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An Inventory Control Plan for A Pharmaceutical Shelf-Life Deteriorating Product Under Preservation

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Abstract

This paper presents a sophisticated inventory control model involving pharmaceutical products with a short shelf life that degrade even under optimal preservation conditions. Compared to the traditional models where the degradation rate is held constant or where the storage environment is considered ideal, the proposed model couples a dynamic degradation rate that depends on the preservation environment, temperature, humidity, and preservation cost. The goal is to develop the optimal replenishment policy that minimizes the overall price, which is a combination of ordering, holding, deterioration, and preservation prices. At the same time, it must ensure the availability of the drug and its safety. Through the market response and patient demands, a time-dependent demand is factored in. The model utilizes the differential equation to account for depletion in the context of demand and degradation. The determination of the effects of critical parameters is performed using sensitivity analysis, e.g., deterioration rate, preservation efficiency, and replenishment frequency. The results provide a practical guideline that can help pharmaceutical supply chain managers maintain a balance between cost-effectiveness and product effectiveness, especially where there is limited storage infrastructure.

Keywords: Inventory control, Pharmaceutical, Deterioration, shelf-life, preservation,

1. Introduction

In the pharmaceutical supply chain, expired drugs not only mean a massive loss of money but also lead to a lack of treatment for the patients. Practical examples from real life in India have demonstrated that valuable medicines are often wasted due to poor inventory control, posing both economic and environmental problems. The total loss of expired drugs in a country is estimated at 500 crore rupees per year, and in places where the cold chain cannot be entirely relied upon, vaccine wastage can be very high. This scenario makes it clear that having a high-priority inventory policy is crucial to minimize expenditures on orders, warehousing, and product preservation, while also preventing wasteful destruction of goods. The management of pharmaceutical stock is also essential not only to logistics but also to the health of society. Drugs are very sensitive items, particularly those that have a shorter shelf life; hence, they need to be handled in specific ways to evade deterioration. Methods of preservation, e.g., refrigeration and maintaining humidity, extend shelf life but add complexity and cost. As more pressure is applied to reduce the wastage of medicine and enhance the delivery of healthcare to the population, there is a dire need to ensure that the inventory models created are cost-effective, product lifecycle-friendly, and efficient in terms of maintenance. Pharmaceutical products do not lose their effectiveness immediately, as one would expect with common

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commodities. Such a progressive decline in conditions requires close observation and real-time forecasting. The popular classical inventory models, such as EOQ, are not sufficient as their formulas tend to assume no cost of preservation and no sophisticated behavior of the decay of medical goods. Shelf-life limits and temperature-based logistics necessitate more complex modeling techniques to provide successful and cost-effective inventory solutions. Recent advancements in pharmaceutical logistics, driven by technological developments and increased regulations, have made the management of shelf-life deterioration a strategic issue. It has been reported that up to 5-10 percent of medicines are lost every year due to spoilage, and the problem becomes especially acute in developing areas where infrastructure is insufficient. Improper management of stock results in either overstocking or a critical shortage, which impairs the healthcare system. Thus, a preservation-sensitive, optimized inventory policy plays a crucial role in minimizing waste and enhancing the availability of medicine.

This project aims to design a mathematical model tailored explicitly for pharmaceutical products that deteriorate over time, even when stored under optimal conditions. The model features built-in variable rates of deterioration that can be slowed by conservation, albeit at a cost. It combines ordering, holding, preservation, and product loss components of cost and takes into consideration the actual demand trends. The aim is to determine the optimal quantities of order and replenishment cycle that incur the minimum price, subject to the condition that the medicines remain effective during storage and usage. All of this taken together makes the pharmaceutical demand unpredictable. Seasonal fluctuations, epidemics, and changes in policies may also contribute to the patterns. Flexible inventory planning is crucial because end-users, including hospitals and pharmacies, require consistent and reliable supplies. The demand decay curve in the study is exponential, reflecting the reduction in demand as the shelf life approaches its expiry date. This enables superior inventory decisions and a reduction in outdated products. As a real-life model, the proposed model presupposes the known deterioration behavior and its effect on preservation. For example, some vaccines have long shelf lives at low temperatures compared to normal temperatures. Preservation has physical costs associated with it, such as electricity and equipment maintenance; consequently, the model includes a preservation cost function that enables managers to understand the actual value of conservation, along with its financial implications. It is also a model with a sensitivity analysis to determine the changes in the main parameters and their impact on the inventory policy. This is essential in managing uncertainty within the sphere of pharmaceutical logistics, where even minor changes in conditions, such as an increase in ambient temperature or a decline in preservation efficiency, can have a significant impact. Sensitivity analysis makes planning more responsive and robust, allowing organizations to adjust quickly.

