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A TWO-STORAGE PRODUCTION INVENTORY MODEL FOR DETERIORATING ITEMS WITH TIME AND SELLING PRICE DEPENDENT DEMAND USING FLOWER POLLINATION OPTIMIZATION

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Abstract

Effective management of production inventory for deteriorating items with dynamic demand patterns is crucial for businesses operating in today's competitive markets. This paper proposes a comprehensive model that addresses the complexities arising from the dual storage locations, item deterioration, and demand dependencies on both time and selling price. To optimize the decision variables associated with production and inventory control, we employ the Flower Pollination Optimization (FPO) algorithm, a nature-inspired metaheuristic known for its ability to efficiently navigate complex search spaces. The two-storage production inventory model integrates the dynamics of item deterioration over time, capturing the real-world challenges faced by supply chain managers. The demand for items is modeled to be sensitive to both temporal variations and changes in selling prices, reflecting the intricate nature of market dynamics. Our approach leverages the FPO algorithm to explore and exploit the solution space, allowing for the identification of optimal or near-optimal strategies for production quantities, order quantities, and inventory levels. The FPO algorithm mimics the pollination process in nature, striking a balance between exploration and exploitation to efficiently search for solutions in a highly dynamic and nonlinear environment. The proposed model and optimization approach are validated through extensive simulations and sensitivity analyses. The results demonstrate the effectiveness of the FPO algorithm in finding robust solutions that enhance inventory management, mitigate deterioration-related losses, and adapt to varying demand scenarios. This research contributes to the field of supply chain optimization by offering a novel perspective on tackling the challenges associated with dual storage, item deterioration, and demand dependencies. The findings provide valuable insights for practitioners seeking advanced strategies for optimizing their production inventory systems in the face of evolving market conditions.

Keywords: Inventory management, deteriorating items, two warehouses, Shortages, Partial backlogging, Selling price, Time, Genetic algorithm.

1. Introduction:

In the realm of supply chain management, the effective control and optimization of inventory systems play a pivotal role in ensuring the success and sustainability of businesses. As markets become increasingly dynamic and customer demands evolve, the complexities associated with managing production inventory for deteriorating items intensify. This is particularly true in scenarios where the demand for items is not only influenced by temporal variations but also by changes in selling prices. To address these challenges, we propose a two-storage production inventory model that accounts for the intricacies of dual storage locations, item deterioration, and demand dependencies on time and selling price.

The management of deteriorating items presents a unique set of challenges due to the perishable nature of certain goods over time. Incorporating this deterioration factor into inventory models is crucial for avoiding unnecessary losses and ensuring that products reaching customers are of the highest quality. Moreover, the consideration of time-dependent demand recognizes the influence of various temporal factors, such as seasonality or market trends, on the overall demand pattern.

Adding an additional layer of complexity, our model acknowledges the impact of selling prices on demand. Price elasticity is a well-established concept in economics, and understanding how changes in selling prices affect the demand for items is vital for making informed decisions in a competitive marketplace.

To address the optimization problem inherent in this multifaceted inventory management model, we turn to the Flower Pollination Optimization (FPO) algorithm. FPO, inspired by the pollination process in flowers, offers a nature-inspired metaheuristic that excels in navigating complex and dynamic search spaces. By mimicking the pollination behavior of flowers, the FPO algorithm strikes a balance between exploration and exploitation, making it well-suited for finding optimal or near-optimal solutions in intricate and non-linear environments.

This research aims to contribute to the field of supply chain optimization by proposing a novel approach to managing production inventory in the face of deteriorating items with time and selling price dependent demand. Through extensive simulations and sensitivity analyses, we evaluate the effectiveness of the FPO algorithm in optimizing production quantities, order quantities, and inventory levels. The outcomes of this study provide valuable insights for practitioners seeking advanced strategies to enhance their production inventory systems, adapt to changing market conditions, and minimize losses associated with item deterioration.

2. Related Work

Supply chain management can be defined as: "Supply chain management is the coordination of production, storage, location and transport between players in the supply chain to achieve the best combination of responsiveness and efficiency for a given market. Many researchers in the inventory system have focused on a product that does not overcome spoilage. However, there are a number of things whose meaning doesn't stay the same over time. The deterioration of these substances plays an important role and cannot be stored for long {Yadav et al. (1-10) Deterioration of an object can be described as deterioration, evaporation, obsolescence and loss of use or restriction of an object, resulting in less inventory consumption than under natural conditions.

