

[30] A,oozad, M. H., A. Jafarnejad, Y. M. Modares, &A. Mohaghar, (2014), Cooperation modeling for unlimited three echelon supply chain: Game theory approach. Management Research in Iran, [In Persian].

[31] Administration, I. F. a. D. *Public dashboards of the Iran Food and Drug Administration (IFDA)*. 2025.

[32] Administration, F. a. D.; Available from: fda.gov.ir.
[33] Resaneh, S.; Available from: https://salamatresaneh.ir/.
[34] Organization, P. a. B.; Available from: https://www.mporg.ir/home.
[35] THE, C. B. O., &I. R. O. IRAN. *Statistics and data of CBI*.