1.1.Literature survey

This gap is especially noticeable in areas of pharmaceutical supply chains where environmental factors have a direct impact on product stability, and therefore, the safety of patients and the population. The available literature has provided an in-depth critique of mathematical models of perishable inventory. Still, precedents have been wanting in the broad-based coverage of the environmental impact and dynamic loss of certain products. Characteristic of EOQ models, Ghare and Schrader (1963) present exponential deterioration

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into models. Early information on ordering methods of perishable goods, with definite shelf lives, is available in the short research work by Fries (1975). Ray and Chaudhuri (1997) incorporate inflation and time discounting into EOQ models in the case of the stock-dependent demand. Wee (1998) considers discount schemes, expiration-date ordering, and the Q-learning algorithm in the management of competitive perishable markets. Georgiadis & Vlachos (2003) point towards the topicality of sustainable practices, considering both production and product retrieval. Balkhi and Benkherouf (2004) develop a model of inventory that is stock-dependent and time-varying. Tripathi (2012) examines shortages and exponentially growing demand in the context of payment delays, while Khedlekar (2012) models inventory management in cases of production disruption, also considering exponentially increasing demand. Yadav and Swami (2013) address two-warehouse systems and variable holding costs. Damgaard et al. (2013) focused on the issues that are more encompassing in the supply chain. According to Piramuthu and Zhou (2013), shelf-life price and RFID-based demand management are paramount. The paper by Yadav and Devi (2013) adds another aspect of volume flexibility and random deterioration that arise as the demand grows. Herbon et al. (2013) observed technological innovations, which include time and temperature indicators. Verma and Verma (2014) examine exponentially declining demand in line with the worsening. Raj et al. (2014) construct exponential demand-based models of inventories, which involve the use of reverse logistics and a two-warehouse-based system that considers payment delay. Partially backlogged quadratic demands are considered by Yadav and Vats (2014). Fichtinger et al. (2015) provided details of the environment, and the idea of controlling perishable inventory items was implemented more effectively. Fuzzy lead time, partial backlogging, and perpetual production involving a limited shelf life have been considered by Ukil et al. (2015). Fauza et al. (2015) talk about environmental aspects. Yadav et al. (2015) develop a variable demand-market making model with constant holding costs, assuming no shortages. These studies collectively contribute to optimizing inventory systems for perishable products in an environment characterized by fuzziness, seasonality, inflation, and uncertainty. Tripathi et al. (2017) consider variable deterioration, exponential demand, and production costs. The strategies of discounting and expiration-date ordering are discussed by Ketzenberg et al. (2017). Kaliraman et al. (2017) formulate an inventory model with exponential demand, considering reverse logistics and two-warehouse strategies, with payment delays taken into account. The authors of Malik et al. (2018) address the time-varying demand and limited life of products. Daryanto & Wee (2018) covered the environmental areas. Maihami and Ghalehkhondabi (2019) incorporate pricing, advertising, and inventory control of non-instantaneously deteriorating products. Balugani et al. (2019) discuss periodic systems in the context of items that are demanded at different times and have a stable life cycle. Setak et al. (2019) combine pricing and exponential or time-stock-price-dependent demand in perishability and nonlinear costs. Sen and Saha (2020) raised bigger issues in the supply chain. Yang et al. (2020) addressed decision-support tools and developed an even more effective control of perishable inventory. Nyagah et al. (2020) emphasized the importance of perishability, medicine waste, and its social impacts. Zheng et al. (2021) survey discount policies, shelf-life-driven buying, and Q-learning frameworks to govern the rival perishable marketplace. The paper by Macias-Lopez et al. (2021) combines pricing strategy with exponential or time-stock-price-dependent demand under perishability and nonlinear demand costs. Osman et al. (2023) are engaged in addressing

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issues such as the problem of perishability, waste pharmaceuticals, and their societal implications. Kumar et al. (2023) employ fuzzy logic when addressing the seasonal demand of deteriorating goods. Yadav and Kumar (2024) generalize fuzzy modeling to combined pricing and inventory problems with, respectively, partly backlogged and price- and time-dependent demand.

1.2.Deterioration in Pharmaceutical Products

The gathered studies provide valuable and in-depth insights into pharmaceutical inventory and supply chain management, particularly the dynamics of demand variability, product degradation, and supply chain disruptions. Uthayakumar and Priyan (2013) streamline inventory coordination between hospitals and pharmaceutical firms. The study conducted by Jaberidoost et al. (2013) identifies the primary motivators for inventories and audits of risk in pharmaceutical supply chains. Sana et al. (2015) note that optimizing replenishment strategies to the extent that the sales team handles them is also essential. Uthayakumar and colleagues also make a significant contribution, covering scenarios such as variable deterioration (2017), quadratic and time-dependent demand (2016, 2017), complete and partial backlogging (2017, 2018), and trade credit and delay in payment (2017). Ultimately, all these publications demonstrate the need to develop adaptive, risk-aware, and technology-driven inventory management in the pharmaceutical supply chain. Bucalo and Jereb (2017). The authors of the article provide information on pharmaceutical risk management**.** A review of the multi-echelon inventory management in pharma chains is the topic considered by Sbaib and Berrado (2018). Rastogi and Singh (2019) introduce a model that incorporates price sensitivity and a learning effect on deteriorating items. Ellison and Cook (2020) examine inventory levels through the lens of health economics perception. The policies of equitable distributions are proposed by Gallien et al. (2021) in Zambia. Kumar et al. (2021) study the decay of inventory in medicinal products in healthcare. Rathipriya et al. (2022) use neural networks to predict the demand in the field of pharmaceutics. According to Hansen et al., there are three main drivers to increase the inventory. Takawira and Pooe (2024) consider the main lessons to be learned from the pharmaceutical industry's response to COVID-19.