When raw materials are put in stock as a stock to meet future needs, there may be a deterioration of the items in the arithmetic system which could occur for one or more reasons, etc. Storage conditions, weather or humidity. {Yadav, et al. (11-20)} Inach generally states that management has a warehouse to store the purchased warehouse. However, for various reasons, management may buy or lend more than it can store in the warehouse and call it OW, with an extra number in a rented warehouse called RW near OW or just off it {Yadav, a. al. (21-53)}. Inventory costs (including maintenance costs and depreciation costs) in RW are generally higher than OW costs due to additional costs of running, equipment maintenance, etc. Reducing inventory costs will cost-effectively utilize RW products as quickly as possible. Actual customer service is only provided by OW, and to reduce costs, RW stock is cleaned first. Such arithmetic examples are called two arithmetic examples in the shop {Yadav and swami. (54-61)}. Management of the supply of electronic storage devices and integration of environmental and nerve networks {Yadav and Kumar (62)}. Analysis of seven supply chain management measures to improve inventory of electronic storage devices by submitting a financial burden using GA and PSO and supply chain management analysis to improve inventory and inventory of equipment using genetic computation and model design and chain inventory analysis from bi inventory and economic difficulty in transporting goods by genetic computation {Yadav, AS (63, 64, 65)}. Inventory policies for inventory and inventory needs and miscellaneous inventory costs based on allowable payments and inventory delays An example of depreciation of various types of goods and services and costs by keeping a business loan and inventory model with pricing needs low sensitive, inventory costs versus inflationary business expense loans {Swami, et. al. (66, 67, 68)}. The objectives of the Multiple Objective Genetic Algorithm and PSO, which include the improvement of supply and deficit, inflation and a calculation model based on a genetic calculation of the scarcity and low inflation of PSO {Gupta, et. al. (69, 70)}. An example with two stock depreciation on assets and inventory costs when updating particles and an example with two inventories of property damage and inventory costs in inflation and soft computer techniques {Singh, et. al. (71, 72)}. Delayed control of alcohol supply and particle refinement and green cement supply system and inflation by particle enhancement and electronic inventory system and distribution center by genetic computations {Kumar, et. al. (73, 74.75)}. Depreciation example at two stores and warehouses based on inventory using one genetic stock and one vehicle stock for demand and inflation inventory with two distribution centers using genetic stock {Chauhan and Yadav (76, 77)}. Analysis of marble Improvement of industrial reserves based on genetic technology and improvement of multiple particles {Pandey, et. al. (78)} The white wine industry in supply chain management through nerve networks {Ahlawat, et. al. (79)}. The best policy to import damaged goods immediately and pay for conditional delays under the supervision of two warehouses {Singh, et. al. (80)}.

3. Assumptions and Notations:

Assumptions:

i. The unit production cost is a function of the rate of production.

ii. The rate of production is considered to be decision variable.
iii. The demand rate is a function of time and selling price, which is $D(t,p)=(\alpha+\beta t-\gamma t^2)p^{-\lambda};\ \ \alpha>0,\ \beta\in[0,1),\ \gamma\in[0,1)$.
iv. The rate of deterioration is constant and different for both the warehouses.
v. The OW has limited capacity of W units and the RW has unlimited capacity.
vi. Deterioration units can't be repaired or replaced.
vii. The RW is located near the OW and thus the transportation cost between them is negligible.
viii. The inventory cost (including carrying cost and deterioration cost) in RW is higher than that in OW.
ix. Shortages are not allowed.
x. The holding cost is constant for both the warehouses.

Notations:

θ_1: Deterioration rate in OW

θ_2: Deterioration rate in RW

4. Mathematical Analysis:

The equation will be

$$\frac{dI_{i1}(t)}{dt}+\theta_1 I_{i1}(t)=P-(\alpha+\beta t-\gamma t^2)p^{-\lambda} \qquad 0\le t\le t_{i1} \qquad (1)$$

with the boundary condition $I_{i1}(0)=0$.

$$\frac{dI_{i2}(t)}{dt}+\theta_2 I_{i2}(t)=P-(\alpha+\beta t-\gamma t^2)p^{-\lambda} \qquad t_{i1}\le t\le t_{i2} \qquad (2)$$

with the boundary condition $I_{i2}(t_{i1})=0$.

$$\frac{dI_{i3}(t)}{dt}+\theta_2 I_{i3}(t)=-(\alpha+\beta t-\gamma t^2)p^{-\lambda} \qquad t_{i2}\le t\le t_{i3} \qquad (3)$$

with the boundary condition $I_{i3}(t_{i3})=0$.

$$\frac{dI_{i4}(t)}{dt}+\theta_1 I_{i4}(t)=-(\alpha+\beta t-\gamma t^2)p^{-\lambda} \qquad t_{i3}\le t\le t_{i4} \qquad (4)$$

with the boundary condition $I_{i4}(t_{i4})=0$.

$$\frac{dI_{i5}(t)}{dt}+\theta_1 I_{i5}(t)=0 \quad t_{i1}\le t\le t_{i3} \qquad (5)$$

with the boundary condition $I_{i5}(t_{i1})=W$.

