LIFO-BASED OPTIMIZATION OF TWO-WAREHOUSE INVENTORY SYSTEMS WITH DETERIORATING ITEMS

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Abstract

In this study, a two-warehouse inventory model for the red wine industry is presented, focusing on items that deteriorate. The model takes into account the effects of inflation and operates on the LIFO (Last In, First Out) distribution policy. The goal is to minimize the total inventory cost, including the cost of maintaining inventory and the cost of purchasing new inventory. The model assumes a constant and known demand for red wine over time, with no permitted shortages. The stock system consists of warehouse A and warehouse B, with starting stocks fixed in each case. Inventory balance equations track inventory levels at each warehouse, taking into account transfers between warehouses and customer demand. The LIFO shipping policy is implemented to determine the quantities transferred between warehouses. Inflation is factored into the model by adjusting the cost of buying new inventory. This adjustment may be based on historical inflation rates or other relevant factors. The objective function is to minimize the total inventory cost, taking into account inventory costs and inflation-adjusted purchasing costs. The model provides a framework for making decisions about stock levels and transfer rates between warehouses. By optimizing these decisions, the model aims to achieve cost savings while ensuring that demand is met without bottlenecks. The model results can serve as a guide for inventory management strategies in the red wine industry, taking into account the specific challenges presented by the spoiled nature of the product and the impact of inflation.

Keywords: Inventory, Two-warehouse, ramp type demand, deterioration, inflation, and LIFO dispatching policy.

1. Introduction and related work

The red wine industry faces unique inventory management challenges due to the nature of its product, which is a spoiling item. Over time, the quality and value of red wine declines, making it crucial for businesses to effectively manage their inventory. Additionally, inflation can have a significant impact on the cost of purchasing new inventory, further complicating the decision-making process. In this study, we propose a two-storage stock model specifically designed for the red wine industry. The model takes into account the deteriorated nature of red wine and inflation and is based on the LIFO (Last In, First Out) shipping policy. The LIFO policy assumes that inventory purchased last is shipped first, reflecting typical industry storage and retrieval practices. The goal of the inventory model is to minimize the overall cost of inventory while ensuring that customer demand is met without shortages. By optimizing inventory levels and transfer rates between warehouses, companies can realize cost savings and avoid overstocking or understocking. This results in improved profitability and customer satisfaction. To capture the effects of spoilage, the model tracks inventory levels in warehouse A and warehouse B over time. The equilibrium equations take into account customer demand, transfers between warehouses and initial inventory levels. The model dynamically adjusts stock levels based on these factors, while taking into account deterioration in the condition of red wine. Inflation is another critical factor considered in the model. The cost of purchasing new inventory is adjusted for the impact of inflation. This adjustment can be based on historical inflation rates or other relevant factors to ensure that the model provides a realistic representation of industry cost dynamics. Overall, the proposed inventory model provides a comprehensive framework for decision making in the red wine industry. By addressing the unique challenges of item spoilage, inflation, and LIFO shipping policy, businesses can optimize their inventory management strategies and increase their competitive advantage. The following sections of this study detail the details of the model, its formulation, and the potential benefits it offers to the red wine industry.