1.3.Preservation Techniques and Costs

As summarized, the works explore inventory models of deteriorating items, where preservation strategies are significant in reducing losses and ensuring profitability. According to Mishra (2013), there is salvage value and shortages. Hsieh and Dye (2013) and Dye (2013) consider the impacts of preservation investment on non-instantaneous deterioration and time-varying demand. Tayal et al. (2016) consider perishable trade credit with preservation. Mishra et al. (2017) extend this model by incorporating price- and stock-dependent demand, controllable deterioration, and investment in preservation. Shen et al. (2019) employ a collaborative model with implications for carbon taxation. Sepehri et al. (2021) incorporate sustainability into the consideration of quality flaws and investment into preservation technology. Priyamvada et al. (2021) generalize the proposal to cover price- and stock-sensitive demand, controllable depreciation, and preservation investment. The solution to uncertain demand provided by Mahapatra et al. (2022) is an inventory system based on preservation

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tactics. The issue of trapezoidal demand is checked within the preservation technology by Kaushik (2024). Jain and Singh (2024) use metaheuristics to optimize prices and deterioration-free preservation. Sharma & Mandal (2024) devise a model of incorporating stock-sensitive demand, preservation investment, and prepayment schemes. These two papers have similar indications to the strategic nature of preservation technology in contemporary inventory systems that deal with the variable demand, wear and tear, sustainability, and economic policy management to improve the performance of the supply chain as a whole.

In summary, the research proposes a new approach to inventory control that integrates the concepts of deterioration, preservation, and demand for pharmaceutical goods with a limited expiration period. Our model, which considers the cost of preservation and its impact on the rate of deterioration of the product, fills a significant gap in existing inventory management literature. Its mathematical formulation, coupled with numerical solutions and sensitivity analysis, yields a rich decision-making tool that can be utilized by supply chain managers who operate perishable medical inventories. In addition to supporting theoretical knowledge in the field of inventory modeling for deteriorating items, this work offers practical recommendations for pharmaceutical logistics. The model is significant to both public and private stakeholders. Hospitals and healthcare providers can utilize it to reduce waste and optimize storage. At the same time, pharmaceutical companies can use it to create products with a longer shelf life or develop more effective preservation technologies. This is why the model offers a more realistic and holistic approach to supply chain management, particularly in terms of preservation costs during planning.

2. Assumptions and notations

2.1. Assumptions:

- Deteriorates at a controllable rate.
- Incurs explicit preservation cost.
- Faces a time-declining demand $D(t) = D_0 e^{-\lambda(M-t)}$ (where λ= demand-decay parameter), that accelerates as the item approaches its shelf life, M. $0 \le t \le T < M$ Demand rises exponentially as the product approaches expiry.
- Holding cost is constant.
- There are no shortages.
- Time horizon is finite.
- Constant deterioration θ, where $0 < \theta < 1$.

2.2. Notations:

A= Ordering Cost.

M = Shelf-life (Maximum lifetime) of the product.

T= Cycle length time.

D_0 = Base (average) demand rate.

λ = Demand-decay parameter, $0 < \lambda < 1$(control how fast demand accelerates).

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θ = Natural (unpreserved) deterioration rate, where 0 < θ < 1.

a = Effectiveness of preservation.

u = Preservation cost per unit per unit time.

θ_e = Effective deterioration rate, where $\theta_e = \theta e^{-au}$.

h = Holding cost per unit per unit time.

δ = Per unit deterioration cost.

Q = Quantity ordered per cycle.

Z(T)= Total Cost per unit time

3. Mathematical Formulation:

The model aims to optimize inventory levels by minimizing total costs, which encompass ordering, holding, deterioration, and preservation expenses, while ensuring uninterrupted drug supply and patient safety. This robust optimization approach is crucial for high-value pharmaceutical products, where stockouts can have severe health implications and holding excess inventory leads to substantial financial losses due to spoilage.

$$\frac{dI(t)}{dt} + \theta_e I(t) = -D(t)$$

$$\frac{dI(t)}{dt} + \theta_e I(t) = -D_0 e^{-\lambda(M-t)} \tag{1}$$

Where $I(0) = Q$ and $I(T) = 0,$ and T is the cycle length

Solution of equation (1),

$$I(t) = \frac{D_0 e^{-\lambda M}}{(\theta_e + \lambda)}\left[e^{(\theta_e+\lambda)T} . e^{-\theta_e t} - e^{\lambda_e t}\right] \tag{2}$$

and

$$Q = \frac{D}{\theta_e + \lambda}\left(e^{(\theta_e+\lambda)} - 1\right) \tag{3}$$

Ordering Cost

$$\text{OC}=A$$

Holding cost

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$$HC = h\int_0^T I(t).dt$$

$$HC = h\int_0^T \frac{D_0 e^{-\lambda M}}{(\theta_e+\lambda)}\left[e^{(\theta_e+\lambda)T}.e^{-\theta_e t} - e^{\lambda_e t}\right]dt$$

$$HC = \frac{D_0 h e^{-\lambda M}}{(\theta_e+\lambda)}\left[\frac{e^{(\theta_e+\lambda)T}}{\theta}(1-e^{-\theta_e T}) - \frac{1}{\lambda}(e^{\lambda T}-1)\right] \tag{4}$$

Deterioration cost $$DC = \delta\theta_e\int_0^T I(t)dt$$

$$DC = \frac{D_0\delta\theta_e e^{-\lambda M}}{(\theta_e+\lambda)}\left[\frac{e^{(\theta_e+\lambda)T}}{\theta}(1-e^{-\theta_e T}) - \frac{1}{\lambda}(e^{\lambda T}-1)\right] \tag{5}$$

