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Integrated Inventory Model with Inflation for Deteriorating Items

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

The integrated inventory model works like a multi-tier supply chain involving a manufacturer, buyer, supplier, and customer. In the proposed article, integrated inventory management for perishable items has been developed. It is an essential responsibility of every supply chain member to ensure that any inventory can be delivered to the customer smoothly and on time. The model of inflation fluctuations takes into account inflation as one of its factors. This model considers the movement of inventory from production to supply in real data; Numerical examples have been explored to facilitate a practical understanding of this model in real-life situations, and the aggregate cost from the entire supply chain has been calculated. The model concludes with a sensitivity analysis, revealing the effects on the overall model stemming from alterations in key parameters that exert significant influence.

Keywords: Multi echelon; inflation; deteriorating items.

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1 Introduction

In the current landscape of heightened competition across various industries, it is undeniably crucial for businesses to efficiently reach a maximum number of customers, providing products or services at competitive prices and meeting customer demands within stipulated timelines. The involvement of a supply chain system with multiple tiers has been significant in various aspects beacause the multi-echelon supply chain management functions as an entity, akin to an organization, where all its members share the responsibility of meeting customer requirements. Many authors discussed about inventory managment base don economic condition. Asghar et al. [1] present an automated Inventory Management (I.M.) system based on policy economic production, specifically designed to encompass high-technology items. Mallick et al. [2] created an Inventory Management (IM) model that includes permissible delays in payment and accounts for time-dependent demand. The supply chain management functions akin to an organization, and it is the collective responsibility of all its members to meet customer needs and ensure each stage of the supply chain system is highly profitable Mashud et al. [3] explored a sustainable Inventory Management (IM) approach considering controllable emissions for imperfect products. Sarkar and Chung [4] formulated a sustainable Inventory Management (IM) model, combining a versatile production system with the integration of technology focused on reducing carbon emissions. Mishra et al. [5] created a sustainable production Inventory Management (IM) model focusing on a singular item type. In this model, all items are conveyed to consumers using a single transportation mode, and considerations are made for shortages while concurrently addressing the reduction of carbon emissions. In the broader context, the Supply Chain Inventory Model (SCIM) has traditionally taken into account various sub-systems. However, with recent advancements in transmission and information technologies, the integration of these functions has become a common and noticeable trend. The supply chain (SC) has gained paramount importance for researchers amidst the evolving market dynamics. Supply Chain Inventory Models (SCIM) are instrumental in optimizing various scenarios, ranging from the producer's workflow to effectively managing challenges posed by natural disasters. SCIM excels in accurately diagnosing problems and disruptions within organizations. It plays a pivotal role in swiftly, safely, and efficiently delivering goods to their destination. Inventory Management (IM) operates in a unique and unpredictable environment, providing optimal solutions for effective management in such conditionsMany researchers have explored inventory models by considering the perspectives of producers, retailers, and buyers. Chou [6] formulated an integrated Inventory Management (IM) approach specifically designed for deteriorating items. On the other hand, Rani and Kishan [7] presented a Multi-Echelon Inventory Management (MEIM) model focused on deteriorating items, accounting for variable demand in their formulation. Singh and Singh [8] created a Supply Chain Inventory Model (SCIM) incorporating imperfect production within an environment characterized by inflation and a fuzzy sense. Jaggi et al. [9] innovatively developed an Inventory Management (IM) system specifically designed for items experiencing deterioration in a fuzzy environment, incorporating the influence of time-varying demand. Gupta and Singh [10] devised a comprehensive Inventory Management (IM) model incorporating fuzzy variables, variable holding costs, and three-parameter Weibull deterioration, all within the context of inflation. Maihami et al. [11] explored the Multi-Echelon Supply Chain Model (MESCM) focusing on deteriorating items within a probabilistic environment. Meanwhile, Sarkar et al. [12] presented a collaborative Inventory Management (IM) model for an online-to-offline closed-loop supply chain. Jiang et. al. [13] devised a sustainable Supply Chain Inventory Model (SCIM) taking into account carbon footprint considerations. In a separate study, Sebatjane and Adetunji [14] created a Multi-Echelon Inventory Management (MEIM) model incorporating demand that is dependent on price, within the framework of an economic growth quantity model. Sana, S. S. (2020) presented a structural model for Multi-Echelon Inventory Management (MEIM). Lu et al. [15] formulated a multistage sustainable production model incorporating carbon reduction and a Stackelberg game, where demand is contingent on price. Additionally, Padiyar et al. [16] delved into the advantages of preservation, green practices, and quality improvement investments in a fuzzy and learning environment.