Practical inventory management is crucial for perishable goods like red wine, which undergo deterioration over time in addition to fluctuations in demand. This study examines the optimization of a two-warehouse inventory system utilizing the degradation factor and a Last-In-First-Out (LIFO) dispatch strategy. By finding a balance between storage and spoiling costs, we hope to improve efficiency and decrease waste in red wine inventory management. Our study provides valuable insights to improve perishable commodity logistics decision-making. Yadav et al. [1-10] highlighted that the deterioration of these items is significant, limiting their storage duration. Yadav et al. [11-20] further explained that deterioration can manifest as spoilage, evaporation, obsolescence, or loss of functionality, leading to reduced inventory usage compared to natural conditions. When raw materials are stocked for future demands, various factors such as storage conditions, weather, and humidity can cause deterioration. Yadav et al. [21-53] discuss that management typically maintains a warehouse for storing purchased goods. However, for various reasons, they may acquire or lease more items than can be accommodated in the warehouse, referring to the excess as overflow (OW), while the additional stock in a rented warehouse is termed rented warehouse (RW), located near or adjacent to OW. Yadav and Swami [54-61] found that the inventory costs associated with RW, including maintenance and depreciation, are generally higher than those of OW due to added operational and maintenance expenses. To minimize inventory costs, it is important to quickly utilize RW stock. Actual customer service is provided solely by OW, so to lower expenses, RW inventory is prioritized for turnover. These scenarios illustrate what are referred to as two inventory examples within the system. Yadav and Kumar [62] focused on managing the supply of electronic storage devices while integrating environmental and network considerations. Yadav, A.S. [63-65] analyzed seven measures of supply chain management to enhance the inventory of electronic storage devices. This analysis involved assessing financial impacts through the application of genetic algorithms (GA) and particle swarm optimization (PSO). Additionally, the research examined inventory improvement and equipment management using genetic computation, alongside a model design for inventory analysis that addressed economic challenges in transporting goods. Swami et al. [66-68] formulated inventory policies that address inventory requirements and associated costs, taking into account allowable payments and delays in inventory. They provided an example of depreciation across various goods and services, considering business loans and an inventory model that is less sensitive to pricing needs, while comparing inventory costs to inflation-related business expenses. Meanwhile, Gupta et al. [69-70] defined objectives for a Multiple Objective Genetic Algorithm and particle swarm optimization (PSO) aimed at enhancing supply levels and addressing deficits and inflation, along with a calculation model that leverages genetic algorithms to assess scarcity and low inflation scenarios. Singh et al. [71, 72] examined cases involving the depreciation of two types of stock concerning asset and inventory costs while updating particle data, as well as scenarios with two inventories focusing on property damage and inventory costs under inflation, utilizing soft computing techniques. Kumar et al. [73-75] addressed delays in managing alcohol supply, refining particles, and developing a green cement supply system, while also tackling inflation through particle enhancement and the use of an electronic inventory system and distribution center with genetic computations. Chauhan and Yadav [76-77] provided an example of depreciation across two stores and warehouses, utilizing a genetic stock and vehicle stock to manage demand and inflation across two distribution centers. Pandey et al. [78] analyzed the improvement of industrial reserves for marble using genetic technology and enhanced multiple particle approaches. Ahlawat, et. al. [79] studied the white wine industry in supply chain management through nerve networks. Singh, et. al. [80] examines the best policy to import damaged goods immediately and pay for conditional delays under the supervision of two warehouses.

The research by Yadav et al. [81] centers on improving inventory management for perishable commodities through the lens of green technology investments, considering factors such as selling price, carbon emissions, and time-sensitive demand. In another analysis, Yadav, Yadav, and Bansal [82] utilize an interval number technique to explore a two-warehouse inventory management model for perishable goods, addressing demand and cost uncertainties. Their optimization methods highlight how investing in preservation technology can reduce waste and enhance inventory efficiency. Focusing on a two-warehouse approach to optimize inventory levels, Yadav, Yadav, and Bansal [83], Sinha, et. al [84], Hezer and Kara [85], and Negi and Ompal [86] present a model that addresses the deterioration of goods during storage, emphasizing the importance of managing degradation costs to improve overall inventory performance.

2. Notations and assumptions

2.1. Notations

The following notations are used in this model.

Parameters	Descriptions
$\Pi_{ow}^{lifo}(t)$	The Red wine industry inventory level in OW at any time t.
$\Pi_{rw}^{lifo}(t)$	The Red wine industry inventory level in RW at any time t.
α_w	The capacity of the own warehouse.
Q	The ordering quantity per cycle.
T	Planning horizon.
α_4	Inflation rate
$\alpha_h cow$	The holding cost per unit per unit time in Red wine industry OW.
$\alpha_h crw$	The holding cost per unit per unit time in Red wine industry RW.
$\alpha_d c$	The deterioration cost per unit.
$\alpha_s c$	The shortage cost per unit per unit time.
$\alpha_o pc$	The opportunity cost due to lost sales.
$\alpha_o c$	The replenishment cost per order.