Preservation cost $$PC = au\int_0^T I(t)dt$$

$$PC = \frac{auD_0 e^{-\lambda M}}{(\theta_e+\lambda)}\left[\frac{e^{(\theta_e+\lambda)T}}{\theta}(1-e^{-\theta_e T}) - \frac{1}{\lambda}(e^{\lambda T}-1)\right] \tag{6}$$

Total cost per cycle

$$Z(T) = \frac{1}{T}\left[A + HC + DC + PC\right]$$

$$Z(T) = \frac{1}{T}\left[\begin{array}{l} A + \frac{D_0 h e^{-\lambda M}}{(\theta_e+\lambda)}\left(\frac{e^{(\theta_e+\lambda)T}}{\theta}(1-e^{-\theta_e T}) - \frac{1}{\lambda}(e^{\lambda T}-1)\right) \\ + \frac{D_0\delta\theta_e e^{-\lambda M}}{(\theta_e+\lambda)}\left(\frac{e^{(\theta_e+\lambda)T}}{\theta}(1-e^{-\theta_e T}) - \frac{1}{\lambda}(e^{\lambda T}-1)\right) \\ + \frac{auD_0 e^{-\lambda M}}{(\theta_e+\lambda)}\left[\frac{e^{(\theta_e+\lambda)T}}{\theta}(1-e^{-\theta_e T}) - \frac{1}{\lambda}(e^{\lambda T}-1)\right] \end{array}\right] \tag{7}$$

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Equation (7) was minimized using Wolfram Mathematica, a powerful symbolic computation tool. The software efficiently handled the complex, nonlinear nature of the objective function. Through built-in optimization functions, it provided accurate solutions while ensuring computational stability and precision.

4. Numerical Validation of the Mathematical Formulation

Given a pharmaceutical product with an average demand rate D_0 = 100 units, a demand-decay parameter λ=0.3, and a natural deterioration rate θ=0.04, to determine the optimal replenishment cycle *T* and order quantity *Q* that minimize the total inventory cost *Z(T)*, under the influence of preservation efforts. We are assuming a preservation cost of u=4 per unit per time, deterioration cost δ=3 per unit, ordering cost A=100 per order, and holding cost *h* per unit per unit time, and given the preservation effectiveness factor a=0.02, resulting in an effective deterioration rate $\theta_e = \theta(1\text{-}au) = 0.0368$. The optimal inventory policy that yields the minimum total cost ***Z(T)=199.652*** at ***T=0.918385*** with an order quantity ***Q=79.732***.

The optimal solution derived for the test instance yields a cycle length T*= 0.918 time units, an order quantity Q*= 79.7 units, and a minimum total cost Z*= $199.65, illustrating how a mathematically tuned balance between *how much* to buy and *how aggressively* to preserve can outperform rule-of-thumb ordering or blanket refrigeration. In practical terms, it tells a pharmacy manager that replenishing slightly below the static "base demand" of 100 units makes economic sense once deterioration and preservation are explicitly priced: preserving fewer units for a shorter period avoids the twin penalties of high energy bills and drug write-offs, yet still maintains service level because the replenishment frequency is optimized.

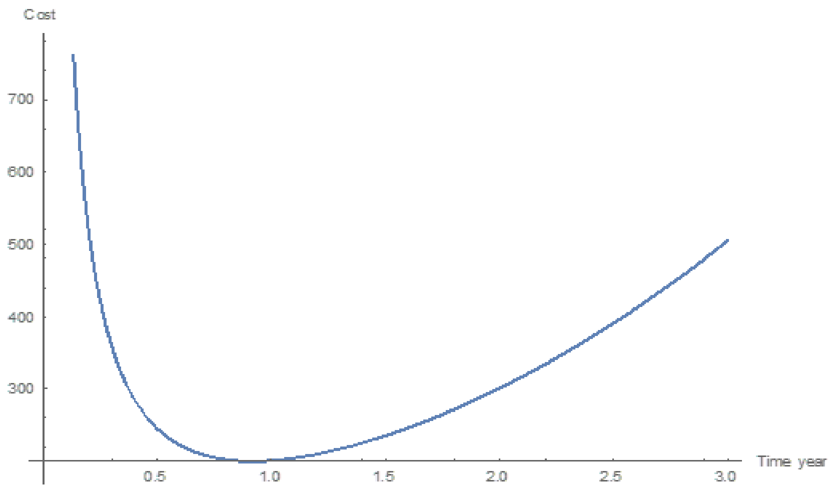

Figure 1. Graphical Representation

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4.1.Sensitivity Analysis

Parameter	Variation	*T*	*Z(T)*	*Q*
A	-20%	0.835316	176.852	71.4636
	-10%	0.878322	188.522	75.7154
	+10%	0.955956	210.322	83.5483
	+20%	0.991385	220.592	87.1916
D_0	-20%	1.008380	180.474	71.1638
	-10%	0.959993	190.334	75.5652
	+10%	0.882078	208.510	80.4248
	+20%	0.850011	216.969	87.4914
λ	-20%	0.922377	201.712	82.6604
	-10%	0.920320	200.675	81.1771
	+10%	0.916565	198.643	78.3238
	+20%	0.914852	197.648	76.9510
θ	-20%	0.924002	198.525	80.0130
	-10%	0.921183	199.089	79.8721
	+10%	0.915610	200.214	79.5929
	+20%	0.912855	200.775	79.4546
a	-20%	0.920742	199.086	79.9948
	-10%	0.919561	199.370	79.8631
	+10%	0.917215	199.935	79.6016
	+20%	0.916049	200.217	79.4718
h	-20%	0.999401	182.231	88.0220
	-10%	0.956132	191.164	83.5663
	+10%	0.885053	207.757	76.3864