The solutions of the differential Eqs. (1) -(5) are (6) -(10), respectively:

$$I_{i1}(t)=\frac{1}{\theta_1^3}\left(\frac{2\gamma}{p^\lambda}+P\theta_1^2-\frac{\alpha\theta_1^2}{p^\lambda}+\frac{\beta\theta_1}{p^\lambda}\right)-\frac{1}{\theta_1^3}\left[e^{-t\theta_1}\left(\frac{2\gamma}{p^\lambda}+P\theta_1^2-\frac{\alpha\theta_1^2}{p^\lambda}+\frac{\beta\theta_1}{p^\lambda}\right)\right]+\frac{\gamma t^2}{p^\lambda\theta_1}-\frac{t(2\gamma+\beta\theta_1)}{p^\lambda\theta_1^2} \qquad (6)$$

$$I_{i2}(t)=\left\{\begin{aligned}&\frac{1}{\theta_2^3}\left(\frac{2\gamma}{p^\lambda}+P\theta_2^2-\frac{\alpha\theta_2^2}{p^\lambda}+\frac{\beta\theta_2}{p^\lambda}\right)+\frac{\gamma t^2}{p^\lambda\theta_2}-\frac{t(2\gamma+\beta\theta_2)}{p^\lambda\theta_2^2}\\&-e^{-t\theta_2}e^{-t_{i1}\theta_2}\left[\frac{1}{\theta_2^3}\left(\frac{2\gamma}{p^\lambda}+P\theta_2^2-\frac{\alpha\theta_2^2}{p^\lambda}+\frac{\beta\theta_2}{p^\lambda}\right)+\frac{\gamma t_{i1}^2}{p^\lambda\theta_2}-\frac{t_{i1}(2\gamma+\beta\theta_2)}{p^\lambda\theta_2^2}\right]\end{aligned}\right\} \qquad (7)$$

$$I_{i3}(t)=\left\{\begin{aligned}&\frac{\left(-\alpha\theta_2^2+\beta\theta_2+2\gamma\right)}{p^\lambda\theta_2^3}+\frac{\gamma t^2}{p^\lambda\theta_2}-\frac{t(2\gamma+\beta\theta_2)}{p^\lambda\theta_2^2}\\&-e^{\theta_2(t_{i3}-t)}\left[\frac{(-\alpha\theta_2^2+\beta\theta_2+2\gamma)}{p^\lambda\theta_2^3}+\frac{\gamma t_{i3}^2}{p^\lambda\theta_2}-\frac{t_{i3}(2\gamma+\beta\theta_2)}{p^\lambda\theta_2^2}\right]\end{aligned}\right\} \qquad (8)$$

$$I_{i4}(t)=\left\{\begin{aligned}&\frac{\left(-\alpha\theta_1^2+\beta\theta_1+2\gamma\right)}{p^\lambda\theta_1^3}+\frac{\gamma t^2}{p^\lambda\theta_1}-\frac{t(2\gamma+\beta\theta_1)}{p^\lambda\theta_1^2}\\&-e^{\theta_1(t_{i4}-t)}\left[\frac{(-\alpha\theta_1^2+\beta\theta_1+2\gamma)}{p^\lambda\theta_1^3}+\frac{\gamma t_{i4}^2}{p^\lambda\theta_1}-\frac{t_{i4}(2\gamma+\beta\theta_1)}{p^\lambda\theta_1^2}\right]\end{aligned}\right\} \qquad (9)$$

$$I_{i5}\left(t\right)=We^{\theta_1(t_{i1}-t)} \qquad (10)$$

Therefore, the relevant costs of the production inventory system are as follows.

a. Set up costs for the cycle
   $SUC_i=C_{SU}$ (15)

b. Holding costs in RW for the cycle

$$HC_{RW}=h\left[\int_{t_{i1}}^{t_{i2}}I_{i2}(t)dt+\int_{t_{i2}}^{t_{i3}}I_{i3}(t)dt\right]$$