2.2. Assumptions

In developing the mathematical model of the Red wine industry inventory system the following assumptions are being made:

1. A single item is considered over a prescribed
2. Period T units of time.

3. The demand rate D(t) at time t is deterministic and taken as a ramp type function of time i.e.
$D(t) = \alpha_0 e^{-\alpha_2 \left(t-(t_\alpha+t_L)\right) H\left(t-(t_\alpha+t_L)\right)}, \alpha_0 > 0, \alpha_2 > 0$ where $H\left(t-(t_\alpha+t_L)\right)$ is the Heaviside™s function defined as

$$H\left(t-(t_\alpha+t_L)\right) = \begin{cases} 0, t < (t_\alpha+t_L) \\ 1, t \geq (t_\alpha+t_L) \end{cases}$$

4. The replenishment rate is infinite and lead-time is zero.
5. When the demand for goods is more than the supply. Shortages will occur. Customers encountering shortages will either wait for the vender to reorder (backlogging cost involved) or go to other vendors (lost sales cost involved). In this model shortages are allowed and the backlogging rate is $e^{-\alpha_3 t}$, when Red wine industry inventory is in shortage. The backlogging parameter α_3 is a positive constant.
6. The variable rate of deterioration in both warehouse is taken as $\alpha_1(t) = \alpha_1 t$. where $0 < \alpha_1 << 1$ and only applied to on hand Red wine industry inventory.
7. No replacement or repair of deteriorated items is made during a given cycle.
8. The Red wine industry owned warehouse (OW) has a fixed capacity of W units; the Red wine industry rented warehouse (RW) has unlimited capacity.
9. The goods of OW are consumed only after consuming the goods kept in RW.

3. FORMULATION AND SOLUTION OF THE MODEL

The Red wine industry inventory levels at OW are governed by the following differential equations under LIFO dispatching policy:

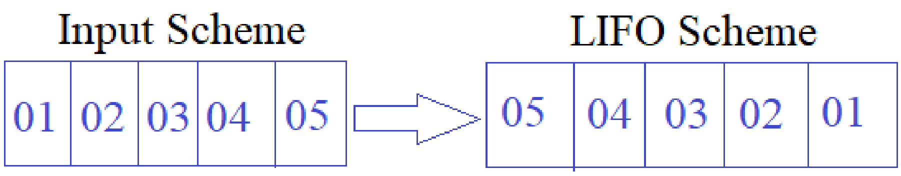

Figure 1: *Flow Chart For LIFO (Last In First Out) Dispatching Policy.*

$$\frac{d\Pi_{ow}^{lifo}(t)}{dt} = [-\alpha_1(t) I^{lifo}(t)], \qquad 0 \leq t \leq (t_\alpha + t_L) \tag{1}$$

$$\frac{d\Pi_{ow}^{lifo}(t)}{dt} + \alpha_1(t) I^{lifo}(t) = -\alpha_0 e^{-\alpha_2(t_\alpha+t_L)}, \qquad (t_\alpha+t_L) \leq t \leq (t_1+t_L) \tag{2}$$