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	+20%	0.855319	215.525	73.4335
u	**-20%**	0.920742	199.086	79.9948
	-10%	0.919561	199.370	79.8631
	+10%	0.917215	199.935	79.6016
	+20%	0.916049	200.217	79.4718
δ	**-20%**	0.922319	198.735	80.1293
	-10%	0.920345	199.194	79.9299
	+10%	0.916439	200.109	79.5356
	+20%	0.914505	200.565	79.3406

4.2.Sensitivity Analysis Observations

The sensitivity analysis examines the impact of changing key variables (in the inventory model) by 10% and 20% on the optimal cycle time (T), total cost (Z(T)), and order quantity (Q). The main lessons are the following:

- *Ordering Cost (A):* The higher the ordering cost, the greater the total costs and the quantity of orders becomes, while the cycle time is prolonged. This implies that increased costs of orders induce fewer but sizable orders to reduce the frequency of orders and total expenditures.
- *Base Demand (D_0):* With an increase in base demand, the cycle time also reduces, as does the ordered quantity of goods, indicating more frequent replenishment of the item and a higher stock level. This, in turn, causes the total cost to increase due to the increased demand.
- *Demand-Decay Rate (λ):* The changes in **λ** depict a minor yet steady trend. As the amount of **λ**, i.e., one amplitude, increases, the cycle time and order quantity decrease marginally, along with a minute decrease in total cost. This implies that the system can respond by ordering simpler quantities at a shorter interval as demand decays more rapidly over time.
- *Natural Deterioration Rate(**θ**):* As the rate of deterioration increases, the cycle time and order quantity will slightly decrease, whereas the total cost will increase. This is relative to the practical consideration that ensures excessive stock is not allocated in other areas where the products used are more perishable.
- *Preservation Effectiveness (a):* The analysis of the variable preservation efforts shows that variations in the preservation efforts do not affect the key outcomes to a large extent. Lowering the preservation level causes a small improvement in all the outputs being evaluated, but increasing the preservation progressively worsens these. Nevertheless, the

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changes are such that the model is relatively non-sensitive to the changes in this specific variable of the entire range tested.

- *Holding Cost (h):* Of all parameters, holding cost reveals one of the most significant effects. An increase in the holding cost significantly lowers the order quantity and cycle time, and the time of inventory turnover is shortened. The total cost becomes very high since it becomes more costly to keep inventory.
- *Preservation Cost (u):* Augmentation of preservation cost has no significant impact on the inventory strategy for any of the three outcomes, indicating that minimal adjustments to preservation activity do not alter them to a significant degree in the tested parameters.
- *Deterioration cost(δ):* The effect of changes in the deterioration cost on the performance of the system is investigated. As δ increases, the performance indicators reveal a gradual decrease in overall efficiency, resulting in a steady decline in benefit or an increase in cost implication. On the other hand, a smaller δ increases the system's results, which suggests that the deterioration cost has a positive impact on performance measures.

5. Managerial Insight

The study provides valuable insights for inventory managers managing items with limited shelf life, such as pharmaceutical products. It points out that the decay process would occur at least twice as fast without preservation, cut the usable shelf life by 74 percent of what it could be, and increase the number of disposals or emergency orders made. Nevertheless, through proper storage of the products using an amount of 4 per unit per month, one could reduce deterioration rate by 0.4 per cent (4 per cent to 3.68 per cent), which translates into an 8 per cent reduction in wastage (saving close to 800 thousand rupees at the rate of 10 million rupee of antibiotics inventory every quarter). Energy and maintenance costs are also factors considered in the model, which reveals that by ensuring the replenishment cycle is kept short by slightly below one year, as opposed to two years, as is the norm now, can save a significant amount of money in terms of electricity costs on compressor usage by about 30 percent. However, operationally, the proposed policy (Q*, T*) should increase the availability of the stock without overstocking. This can dynamically adjust supply to meet demand changes, which can be helpful, particularly when seasonal demands increase, such as during an outbreak of flu. The model also facilitates regulatory compliance, providing a mathematically sound framework for inventory levels that is consistent with the requirements of international GDP. It also enhances risk management, allowing supply plans to be adjusted quickly in response to cost shocks or changes in preservation performance. Ultimately, the model will enable managers to monitor the costs and quality of the decisions they make, develop an efficient in-process pharmaceutical inventory system, and inform their data-driven decision-making.

6. **Conclusion**

This study develops a detailed inventory model that is well-suited for pharmaceutical goods with expiration dates and that degrade even under optimal maintenance conditions. Through a meticulous sensitivity analysis, it becomes clear that variables such as ordering cost, level of demand, holding cost, and deterioration rate significantly influence the effectiveness of an optimal ordering strategy. Specifically, the deterioration and demand rates increase, causing

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more agile and responsive replenishment cycles. Higher ordering and carrying costs, however, encourage managers to place fewer but larger reorders. Alternatively, the parameters related to preservation, such as effort and effectiveness, may not have a significant effect at some point in the future, implying that excessive investment in preservation may never seem worthwhile. The flexibility of the model can also be effective in risk management, where planners can test various scenarios, such as an increase in electricity prices or fluctuations in product stability, and adjust accordingly. Overall, it can be observed that the research presents a robust and viable model for pharmaceutical inventory management.