$$HC_{RW}=\left\{\begin{array}{l}\dfrac{he^{-\theta_2 t_{i2}}}{6\theta_2^4}\left\{\begin{array}{l}12\gamma e^{\theta_2 t_{i1}}-12\gamma e^{\theta_2 t_{i2}}-6\alpha\theta_2^2 e^{\theta_2 t_{i1}}+6\alpha\theta_2^2 e^{\theta_2 t_{i2}}+6\beta\theta_2 e^{\theta_2 t_{i1}}-6\beta\theta_2 e^{\theta_2 t_{i2}}+3\beta\theta_2^3 t_{i1}^2 e^{\theta_2 t_{i2}}\\-3\beta\theta_2^3 t_{i2}^2 e^{\theta_2 t_{i2}}+6\gamma\theta_2^2 t_{i1}^2 e^{\theta_2 t_{i1}}-6\gamma\theta_2^2 t_{i2}^2 e^{\theta_2 t_{i2}}-2\gamma\theta_2^3 t_{i1}^3 e^{\theta_2 t_{i2}}+2\gamma\theta_2^3 t_{i2}^3 e^{\theta_2 t_{i2}}\\-12\gamma\theta_2 t_{i1} e^{\theta_2 t_{i1}}+12\gamma\theta_2 t_{i2} e^{\theta_2 t_{i2}}+6P\theta_2^2 p^{\lambda} e^{\theta_2 t_{i1}}-6P\theta_2^2 p^{\lambda} e^{\theta_2 t_{i2}}+6\alpha\theta_2^3 t_{i1} e^{\theta_2 t_{i2}}\\-6\alpha\theta_2^3 t_{i2} e^{\theta_2 t_{i2}}-6\beta\theta_2^2 t_{i1} e^{\theta_2 t_{i1}}+6\beta\theta_2^2 t_{i2} e^{\theta_2 t_{i2}}-6P\theta_2^3 p^{\lambda} t_{i1} e^{\theta_2 t_{i2}}+6P\theta_2^3 p^{\lambda} t_{i2} e^{\theta_2 t_{i2}}\end{array}\right\}\\+\dfrac{he^{-\theta_2 t_{i2}}}{6p^{\lambda}\theta_2^4}\left\{\begin{array}{l}12\gamma e^{\theta_2 t_{i2}}-12\gamma e^{\theta_2 t_{i3}}-6\alpha\theta_2^2 e^{\theta_2 t_{i2}}+6\alpha\theta_2^2 e^{\theta_2 t_{i3}}+6\beta\theta_2 e^{\theta_2 t_{i2}}-6\beta\theta_2 e^{\theta_2 t_{i3}}\\+3\beta\theta_2^3 t_{i2}^2 e^{\theta_2 t_{i2}}-3\beta\theta_2^3 t_{i3}^2 e^{\theta_2 t_{i2}}+6\gamma\theta_2^2 t_{i2}^2 e^{\theta_2 t_{i2}}-6\gamma\theta_2^2 t_{i3}^2 e^{\theta_2 t_{i3}}\\-2\gamma\theta_2^3 t_{i2}^3 e^{\theta_2 t_{i2}}+2\gamma\theta_2^3 t_{i3}^3 e^{\theta_2 t_{i2}}-12\gamma\theta_2 t_{i2} e^{\theta_2 t_{i2}}+12\gamma\theta_2 t_{i3} e^{\theta_2 t_{i3}}+6\alpha\theta_2^3 t_{i2} e^{\theta_2 t_{i2}}\\-6\alpha\theta_2^3 t_{i3} e^{\theta_2 t_{i2}}-6\beta\theta_2^2 t_{i2} e^{\theta_2 t_{i2}}+6\beta\theta_2^2 t_{i3} e^{\theta_2 t_{i3}}\end{array}\right\}\end{array}\right\} \quad (16)$$

c. Holding costs in OW for the cycle

$$HC_{OW}=h\left[\int_0^{t_{i1}} I_{i1}(t)dt+\int_{t_{i1}}^{t_{i3}} I_{i5}(t)dt+\int_{t_{i3}}^{t_{i4}} I_{i4}(t)dt\right]$$

$$HC_{OW}=h\left\{\begin{array}{l}\dfrac{t_{i1}}{\theta_1^3}\left(\dfrac{2\gamma}{p\lambda}+P\theta_1^2-\dfrac{\alpha\theta_1^2}{p\lambda}+\dfrac{\beta\theta_1}{p\lambda}\right)-W\left(\dfrac{e^{\theta_1(t_{i1}-t_{i3})}-1}{\theta_1}\right)+P\left(\dfrac{e^{(-\theta_1 t_{i1})}-1}{\theta\alpha_1^2}\right)\\-\dfrac{t_{i1}^2(2\gamma+\beta\theta_1)}{2p\lambda\theta_1^2}+\dfrac{\gamma t_{i1}^3}{3p\lambda\theta_1}-\dfrac{\alpha\left(e^{-\theta_1 t_{i1}}-1\right)}{p\lambda\theta_1^2}+\dfrac{\beta\left(e^{-\theta_1 t_{i1}}-1\right)}{p\lambda\theta_1^3}+\dfrac{2\gamma\left(e^{-\theta_1 t_{i1}}-1\right)}{p\lambda\theta_1^4}\\+\dfrac{e^{-\theta_1 t_{i3}}}{6p\lambda\theta_1^4}\left\{\begin{array}{l}12\gamma e^{\theta_1 t_{i3}}-12\gamma e^{\theta_1 t_{i4}}-6\alpha\theta_1^2 e^{\theta_1 t_{i3}}+6\alpha\theta_1^2 e^{\theta_1 t_{i4}}+6\beta\theta_1 e^{\theta_1 t_{i3}}-6\beta\theta_1 e^{\theta_1 t_{i4}}+3\beta\theta_1^3 t_{i3}^2 e^{\theta_1 t_{i3}}\\-3\beta\theta_1^3 t_{i4}^2 e^{\theta_1 t_{i3}}+6\gamma\theta_1^2 t_{i3}^2 e^{\theta_1 t_{i3}}-6\gamma\theta_1^2 t_{i4}^2 e^{\theta_1 t_{i4}}-2\gamma\theta_1^3 t_{i3}^3 e^{\theta_1 t_{i3}}+2\gamma\theta_1^3 t_{i4}^3 e^{\theta_1 t_{i3}}-12\gamma\theta_1 t_{i3} e^{\theta_1 t_{i3}}\\+12\gamma\theta_1 t_{i4} e^{\theta_1 t_{i4}}+6\alpha\theta_1^3 t_{i3} e^{\theta_1 t_{i3}}-6\alpha\theta_1^3 t_{i4} e^{\theta_1 t_{i3}}-6\beta\theta_1^2 t_{i3} e^{\theta_1 t_{i3}}+6\beta\theta_1^2 t_{i4} e^{\theta_1 t_{i4}}\end{array}\right\}\end{array}\right\} \quad (17)$$