And

$$\left[\frac{d\Pi_{ow}^{lifo}(t)}{dt}\right] = \left[-\alpha_0 e^{-\alpha_2(t_\alpha+t_L)} e^{-\alpha_3 t}\right], \qquad (t_1+t_L) \leq t \leq (T+t_L) \tag{3}$$

with the boundary conditions,

$$\Pi_{ow}^{lifo}(0) = \alpha_w \text{ and } I^{lifo}(t_1+t_F) = 0 \tag{4}$$

The solutions of equations (1), (2) and (3) are given by

$$\Pi_{ow}^{lifo}(t) = \alpha_w e^{-\alpha_1 t^2}, \;\; 0 \le t \le (t_\alpha + t_L) \tag{5}$$

$$\Pi_{ow}^{lifo}(t) = \left[\alpha_0 e^{-\alpha_2(t_\alpha+t_L)}(t_1+t_L) - t + \frac{\alpha_1(t_1+t_L)^3 - t^3}{6} e^{-\alpha_1 t^2}\right], \;\; (t_\alpha+t_L) \le t \le (t_1+t_L) \tag{6}$$

and

$$\Pi_{ow}^{lifo}(t) = \left[\frac{\frac{\alpha_0}{\alpha_3}}{\alpha_3} e^{-\alpha_2(t_\alpha+t_L)} + e^{-\alpha_3 t - e^{-\alpha_3(t_1+t_L)}}\right], \;\; (t_\alpha+t_L) \le t \le (T_1+t_L) \tag{7}$$

The Red wine industry inventory level at RW is governed by the following differential equations:

$$\frac{d\Pi_{ow}^{lifo}(t)}{dt} + \alpha_1(t)\Pi^{lifo}(t) = -(\alpha_0+\alpha)e^{-\alpha_2 t}, \qquad 0 \le t \le (t_\alpha+t_L) \tag{8}$$

With the boundary condition $\Pi_{rw}^{lifo}(0) = 0$ the solution of the equation (8) is

$$\Pi_{rw}^{lifo}(t) = \left[\alpha_0\left((t_\alpha+t_L-t) - \frac{\alpha_2}{2}\left(((t_\alpha+t_L)^2 - t^2)\right)\right.\right. \\ \left.\left. + \frac{\alpha_2}{2}\left(((t_\alpha+t_L)^2 - t^2)\right)e^{-\alpha_1(t^2)}\right], \;\; (t_\alpha+t_L) \le t \le (t_1+t_L) \tag{9}$$

Due to continuity of $\Pi_{ow}^{lifo}(t)$ at point $t = (t_\alpha + t_L)$ it follows from equations (5) and (6), one has

$$\alpha_w = \left[\alpha_0 e^{-\alpha_2(t_\alpha+t_L)}\left\{(t_1+t_L) - (t_\alpha+t_L) + \frac{\alpha_1(t_1+t_L)^3 - (t_\alpha+t_L)^3}{6}\right\}\right] \tag{10}$$

Next, we calculate all the associated inventory costs as follow:

1. Ordering Cost (OC):
$$OC = \alpha_{OC} \tag{11}$$

2. Holding Cost in Dairy industry (HC):

$$\begin{aligned} HC &= \left[\alpha_{hcow}\left\{\int_0^{(t_\alpha+t_L)} \Pi_{ow}^{lifo}(t)e^{-\alpha_4 t}dt + \int_{(t_\alpha+t_L)}^{(t_1+t_L)} \Pi_{ow}^{lifo}(t)e^{-\alpha_4\left\{(t_\alpha+t_L)+t\right\}}dt\right\}\right] \\ &\quad + \left[\alpha_{hcrw}\left\{\int_0^{(t_\alpha+t_L)} \Pi_{rw}^{lifo}(t)e^{-\alpha_4 t}dt\right\}\right] \\ &= \left[\alpha_{hcrw}(\alpha_0+\alpha)\left\{\frac{(t_\alpha+t_L)^2}{2} - \frac{(3\alpha_2+\alpha_4)}{6}(t_\alpha+t_L)^3 + \left(\frac{\alpha_1}{12}\right.\right.\right. \\ &\quad \left.\left.\left. + \frac{\alpha_2\alpha_4}{8}\right)(t_\alpha+t_L)^4 - \left(\frac{\alpha_4\alpha_1}{20} + \frac{\alpha_2\alpha_1}{30}\right\}\right] \end{aligned} \tag{12}$$