References

1. Balkhi, Z. T., &Benkherouf, L. (2004). On an inventory model for deteriorating items with stock-dependent and time-varying demand rates. *Computers & Operations Research*, *31*(2), 223-240.
2. Balugani, E., Lolli, F., Gamberini, R., Rimini, B., & Babai, M. Z. (2019). A periodic inventory system of intermittent demand items with fixed lifetimes. International Journal of Production Research, 57(22), 6993. https://doi.org/10.1080/00207543.2019.1572935
3. Bucalo, N., & Jereb, B. (2017). Risk Management in the Pharmaceutical Industry in Slovenian Companies. Logistics Supply Chain Sustainability and Global Challenges, 8(1), 42. https://doi.org/10.1515/jlst-2017-0004
4. Damgaard, C. M., Nguyen, V. T., Hvolby, H., & Steger-Jensen, K. (2013). Perishable Inventory Challenges. In IFIP advances in information and communication technology (p. 670). Springer Science+Business Media. https://doi.org/10.1007/978-3-642-40361-3_85
5. Daryanto, Y., & Wee, H. (2018). Sustainable Economic Production Quantity Models: An Approach toward a Cleaner Production. Deleted Journal, 6(4), 206. https://doi.org/10.18178/joams.6.4.206-212
6. Dye, C. Y. (2013). The Effect of Preservation Technology Investment on a Non-Instantaneous Deteriorating Inventory Model. *Omega*, *41*(5), 872-880.
7. Ellison, P. B., & Cook, R. A. (2020). Health economic analysis of pharmaceutical inventory levels. Journal of Humanitarian Logistics and Supply Chain Management, 10(4), 603. https://doi.org/10.1108/jhlscm-01-2020-0001
8. Fauza, G., Amer, Y., Lee, S., &Prasetyo, H. (2015). A Vendor-Buyer Inventory Model for Food Products Based On Shelf-Life Pricing. Operations and Supply Chain Management An International Journal, 67. https://doi.org/10.31387/oscm0200146
9. Fichtinger, J., Ries, J. M., Grosse, E. H., & Baker, P. (2015). Assessing the environmental impact of integrated inventory and warehouse management. International Journal of Production Economics, 170, 717. https://doi.org/10.1016/j.ijpe.2015.06.025

10.48047/jocaaa.2024.32.02.51

10. Fries, B. E. (1975). Optimal ordering policy for a perishable commodity with fixed lifetime. *Operations research*, *23*(1), 46-61.
11. Gallien, J., Leung, N.-H. Z., & Yadav, P. (2021). Inventory Policies for Pharmaceutical Distribution in Zambia: Improving Availability and Access Equity. Production and Operations Management, 30(12), 4501. https://doi.org/10.1111/poms.13541

12. Georgiadis, P., & Vlachos, D. (2003). The effect of environmental parameters on product recovery. European Journal of Operational Research, 157(2), 449. https://doi.org/10.1016/s0377-2217(03)00203-0

13. Ghare, P. M., & Schrader, G. F. (1963). An inventory model for exponentially deteriorating items. *Journal of Industrial Engineering*, *14*(2), 238-243.
14. Hansen, Z. N. L., Andreu, C. M., Khan, O., Haug, A., Hvam, L., & Hansen, N. E. (2023). Identification of key drivers for improving inventory management in pharmaceutical supply chains. Production Engineering, 17(5), 763. https://doi.org/10.1007/s11740-023-01199-2

15. Herbon, A., Levner, E., & Cheng, T. C. E. (2013). Perishable inventory management with dynamic pricing using time–temperature indicators linked to automatic detecting devices. International Journal of Production Economics, 147, 605. https://doi.org/10.1016/j.ijpe.2013.07.021

16. Hsieh, T. P., & Dye, C. Y. (2013). A production–inventory model incorporating the effect of preservation technology investment when demand is fluctuating with time. *Journal of Computational and Applied Mathematics*, *239*, 25-36.
17. Jaberidoost, M., Nikfar, S., Abdollahiasl, A., &Dinarvand, R. (2013). Pharmaceutical supply chain risks: a systematic review [Review of Pharmaceutical supply chain risks: a systematic review]. DARU Journal of Pharmaceutical Sciences, 21(1). Springer Nature. https://doi.org/10.1186/2008-2231-21-69
18. Jain, M., & Singh, P. (2024). Pricing, prepayment and preservation strategy for inventory model with deterioration using metaheuristic algorithms. *Soft Computing*, *28*(4), 3415-3430.
19. Kaliraman, N. K., Raj, R., Chandra, S., & Chaudhary, H. (2017). Two warehouse inventory model for deteriorating item with exponential demand rate and permissible delay in payment. *YUJOR*, *27*(1), 109-124.
20. Kaushik, J. (2024). An inventory model for deteriorating items towards trapezoidal type demand with preservation technology. *Opsearch*, *61*(4), 1681-1712.
21. Ketzenberg, M., Gaukler, G. M., & Salin, V. (2017). Expiration dates and order quantities for perishables. European Journal of Operational Research, 266(2), 569. https://doi.org/10.1016/j.ejor.2017.10.005

22. Khedlekar, U. K. (2012). A disruption production model with exponential demand. *International Journal of Industrial Engineering Computations*, *3*(4), 607-616.