Inflation is calculated as the yearly percentage rise. As inflation increases, every price you own buys a little percentage of a good or service. Jaggi et al. [17] suggested the best strategy for restocking inventory. of damaged items under inflation using a discounted cash flow approach for a finite horizon. Kumar et al. [18] explored an inventory model involving quadratic demand for perishable goods, considering factors like inflation and trade credits. Yang et. al. [19] examined a model for determining the lot size of perishable items, considering the impact of inflation. Gilding [20] explored a model addressing inflation and the schedule for inventory replenishment within a limited planning timeframe. This paper aims to discover the best replenishment schedule for an inventory management system, considering time-dependent demand and assuming a finite planning horizon. It is also shown that by taking inflation into account has a profound effect on the solution of the problema. Palanivel and Uthayakumar (2016) introduced a two-warehouse inventory management model for non-instantaneous deteriorating items, incorporating credit periods, inflation, and partial backlogging. Singh et al. [21] developed a two-warehouse inventory management model for damaged items, considering variable demand and partial backlogging in the presence of inflation.

Inventory serves as a crucial physical resource essential for the smooth operation of any business. In the market, various products have specific lifespans or safety periods. Once this period ends, these products experience a decline and fall into the category of deteriorating items. Numerous products in the market can be returned in case of damage, yet some, like dairy products and medicines, cannot be returned after spoilage. Several authors have devised inventory models specifically for deteriorating products. Rau et al. [22] developed the Multi-Echelon Inventory Model (MEIM) tailored for defective goods. Singh and Gupta [23] formulated an IM with error in quality inspection. They have also taken demand as a function of selling price and volumen agility. Mishra [5] developed a three rate of production IM for deteriorating ítems under selling price dependent demand. Panda et al. (2019) created an inventory management model for deteriorating ítems with warehouse. They have also taken demand as a function of price. Rani et al. [24] devised an inventory management model, implementing green supply chain management for deteriorating products. They incorporated demand as a function of the credit period. Shaikh et al. [25] explored an inventory management model for deteriorating items, considering preservation technology and shortages. Their model involved demand as a ramp type and incorporated a trade credit policy. Gupta et. al. [26] presented an inventory management model addressing storage issues, partial backlogging, and trade credit policy for deteriorating items. Padiyar et al. [27] created an inventory management model incorporating price-dependent consumption for deteriorating items, considering shortages in a fuzzy environment. Padiyar et al. [28] explored a fuzzy inventory model incorporating price-dependent demand and shortages for deteriorating goods. Padiyar et al. [29] formulated a production inventory model for perishable items under learning inspection. The research considers two distinct demands for two warehouses, characterized by exponential and selling price-dependent demand, incorporating shortage considerations. Additionally, the study addresses the storage problem in the given contextPadiyar et al. [30] proposed a green integrated model for an imperfect production process under reliability considerationsPadiyar et al. [31] crafted an integrated inventory model for a producer and buyer, incorporating an imperfect production process with two distinct demands. The producer faces exponential demand, while the buyer encounters triangular demand. The model accounts for preservation facilities aimed at mitigating the deterioration rate of perishable items. Additionally, the proposed theory addresses the challenge of reducing deterioration rates in the presence of inflationary effects. Padiyar et al. [32] formulated a three-echelon supply chain model designed to facilitate the seamless delivery of products to customers. This model encompasses one producer and multiple buyers, each having a distinct group with multiple suppliers. The inclusion of inflation in the model accounts for inflationary fluctuations. Kuraie et al. [33] constructed an integrated inventory model focusing on the vendor and supplier within an imperfect production process framework. The vendor's demand rate is contingent on the inventory level, selling price, and frequency of advertisement, while the supplier is assumed to have a multivariable demand rate. Jain et al. [34] emphasize that efficient supply chain management requires the integration of technology, collaboration within the supply chain, a focus on reducing carbon emissions, effective management of deteriorating products, optimization of financial operations through trade credit, and the promotion of agility to enhance operational efficiency. Ummeferva et al. [35] have devised an economic production quantity model under a partial trade credit policy, taking into account the impact of reliability. The demand is contingent upon the price and the greening level of the products. Padiyar et al. [36] have formulated a multi-echelon inventory model for deteriorating multiple items within an imperfect production framework, considering the aspects of both fuzziness and inflation. Padiyar et al. [37] have developed a multi-echelon inventory model for deteriorating items, incorporating imperfect production and reliability, within an inflationary environment. Kuraie et al. [38] have designed a production inventory model featuring an imperfect production process and reliability, specifically tailored for deteriorating items with a demand rate dependent on the selling price. Padiyar et al. [39] have crafted a multi-echelon supply chain inventory model tailored for perishable items. This model incorporates a fuzzy deterioration rate, imperfect production, and a two-warehouse system within an inflationary environment. Padiyar et al. [40] underscore an optimal strategy for a supply chain model incorporating a defective manufacturing process for deteriorating items, considering the influence of cloudy fuzzy inflation. Padiyar et al. [41] addressed a mathematical imperfect production inventory problem specific to perishable items. The study takes into account two different warehouses under a fuzzy environment. Padiyar et al. [42] have developed a green production inventory model incorporating a remanufacture process and backordering within the context of reverse logistics. Padiyar et al. [43] have formulated an inventory system tailored for deteriorating items with price-sensitive demand, incorporating the principles of fuzzy logic. Padiyar et al. [44] introduces a mathematical framework to derive an Economic Production Quantity (EPQ) model with an imperfect production process for deteriorating items, considering the impact of inflation. The model also takes into account the production of fresh items, the collection of returned items, and the remanufacturing of returned items.