3. Shortage Cost (SC):

$$\begin{aligned} SC &= \left[\alpha_{sc}\left\{\int_{t_1+t_L}^{(T+t_L)} -\Pi_{rw}^{lifo}(t)e^{-\alpha_4\left(t_1+t_L)+t\right.}dt\right\}\right] \\ &= \left[\frac{(\alpha_0+\alpha)\alpha_{sc}e^{-(\alpha_4(t_1+t_L)+\alpha_2(t_\alpha+t_L))}}{\alpha_3\alpha_4(\alpha_3+\alpha_4)}\left[\alpha_3 e^{-(\alpha_3+\alpha_4)(t_1+t_L)}\right.\right. \\ &\quad \left.\left. + e^{-\alpha_4(T+t_L)}\left(re^{-\alpha_3(T+t_L)} - (\alpha_3+\alpha_4)e^{-\alpha_3(t_1+t_L)}\right)\right]\right] \end{aligned} \tag{13}$$

4. Deterioration Cost (DC):

$$DC = \left[\alpha_{dc}\left\{\int_0^{(t_\alpha+t_L)} \alpha_1 t \Pi_{rw}^{lifo}(t) e^{-\alpha_4 t} dt + \int_{(t_\alpha+t_L)}^{(t_1+t_L)} \Pi_{ow}^{lifo}(t) e^{-\alpha_4\left\{(t_\alpha+t_L)+t\right\}} dt\right\}\right] \quad (14)$$

5. Lost Sale Cost (LSC):

$$LSC = \left[\alpha_{opc}\left\{\int_{t_1+t_F}^{(T+t_L)} -(\alpha_0+\alpha)(1-e^{-\alpha_3 t})e^{-\alpha_2(t_\alpha+t_L)}e^{-\alpha_4(t_1+t_L)+t}\right\}\right]$$
$$= \left[\frac{(\alpha_0+\alpha)\alpha_{opc}e^{-(\alpha_4(t_1+t_L)+\alpha_2(t_\alpha+t_L))}}{\alpha_4(\alpha_3+\alpha_4)}\left[e^{-\alpha_4(t_1+t_L)}((\alpha_3+\alpha_4)-\alpha_4 e^{-\alpha_3(t_1+t_L)})\right.\right.$$
$$\left.\left. - e^{-\alpha_4(T+t_L)}((\alpha_3+\alpha_4)-\alpha_4 e^{-\alpha_3(t_1+t_L)})\right]\right] \quad (15)$$

Therefore, the total average cost per unit time of our model is obtained as follows

$$T(t_1+t_L, T+t_L)C = \frac{1}{T}\left[OC + HC + SC + DC + LSC\right] \quad (16)$$

4. Optimization Methodology

To minimize the total cost per unit time, the optimal values of t_1 and T can be obtained by solving the following equations simultaneously

$$\frac{\partial TC}{\partial(t_1+t_L)} = 0,$$

and

$$\frac{\partial TC}{\partial(T+t_L)} = 0$$

provided, they satisfy the following conditions which is the necessary and sufficient conditions for convexity.

$$\frac{\partial^2 TC}{\partial(t_1+t_L)^2} > 0, \frac{\partial^2 TC}{\partial(T+t_L)^2} > 0,$$

and

$$\left(\frac{\partial^2 TC}{\partial(t_1+t_L)^2}\right)\left(\frac{\partial^2 TC}{\partial(T+t_L)^2}\right) - \left(\frac{\partial^2 TC}{\partial(t_1+t_L)\partial(T+t_L)}\right)^2 > 0$$

These equations are highly nonlinear equations. Therefore, numerical solution of these equations can be obtained by using the software MATLAB 7.0.1.