10.48047/jocaaa.2024.32.02.51

23. Kumar, K., Kumar, N., & Meenu, M. (2021). An inventory system for varying decaying medicinal products in the healthcare trade. Yugoslav Journal of Operations Research, 31(2), 273. https://doi.org/10.2298/yjor200125011k
24. Kumar, S., Yadav, R. K., & Singh, A. (2023). Study on fuzzy inventory model for deteriorating items with recurring seasonal demand pattern. *International Journal of Mathematics in Operational Research*, *24*(3), 408-424.
25. Macías-López, A., Cárdenas-Barrón, L. E., Peimbert-García, R. E., & Mandal, B. (2021). An Inventory Model for Perishable Items with Price-, Stock-, and Time-Dependent Demand Rate considering Shelf-Life and Nonlinear Holding Costs. *Mathematical problems in Engineering*, *2021*(1), 6630938.
26. Mahapatra, A. S., Dasgupta, A., Shaw, A. K., & Sarkar, B. (2022). An inventory model with uncertain demand under preservation strategy for deteriorating items. *RAIRO-Operations Research*, *56*(6), 4251-4280.
27. Mahapatra, A. S., Dasgupta, A., Shaw, A. K., & Sarkar, B. (2022). An inventory model with uncertain demand under preservation strategy for deteriorating items. *RAIRO-Operations Research*, *56*(6), 4251-4280.
28. Maihami, R., &Ghalehkhondabi, I. (2019). Combining the Inventory Control Policy with Pricing and Advertisement Decisions for a Non-instantaneous Deteriorating Product. In IFIP advances in information and communication technology (p. 256). Springer Science+Business Media. https://doi.org/10.1007/978-3-030-29996-5_30
29. Malik AK, Vedi P, Kumar S (2018): Inventory Model with Time-Varying Demand for Non-Instantaneous Deteriorating Items with Maximum Life Time,International Journal of Applied Engineering Research, Volume 13: 7162-7167.
30. Mishra, U., Cárdenas-Barrón, L. E., Tiwari, S., Shaikh, A. A., & Treviño-Garza, G. (2017). An inventory model under price and stock dependent demand for controllable deterioration rate with shortages and preservation technology investment. *Annals of operations research*, *254*, 165-190.
31. Mishra, V. K. (2013). Deteriorating inventory model using preservation technology with salvage value and shortages. *Advances in Production Engineering and Management*, *8*(3), 185-192.
32. Nyagah, D. M., Njagi, A., & Nyaga, M. N. (2020). Pharmaceutical waste: overview, management and impact of improper disposal. Zenodo (CERN European Organization for Nuclear Research). https://doi.org/10.5281/zenodo.4088224
33. Osman, S. A., Xu, C., Akuful, M., & Paul, E. R. (2023). Perishable Food Supply Chain Management: Challenges and the Way Forward. Open Journal of Social Sciences, 11(7), 349. https://doi.org/10.4236/jss.2023.117025
34. Piramuthu, S., & Zhou, W. (2013). RFID and perishable inventory management with shelf-space and freshness dependent demand. International Journal of Production Economics, 144(2), 635. https://doi.org/10.1016/j.ijpe.2013.04.035
35. Priyamvada, Rini, Khanna, A., & Jaggi, C. K. (2021). An inventory model under price and stock dependent demand for controllable deterioration rate with shortages and preservation technology investment: revisited. *Opsearch*, *58*, 181-202.

10.48047/jocaaa.2024.32.02.51

36. Raj, R., Kaliraman, N. K., Chandra, S., & Chaudhary, H. (2014). A production inventory model with exponential demand rate and reverse logistics. *International Journal of Industrial Engineering Computations*, *5*(4), 521.
37. Rastogi M, Singh S R, (2019): A Pharmaceutical Inventory Model for Varying Deteriorating Items with Price Sensitive Demand and Partial Backlogging Under the Effect of Learning,Int. J. Appl. Comput. Math 5, 74-92.
38. Rathipriya, R., Rahman, A. A. A., Dhamodharavadhani, S., Meero, A., &Yoganandan, G. (2022). Demand forecasting model for time-series pharmaceutical data using shallow and deep neural network models. Neural Computing and Applications, 35(2), 1945. https://doi.org/10.1007/s00521-022-07889-9
39. Ray, J., & Chaudhuri, K. S. (1997). An EOQ model with stock-dependent demand, shortage, inflation, and time discounting. *International Journal of Production Economics*, *53*(2), 171-180.
40. Sana S S, Panda S, Modak N M(2015) Optimal replenishment and sales team initiatives for pharmaceutical products e A mathematical model, Pacific Science Review B: Humanities and Social Sciences 1, 15-21
41. Sbai, N., &Berrado, A. (2018). A literature review on multi-echelon inventory management: the case of pharmaceutical supply chain [Review of A literature review on multi-echelon inventory management: the case of pharmaceutical supply chain]. MATEC Web of Conferences, 200, 13. EDP Sciences. https://doi.org/10.1051/matecconf/201820000013
42. Sen, N., & Saha, S. (2020). Inventory model for deteriorating items with negative exponential demand, probabilistic deterioration and fuzzy lead time under partial back logging. *Operations Research and Decisions*, *30*.
43. Sepehri, A., Mishra, U., & Sarkar, B. (2021). A sustainable production-inventory model with imperfect quality under preservation technology and quality improvement investment. *Journal of Cleaner Production*, *310*, 127332.
44. Setak, M., Fozooni, N., &Daneshvari, H. (2019). Developing a model for pricing and control the inventory of perishable products with exponential demand. *Journal of industrial and systems engineering*, *12*(3), 120-140.
45. Sharma, M. K., & Mandal, D. (2024). An inventory model with preservation technology investments and stock-varying demand under advanced payment scheme. *Opsearch*, 1-22.
46. Shen, Y., Shen, K., & Yang, C. (2019). A production inventory model for deteriorating items with collaborative preservation technology investment under carbon tax. *Sustainability*, *11*(18), 5027.
47. Takawira, B., &Pooe, R. I. (2024). Supply chain disruptions during COVID-19 pandemic: Key lessons from the pharmaceutical industry. *South African Journal of Business Management*, *55*(1), 4048.
48. Tayal, S., Singh, S. R., & Sharma, R. (2016). An integrated production inventory model for perishable products with trade credit period and investment in preservation