2 Assumptions and Notation

2.1 The inventory management model is developed based on the following key assumptions:

- The development of this model incorporates a supply chain framework, with a focus on two primary roles: the producer and the buyer. The producer operates akin to a company, overseeing the manufacturing of inventory and its distribution to each buyer.
- Shortage are not allowed
- Production rate is constant
- Inflation is considered

2.2 In developing this model, the following symbols are utilized:

P: Production rate attributed to the producer
D: Rate of demand from the producer
θ_1: Deterioration rate for the producer
h_p: Holding cost incurred by the producer
d_p: Deterioration cost for the producer
T_p: Fixed transport cost for the producer
t_a: Variable transportation cost associated with transferring inventory from the producer to the αth buyer
L_a: Demand rate for the αth buyer
θ_2: Deteriorating rate applicable to each buyer
J: Total number of shipments to the buyer from the producer
R: Overall count of shipments to the supplier from the buyer
h_a: Holding cost for the αth buyer
d_a: Deterioration cost for the αth buyer
A_a: Ordering cost for the αth buyer

3 Mathematical Model

The primary aim in formulating this model was to ensure the prompt and secure delivery of products from the production house to the end consumer. Consequently, a multi-echelon supply chain model was devised. In which the producer prepares the inventory in the production house and fulfills the demand as per the requirement of the buyer,

This supply chain operates on two levels, with the company serving as the manufacturer, and the buyers organized into distinct groups. Each buyer places orders for inventory based on their specific demand from the company.