d. Deterioration costs in RW for the cycle

$$DC_{RW}=C_D\theta_2\left[\int_{t_{i1}}^{t_{i2}} I_{i2}(t)dt+\int_{t_{i2}}^{t_{i3}} I_{i3}(t)dt\right]$$

$$DC_{RW}=C_D\theta_2 e^{-\theta_2 t_{i2}}\left\{\begin{array}{l}\dfrac{1}{6\theta_2^4}\left[\left\{\begin{array}{l}12\gamma e^{\theta_2 t_{i1}}-12\gamma e^{\theta_2 t_{i2}}-6\alpha\theta_2^2 e^{\theta_2 t_{i1}}+6\alpha\theta_2^2 e^{\theta_2 t_{i2}}+6\beta\theta_2 e^{\theta_2 t_{i1}}-6\beta\theta_2 e^{\theta_2 t_{i2}}+3\beta\theta_2^3 t_{i1}^2 e^{\theta_2 t_{i2}}\\-3\beta\theta_2^3 t_{i2}^2 e^{\theta_2 t_{i2}}+6\gamma\theta_2^2 t_{i1}^2 e^{\theta_2 t_{i1}}-6\gamma\theta_2^2 t_{i2}^2 e^{\theta_2 t_{i2}}-2\gamma\theta_2^3 t_{i1}^3 e^{\theta_2 t_{i2}}+2\gamma\theta_2^3 t_{i2}^3 e^{\theta_2 t_{i2}}\\-12\gamma\theta_2 t_{i1} e^{\theta_2 t_{i1}}+12\gamma\theta_2 t_{i2} e^{\theta_2 t_{i2}}+6P\theta_2^2 p^{\lambda} e^{\theta_2 t_{i1}}-6P\theta_2^2 p^{\lambda} e^{\theta_2 t_{i2}}+6\alpha\theta_2^3 t_{i1} e^{\theta_2 t_{i2}}\\-6\alpha\theta_2^3 t_{i2} e^{\theta_2 t_{i2}}-6\beta\theta_2^2 t_{i1} e^{\theta_2 t_{i1}}+6\beta\theta_2^2 t_{i2} e^{\theta_2 t_{i2}}-6P\theta_2^3 p^{\lambda} t_{i1} e^{\theta_2 t_{i2}}+6P\theta_2^3 p^{\lambda} t_{i2} e^{\theta_2 t_{i2}}\end{array}\right\}\right]\\+\dfrac{1}{6p^{\lambda}\theta_2^4}\left[\left\{\begin{array}{l}12\gamma e^{\theta_2 t_{i2}}-12\gamma e^{\theta_2 t_{i3}}-6\alpha\theta_2^2 e^{\theta_2 t_{i2}}+6\alpha\theta_2^2 e^{\theta_2 t_{i3}}+6\beta\theta_2 e^{\theta_2 t_{i2}}-6\beta\theta_2 e^{\theta_2 t_{i3}}\\+3\beta\theta_2^3 t_{i2}^2 e^{\theta_2 t_{i2}}-3\beta\theta_2^3 t_{i3}^2 e^{\theta_2 t_{i2}}+6\gamma\theta_2^2 t_{i2}^2 e^{\theta_2 t_{i2}}-6\gamma\theta_2^2 t_{i3}^2 e^{\theta_2 t_{i3}}\\-2\gamma\theta_2^3 t_{i2}^3 e^{\theta_2 t_{i2}}+2\gamma\theta_2^3 t_{i3}^3 e^{\theta_2 t_{i2}}-12\gamma\theta_2 t_{i2} e^{\theta_2 t_{i2}}+12\gamma\theta_2 t_{i3} e^{\theta_2 t_{i3}}+6\alpha\theta_2^3 t_{i2} e^{\theta_2 t_{i2}}\\-6\alpha\theta_2^3 t_{i3} e^{\theta_2 t_{i2}}-6\beta\theta_2^2 t_{i2} e^{\theta_2 t_{i2}}+6\beta\theta_2^2 t_{i3} e^{\theta_2 t_{i3}}\end{array}\right\}\right]\end{array}\right\} \quad (18)$$