technology. *International Journal of Mathematics in Operational Research*, *8*(2), 137-163.

49. Tripathi, R. P. (2012). An inventory model with shortage and exponential demand rate under permissible delay in payments. *International Journal of Management Science and Engineering Management*, *7*(2), 134-139.
50. Tripathi, R. P., Pareek, S., & Kaur, M. (2017). Inventory model with exponential time-dependent demand rate, variable deterioration, shortages and production cost. *International journal of applied and computational mathematics*, *3*, 1407-1419.
51. Ukil, S. I., Islam, M. E., & Uddin, M. S. (2015). A Production Inventory Model of Power Demand and Constant Production Rate Where the Products Have Finite Shelf-Life. *Journal of Service Science and Management*, *8*(06), 874.
52. Uthayakumar R, Priyan S (2013) Pharmaceutical supply chain and inventory management strategies:Optimization for a pharmaceutical company and a hospital. Elsevier,Operations Research for Health Care,Volume 2, p. 52–64.
53. Uthayakumar R., Karuppasamy S.K. (2016)A pharmaceutical inventory model for healthcare industries with quadratic demand, linear holding cost and shortages. Int. J. Pure Appl. Math. **106**(8), 73–83
54. Uthayakumar R., Karuppasamy S.K. (2017) An inventory model for variable deteriorating pharmaceutical items with time-dependent demand and time-dependentholding cost under trade credit in healthcare industries. Commun. Appl. Anal. **21**(4), 533–549
55. Uthayakumar R., KaruppasamyS.K.(2017) A pharmaceutical inventory model for variable demand and variable holding cost with partially backlogged under permissible delay in payments in healthcare industries. Int. J. Appl. Comput. Math. **3**(S1), 327–341
56. Uthayakumar R., Tharani S. (2018)An Inventory model for deteriorating pharmaceutical items with time-dependent demand under complete backlogging. Int. J. Appl. Comput. Math. **4**(S1), 511-530
57. Verma, V. K., & Verma, B. B. (2014). An Inventory Model with Exponentially Decreasing Demand and Linearly Increasing Deterioration. *International Journal of Physical, Chemical and Mathematical Sciences*, *3*(1).
58. Wee, H. (1998). Optimal Buyer-Seller Discount Pricing and Ordering Policy for Deteriorating Items. The Engineering Economist, 43(2), 151. https://doi.org/10.1080/00137919808903194
59. Yadav, A. K., Yadav, R. K., & Kumar, S. (2024). AN INVENTORY MODEL FOR DETERIORATING ITEMS IN FUZZY ENVIRONMENT FOR JOINT PRICING AND INVENTORY CONTROL WITH PARTIAL BACKLOGGING AND TIME AND PRICE DEPENDENT DEMAND.
60. Yadav, A. S., & Swami, A. (2013). A two-warehouse inventory model for decaying items with exponential demand and variable holding cost. *International Journal of Inventive Engineering and Sciences (IJIES)*, *1*(5), 18-22.
61. Yadav, R. K., & Devi, M. P. (2013). Development of an inventory model with Volume flexibility, random deterioration, and exponentially increasing demand rate. *IOSR Journal of Mathematics*.

10.48047/jocaaa.2024.32.02.51

62. Yadav, R. K., & Vats, A. K. (2014). A deteriorating inventory model for quadratic demand and constant holding cost with partial backlogging and inflation. *IOSR Journal of Mathematics (IOSR-JM)*, *10*(3), 47-52.
63. Yadav, R. K., Vats, A. K., & Kaur, R. (2015). An inventory model for variable demand, constant holding cost and without shortages. *Journal of Mathematics (IOSR-JM)*, *11*(1), 49-55.
64. Yang, Y., Chi, H., Zhou, W., Fan, T., &Piramuthu, S. (2020). Deterioration control decision support for perishable inventory management. Decision Support Systems, 134, 113308. https://doi.org/10.1016/j.dss.2020.113308
65. Zheng, J., Gan, Y., Liang, Y., Jiang, Q., & Chang, J. (2021). Joint Strategy of Dynamic Ordering and Pricing for Competing Perishables with Q-Learning Algorithm. Wireless Communications and Mobile Computing, 2021(1). https://doi.org/10.1155/2021/6643195