3.1 Model for producers

In the presented inventory model, a sole producer is tasked with manufacturing inventory tailored to the individual requirements of each buyer. The complete inventory cycle is categorized into two segments, delineating time intervals [0, T_1] and [T_1, T]. During the time interval [0, T_1], the quantity is influenced by a combined impact of production, deterioration, and demand. In the subsequent time interval [T_1, T], the inventory is solely affected by demand and deterioration. Producer inventory model can be represented by the following first order linear differential equations**;**

$$\frac{dI_{P1}(t)}{dt} = P - D - \theta_1 I_{P1}(t), \qquad 0 \leq t \leq T_1 \tag{1}$$

$$\frac{dI_{P2}(t)}{dt} = -D - \theta_1 I_{P2}(t), \qquad T_1 \le t \le T \tag{2}$$

Utilizing the boundary conditions $I_{P1}(0)=0$, $I_{P2}(T)=0$,

Solution of equation (1) and (2) are

$$I_{P1}(t)=\frac{(P-D)}{\theta_1}\left[1-e^{-\theta_1 t}\right] \tag{3}$$

$$I_{P2}(t)=\frac{D}{\theta_1}\left[e^{\theta_1(T-t)}-1\right] \tag{4}$$

(a) Holding cost: The holding cost involves the expenses associated with the meticulous storage and upkeep of inventory, covering hardware and material handling equipment, as well as IT software applications. Furthermore, the holding cost for the producer is

$$H_P=h_p\left[\int_0^{T_1} I_{P1i}(t)e^{-rt}dt+\int_{T_1}^{T} I_{P2i}(t)e^{-rt}dt\right]$$

$$H_P=h_p\left[\begin{array}{c}\left(\frac{P-D}{\theta_1}\right)\left\{\left(\frac{1-e^{-rT_1}}{r}\right)+\left(\frac{e^{-(\theta_1+r)T_1-1}}{\theta_1+r}\right)\right\}+\\ \frac{D}{\theta_1}\left\{e^{\theta_1 T}\left(\frac{e^{-(\theta_1+r)T_1-e^{-(\theta_1+r)T}}}{\theta_1+r}\right)+\left(\frac{e^{-rT}-e^{-rT_1}}{r}\right)\right\}\end{array}\right] \tag{5}$$

(b) Deterioration cost: Deterioration cost arises from the loss of usability in items, rendering them useless. Therefore, the deteriorating cost for the producer is...

$$D_P=\theta_1 d_p\left[\int_0^{T_1} I_{P1i}(t)e^{-rt}dt+\int_{T_1}^{T} I_{P2i}(t)e^{-rt}dt\right]$$

$$D_P=\theta_1 d_p\left[\begin{array}{c}\left(\frac{P-D}{\theta_1}\right)\left\{\left(\frac{1-e^{-rT_1}}{r}\right)+\left(\frac{e^{-(\theta_1+r)T_1-1}}{\theta_1+r}\right)\right\}+\\ \frac{D}{\theta_1}\left\{e^{\theta_1 T}\left(\frac{e^{-(\theta_1+r)T_1-e^{-(\theta_1+r)T}}}{\theta_1+r}\right)+\left(\frac{e^{-rT}-e^{-rT_1}}{r}\right)\right\}\end{array}\right] \tag{6}$$

(c) Transportation cost:

$$TPC_P=T_P+\sum_{\alpha=1}^{m}(I_{B\alpha})t_\alpha\left(\frac{1-e^{-rjT_2}}{1-e^{-rT_2}}\right) \tag{7}$$

The overall profit cost for the producer is contingent on all the aforementioned costs. Thus, the total profit cost for the producer is:

$$\text{TCP}=\frac{1}{T}\left[H_P+D_P+TPC_P\right] \tag{8}$$

3.2 Model for Buyers

There is a total of m buyers, and each buyer operates within its distinct supply chain, wherein varying numbers of suppliers are involved. At the initiation of the cycle, the αth buyer receives unit inventory by the multi producers, which it transport to a total of R shipments to their designated group of suppliers. The representation of the buyer's inventory model is captured by the following equation:

$$\frac{dI_{B\alpha}(t)}{dt}=-L_\alpha-\theta_2 I_{B\alpha}(t), \quad 0\le t\le T_2 \tag{9}$$