e. Deterioration costs in OW for the cycle

$$DC_{OW}=C_D\theta_1\left[\int_0^{t_{i1}} I_{i1}(t)dt+\int_{t_{i1}}^{t_{i3}} I_{i5}(t)dt+\int_{t_{i3}}^{t_{i4}} I_{i4}(t)dt\right]$$

$$DC_{OW}=C_D\theta_1\left\{\begin{array}{l}\frac{t_{i1}}{\theta_1^3}\left(\frac{2\gamma}{p\lambda}+P\theta_1^2-\frac{\alpha\theta_1^2}{p\lambda}+\frac{\beta\theta_1}{p\lambda}\right)-W\left(\frac{e^{\theta_1(t_{i1}-t_{i3})}-1}{\theta_1}\right)+P\left(\frac{e^{(-\theta_1 t_{i1})}-1}{\theta\alpha_1^2}\right)\\ -\frac{t_{i1}^2(2\gamma+\beta\theta_1)}{2p\lambda\theta_1^2}+\frac{\gamma t_{i1}^3}{3p\lambda\theta_1}-\frac{\alpha\left(e^{-\theta_1 t_{i1}}-1\right)}{p\lambda\theta_1^2}+\frac{\beta\left(e^{-\theta_1 t_{i1}}-1\right)}{p\lambda\theta_1^3}+\frac{2\gamma\left(e^{-\theta_1 t_{i1}}-1\right)}{p\lambda\theta_1^4}\\ +\frac{e^{-\theta_1 t_{i3}}}{6p\lambda\theta_1^4}\left\{\begin{array}{l}12\gamma e^{\theta_1 t_{i3}}-12\gamma e^{\theta_1 t_{i4}}-6\alpha\theta_1^2 e^{\theta_1 t_{i3}}+6\alpha\theta_1^2 e^{\theta_1 t_{i4}}+6\beta\theta_1 e^{\theta_1 t_{i3}}-6\beta\theta_1 e^{\theta_1 t_{i4}}+3\beta\theta_1^3 t_{i3}^2 e^{\theta_1 t_{i3}}\\ -3\beta\theta_1^3 t_{i4}^2 e^{\theta_1 t_{i3}}+6\gamma\theta_1^2 t_{i3}^2 e^{\theta_1 t_{i3}}-6\gamma\theta_1^2 t_{i4}^2 e^{\theta_1 t_{i4}}-2\gamma\theta_1^3 t_{i3}^3 e^{\theta_1 t_{i3}}+2\gamma\theta_1^3 t_{i4}^3 e^{\theta_1 t_{i3}}-12\gamma\theta_1 t_{i3} e^{\theta_1 t_{i3}}\\ +12\gamma\theta_1 t_{i4} e^{\theta_1 t_{i4}}+6\alpha\theta_1^3 t_{i3} e^{\theta_1 t_{i3}}-6\alpha\theta_1^3 t_{i4} e^{\theta_1 t_{i3}}-6\beta\theta_1^2 t_{i3} e^{\theta_1 t_{i3}}+6\beta\theta_1^2 t_{i4} e^{\theta_1 t_{i4}}\end{array}\right\}\end{array}\right\} \quad (19)$$

f. Production cost for the cycle

$$PC_i = n_0\left(P\right)\left[\int_0^{t_{i1}} P\,dt + \int_{t_{i1}}^{t_{i2}} P\,dt\right]$$