5. Graphical Representation

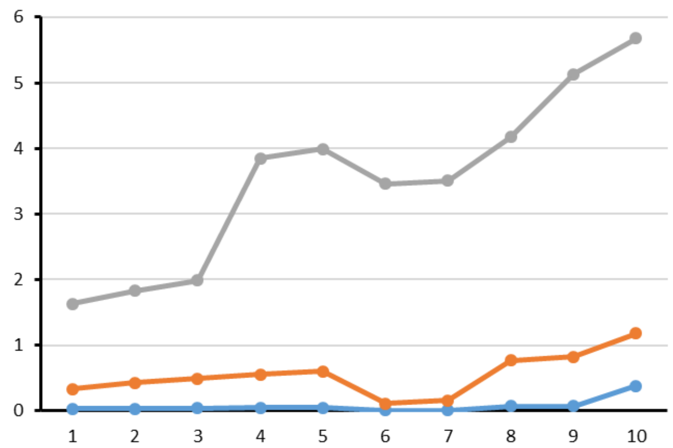

Figure 2: *Variation between time and demand rate.*

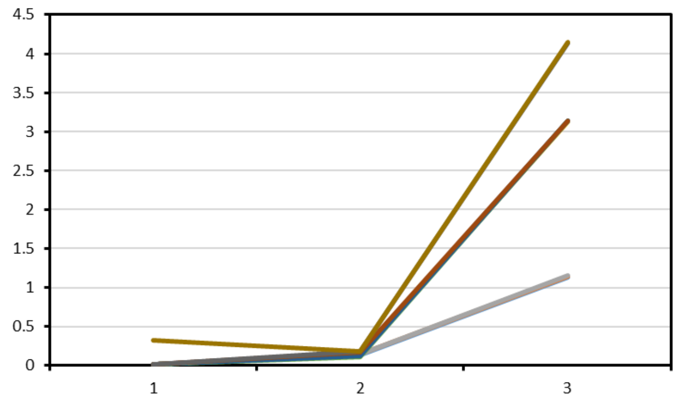

Figure 3: *Variation between time and deterioration rate.*

The graphical depictions in this part provide a comprehensive grasp of the dynamics within the deteriorated inventory model of two-warehouses. Figure 2 and Figure 3 explains the link between demand rates, deterioration rate and time.

6. Conclusion

The two-warehouse inventory model for the red wine industry provides a valuable framework for effective inventory management, taking into account item spoilage, inflation, and LIFO (Last In , First Out). By integrating these factors into the model, companies can make informed decisions about inventory levels and transfer rates between warehouses, reducing costs and improving customer satisfaction. Deteriorating red wine condition requires careful inventory management to avoid overstocking and product obsolescence. The proposed model takes this into account by dynamically adjusting stock levels based on equilibrium equations that take into account customer demand and transfers between stocks. By optimizing these inventories, companies can minimize storage costs and reduce spoilage losses. Inflation is another critical factor that can significantly affect the cost of purchasing new inventory. By adjusting purchase costs in the model for inflation, companies can make more accurate cost calculations and ensure that model results are consistent with current economic conditions. This allows them to make cost-effective decisions while maintaining desired service levels. The LIFO shipping policy reflects typical industry storage and retrieval practices. By adopting this policy in the model, companies can ensure that inventory purchased last is shipped first, which is consistent with industry practice and minimizes potential obsolescence costs. Overall, the dual warehouse inventory model presented in this study provides a comprehensive solution to inventory management challenges in the red wine industry. By taking into account the unique characteristics of red wine, inflation, and LIFO shipping policies, companies can optimize inventory levels, reduce costs, and improve overall operational efficiency. It should be noted that the efficiency of the model can be increased by incorporating additional factors such as batch ordering, lead times and storage capacity constraints depending on the specific needs of the red wine industry. Additionally, future research could explore the integration of advanced forecasting techniques and real-time data to improve the accuracy of demand forecasting and further improve model performance.

Ultimately, by adopting and implementing the two-warehouse inventory model, considering degradation, inflation, and LIFO shipping policy, companies in the red wine industry can gain a competitive advantage, reduce costs and provide superior customer service, contributing to their long-term success in the marketplace.

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