Where α=1,2,3…m, and $I_{B\alpha}(T_2)=0$,

Solution of equation (9) is

$$I_{B\alpha}(t)=\frac{L_\alpha}{\theta_2}\left(e^{\theta_2(T_2-t)}-1\right), \tag{10}$$

Buyer’s total cost depends on following factors;

(a) Holding cost:

$$H_B = \sum_{\alpha=1}^{m} \sum_{\chi=1}^{j} h_\alpha \left[\int_{(\chi-1)T_2}^{\chi T_2} I_{B\alpha}(t) e^{-rt} dt\right]$$

$$H_B = \sum_{\alpha=1}^{m} \sum_{\chi=1}^{j} h_\alpha \frac{L_\alpha}{\theta_2} \begin{bmatrix} e^{\theta_2 T_2} \left(\frac{e^{-(\theta_2+r)(\chi-1)T_2} - e^{-(\theta_2+r)\chi T_2}}{\theta_2+r}\right) \\ + \left(\frac{e^{-r\chi T_2} - e^{-r(\chi-1)T_2}}{r}\right) \end{bmatrix} \tag{11}$$

(b) Deterioration cost: deteriorating cost arises as a result of items deteriorating to the point of becoming unusable. Consequently, the deteriorating cost for the buyer is

$$D_B = \sum_{\alpha=1}^{m} \sum_{\chi=1}^{j} d_\alpha \theta_2 \left[\int_{(\chi-1)T_2}^{\chi T_2} I_{B\alpha}(t) e^{-rt} dt\right]$$

$$D_B = \sum_{\alpha=1}^{m} \sum_{\chi=1}^{j} d_\alpha L_\alpha \begin{bmatrix} e^{\theta_2 T_2} \left(\frac{e^{-(\theta_2+r)(\chi-1)T_2} - e^{-(\theta_2+r)\chi T_2}}{\theta_2+r}\right) \\ + \left(\frac{e^{-r\chi T_2} - e^{-r(\chi-1)T_2}}{r}\right) \end{bmatrix} \tag{12}$$

(c) Ordering cost: Ordering cost encompasses the total expenses incurred in the process of ordering items, including the costs associated with locating the producer and inspecting the inventory. Thus, the total ordering cost for the buyer is

$$O_B = \sum_{\alpha=1}^{m} A_\alpha \tag{13}$$

Total cost for buyers is depend on, ordering cost, holding cost, and deteriorating costso total cost for buyer is:

$$\text{TCB} = \frac{1}{T}\left[H_B + D_B + O_B\right] \tag{14}$$

Total cost in this supply chain is

$$\text{TPC} = TCP + TCB \tag{16}$$

4 Numerical Example

This section demonstrates the stability and effectiveness of the proposed models through the implementation of a continuous review inventory system. Utilizing numerical values for the parameters, along with appropriate units, the mathematical model developed is illustrated as follows:
Here T and T_1 are decision variable and $T_2 = \frac{T}{J}$, J=2, r = 0.15, Using190 the software Mathematica -12.0 for solving the problem.

P= 100, D =95, θ_1= 0.5, , h_p = 0.2\$/unit, d_p = 0.15\$/unit, t_1 =0.5\$/unit, t_2 = 0.6\$/unit, T_p = 1.8\$, θ_2=0.35, L_1= 65, L_2= 40, h_1= 0.4\$/unit, h_2 = 0.5\$/unit, d_1 = 0.2\$/unit,d_2 = 0.15\$/unit, A_1 = 0.7\$, A_2 = 0.5\$, We get TC =190 \$, T=30, $T_1 = 16$, $T_2 = 8$.