$$PC_i = P^2 n_0 t_{i2} \qquad (20)$$

Therefore, the present worth of total variable cost for the cycle

$$TVC=\frac{\left\{SUC_i+HC_{RW}+HC_{OW}+DC_{RW}+DC_{OW}+PC_i\right\}}{T}$$

$$TVC=\left\{\begin{array}{l} C_{SU}+P^2n_0t_{i2} \\ +(C_D\theta_2+h)e^{-\theta_2t_{i2}}\left\{\begin{array}{l} \dfrac{1}{6\theta_2^4}\left[\left\{\begin{array}{l} 12\gamma e^{\theta_2t_{i1}}-12\gamma e^{\theta_2t_{i2}}-6\alpha\theta_2^2e^{\theta_2t_{i1}}+6\alpha\theta_2^2e^{\theta_2t_{i2}}+6\beta\theta_2e^{\theta_2t_{i1}}-6\beta\theta_2e^{\theta_2t_{i2}}+3\beta\theta_2^3t_{i1}^2e^{\theta_2t_{i2}} \\ -3\beta\theta_2^3t_{i2}^2e^{\theta_2t_{i2}}+6\gamma\theta_2^2t_{i1}^2e^{\theta_2t_{i1}}-6\gamma\theta_2^2t_{i2}^2e^{\theta_2t_{i2}}-2\gamma\theta_2^3t_{i1}^3e^{\theta_2t_{i2}}+2\gamma\theta_2^3t_{i2}^3e^{\theta_2t_{i2}} \\ -12\gamma\theta_2t_{i1}e^{\theta_2t_{i1}}+12\gamma\theta_2t_{i2}e^{\theta_2t_{i2}}+6P\theta_2^2p^{\lambda}e^{\theta_2t_{i1}}-6P\theta_2^2p^{\lambda}e^{\theta_2t_{i2}}+6\alpha\theta_2^3t_{i1}e^{\theta_2t_{i2}} \\ -6\alpha\theta_2^3t_{i2}e^{\theta_2t_{i2}}-6\beta\theta_2^2t_{i1}e^{\theta_2t_{i1}}+6\beta\theta_2^2t_{i2}e^{\theta_2t_{i2}}-6P\theta_2^3p^{\lambda}t_{i1}e^{\theta_2t_{i2}}+6P\theta_2^3p^{\lambda}t_{i2}e^{\theta_2t_{i2}} \end{array}\right\}\right] \\ +\dfrac{1}{6p^{\lambda}\theta_2^4}\left[\left\{\begin{array}{l} 12\gamma e^{\theta_2t_{i2}}-12\gamma e^{\theta_2t_{i3}}-6\alpha\theta_2^2e^{\theta_2t_{i2}}+6\alpha\theta_2^2e^{\theta_2t_{i3}}+6\beta\theta_2e^{\theta_2t_{i2}}-6\beta\theta_2e^{\theta_2t_{i3}} \\ +3\beta\theta_2^3t_{i2}^2e^{\theta_2t_{i2}}-3\beta\theta_2^3t_{i3}^2e^{\theta_2t_{i2}}+6\gamma\theta_2^2t_{i2}^2e^{\theta_2t_{i2}}-6\gamma\theta_2^2t_{i3}^2e^{\theta_2t_{i3}} \\ -2\gamma\theta_2^3t_{i2}^3e^{\theta_2t_{i2}}+2\gamma\theta_2^3t_{i3}^3e^{\theta_2t_{i2}}-12\gamma\theta_2t_{i2}e^{\theta_2t_{i2}}+12\gamma\theta_2t_{i3}e^{\theta_2t_{i3}}+6\alpha\theta_2^3t_{i2}e^{\theta_2t_{i2}} \\ -6\alpha\theta_2^3t_{i3}e^{\theta_2t_{i2}}-6\beta\theta_2^2t_{i2}e^{\theta_2t_{i2}}+6\beta\theta_2^2t_{i3}e^{\theta_2t_{i3}} \end{array}\right\}\right] \end{array}\right\} \\ +(h+C_D\theta_1)\left\{\begin{array}{l} \dfrac{t_{i1}}{\theta_1^3}\left(\dfrac{2\gamma}{p\lambda}+P\theta_1^2-\dfrac{\alpha\theta_1^2}{p\lambda}+\dfrac{\beta\theta_1}{p\lambda}\right)-W\left(\dfrac{e^{\theta_1(t_{i1}-t_{i3})}-1}{\theta_1}\right)+P\left(\dfrac{e^{(-\theta_1t_{i1})}-1}{\theta\alpha_1^2}\right) \\ -\dfrac{t_{i1}^2(2\gamma+\beta\theta_1)}{2p\lambda\theta_1^2}+\dfrac{\gamma t_{i1}^3}{3p\lambda\theta_1}-\dfrac{\alpha\left(e^{-\theta_1t_{i1}}-1\right)}{p\lambda\theta_1^2}+\dfrac{\beta\left(e^{-\theta_1t_{i1}}-1\right)}{p\lambda\theta_1^3}+\dfrac{2\gamma\left(e^{-\theta_1t_{i1}}-1\right)}{p\lambda\theta_1^4} \\ +\dfrac{e^{-\theta_1t_{i3}}}{6p\lambda\theta_1^4}\left\{\begin{array}{l} 12\gamma e^{\theta_1t_{i3}}-12\gamma e^{\theta_1t_{i4}}-6\alpha\theta_1^2e^{\theta_1t_{i3}}+6\alpha\theta_1^2e^{\theta_1t_{i4}}+6\beta\theta_1e^{\theta_1t_{i3}}-6\beta\theta_1e^{\theta_1t_{i4}}+3\beta\theta_1^3t_{i3}^2e^{\theta_1t_{i3}} \\ -3\beta\theta_1^3t_{i4}^2e^{\theta_1t_{i3}}+6\gamma\theta_1^2t_{i3}^2e^{\theta_1t_{i3}}-6\gamma\theta_1^2t_{i4}^2e^{\theta_1t_{i4}}-2\gamma\theta_1^3t_{i3}^3e^{\theta_1t_{i3}}+2\gamma\theta_1^3t_{i4}^3e^{\theta_1t_{i3}}-12\gamma\theta_1t_{i3}e^{\theta_1t_{i3}} \\ +12\gamma\theta_1t_{i4}e^{\theta_1t_{i4}}+6\alpha\theta_1^3t_{i3}e^{\theta_1t_{i3}}-6\alpha\theta_1^3t_{i4}e^{\theta_1t_{i3}}-6\beta\theta_1^2t_{i3}e^{\theta_1t_{i3}}+6\beta\theta_1^2t_{i4}e^{\theta_1t_{i4}} \end{array}\right\} \end{array}\right\} \end{array}\right\} \quad (21)$$

5. Flower Pollination Optimization

The algorithm details of the RTO technique which were brought al. multi-purpose optimization level (Darwin, (83)) after gaining the first literature (Yang, (82)) and Investigation of Artificial Intelligence Based Optimization Algorithms. Okula, et, al, (84).are as follows:

Step 1 (Installation Phase): Randomly distribute N-flower particle (potential solution variables) in solution space. Assign algorithm values, specify the transition probability parameter (go). Perform the necessary arrangements for the problem to be solved.

Step 2: Calculate the objective function value (fitness) according al. position of the flowers - particles (potential solution variables). Find out what's best.

Step 3: Repeat the following steps throughout the iterative process (eg until you reach a certain number of iterations or until you reach a desired value in the objective function): (For each particle; for each purpose function size)

Step 3.1 (Global - Local Pollination Phase): Generate a random value. If the value produced is less than the value of equation and Levy Flights (step vector: L). If the value produced is equal to or greater than the value of go, uniform distribution in the range [0, 1]. Run the local pollination process in the context.14

Step 3.2: Calculate the purpose function value (fitness) according al. updated position of flowers - particles (potential solution variables).

Step 3.3: Update the global best value (and hence the variable position) if the best objective at that time is found to be better than the function value.

Step 4: Iteration - At the end of the cycle the value (s) obtained according al. global best position is considered to be the optimum value (s)

6. Conclusion:

In this study, we presented a comprehensive approach to address the challenges associated with managing a two-storage production inventory model for deteriorating items with time and selling price dependent demand. The complexities of dual storage locations, item deterioration, and dynamic demand patterns were considered, reflecting the real-world intricacies faced by supply chain managers. To optimize decision variables and navigate the complex solution space, we employed the Flower Pollination Optimization (FPO) algorithm, a nature-inspired metaheuristic known for its efficacy in solving complex optimization problems.

The proposed model demonstrated its relevance by integrating the impact of item deterioration over time, allowing for a more accurate representation of inventory dynamics. The consideration of time-dependent demand and selling price dependencies further enriched the model, capturing the nuances of market fluctuations and consumer behavior.

Our choice of the FPO algorithm proved effective in finding solutions that strike a balance between exploration and exploitation. By simulating the pollination process in flowers, the FPO algorithm efficiently explored the solution space, leading to robust strategies for production quantities, order quantities, and inventory levels. The adaptability of FPO to dynamic and non-linear environments was crucial in addressing the intricate nature of the proposed inventory model.

Through extensive simulations and sensitivity analyses, we validated the effectiveness of our approach, showcasing its ability to enhance inventory management, mitigate deterioration-related losses, and adapt to varying demand scenarios. The findings contribute valuable insights for supply chain practitioners seeking advanced strategies to optimize their production inventory systems in the face of evolving market conditions.

As we conclude, it is important to emphasize the practical implications of our research. The proposed model and optimization approach offer a forward-looking perspective on addressing the challenges in dual storage inventory systems. The integration of FPO provides a powerful tool for decision-makers to refine their inventory strategies, ultimately improving overall supply chain efficiency and resilience.

While this study has provided significant contributions, there are opportunities for further research. Future investigations could explore the applicability of the proposed model in different industry contexts and evaluate the performance of other metaheuristic algorithms for comparison. Additionally, incorporating more nuanced factors such as supply chain disruptions or sustainability considerations could enrich the model further.

In conclusion, this research contributes to advancing the field of supply chain optimization by proposing an innovative solution to a complex inventory management problem. The integration of a two-storage production inventory model with FPO optimization provides a robust framework for addressing real-world challenges and paves the way for more resilient and adaptive supply chain strategies.

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