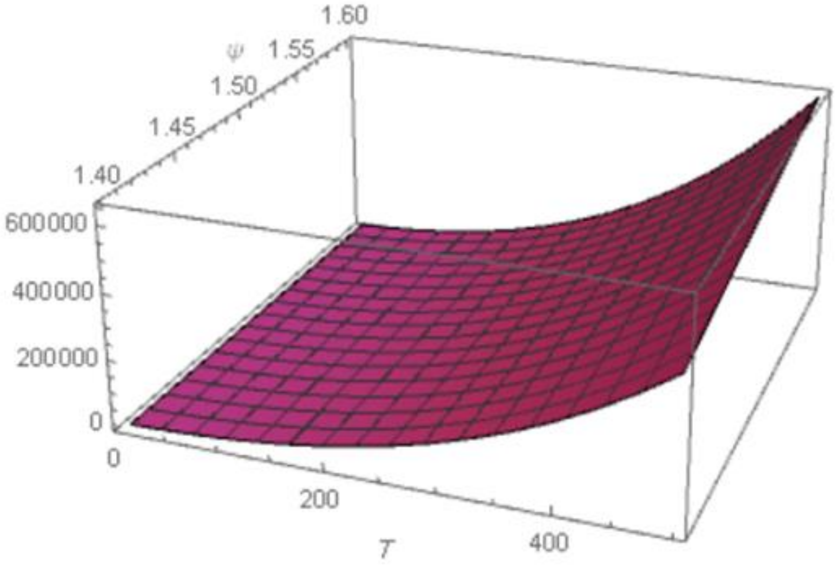

Fig. 1. Stability and viability of the proposed models

Table 1. Sensitivity analysis with respect to diverse parameters

Parameters	% Change	*(Time)T_1*	*(Time)T*	*Total cost(TC)*
P=100	-20	*13.65*	*31*	*192.675*
	-10	*14.932*	*30.87*	*192.543*
	10	*16.55*	*30.01*	*189.51*
	20	*16.90*	*30.0025*	*188.57*

Parameters	% Change	*(Time)T_1*	*(Time)T*	*Total cost(TC)*
D=95	-20	*14.152*	*30.515*	*184.56*
	-10	*14.27*	*30.515*	*185.432*
	10	*15.9*	*30.515*	*192.90*
	20	*15.93*	*30.515*	*191.959*
Parameters	**% Change**	***(Time)T1***	***(Time)T***	***Total cost(TC)***
θ_1=0.5	-20	15	*32.12*	*190.187*
	-10	*15*	*32.679*	*190.146*
	10	*15*	*30.675*	*190.135*
	20	*15*	*28.567*	*190.134*
Parameters	**% Change**	***(Time)T1***	***(Time)T***	***Total cost(TC)***
θ_2=0.35	-20	*15.988*	*30.95*	*190.865*
	-10	*15.95*	*30.5*	*190.756*
	10	*15.07*	*30.565*	*190.189*
	20	*15.05*	*32.567*	*190.156*

5 Observation

- If the production rate increases, then it is seen that the production period is increasing and at the same time the total cost is decreasing.
- Through sensitivity, it was found that if the demand rate increases, then the production time period is decreasing and at the same time the total cost is increasing but there is no effect on the cycle length T.

- After slightly increasing the Deterioration Rate acceptable to the producer, it was found that the production lead time was decreasing and the total cost and cycle length T were also continuously decreasing.
- After slightly increasing the Deterioration rate acceptable to the buyer, it was found that the production time period is decreasing and the total cost is also decreasing but the cycle length T is continuously increasing.

6 Conclusion

This study has formulated a supply chain model to facilitate the prompt delivery of inventory to each buyer. The model involves a producer and multiple buyers, with the inclusion of inflation to account for inflationary fluctuationsTo grasp the practical implications of this model, a numerical example is presented, and the total cost from the supply chain is derived. The study concludes that the total cost is minimized when the production rate increases. The model can be extended by incorporating sustainability factors into the supply chain model, including inflation in a fuzzy environment along with the environmental impact of production and distribution decisions.and using machine learning to improve decision making and incorporating advanced analytics techniques such as artificial intelligence for inventory optimization

Competing Interests

Authors have declared that no competing interests exist.

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