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Research Article

Optimizing Sorghum Distribution for the WFP: Addressing Deterioration During the Boko Haram Crisis

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ABSTRACT

This study explores the logistical challenges faced by the World Food Program (WFP) in regions afflicted by the Boko Haram insurgency, where high-risk conditions significantly complicate operations. Key issues include increased transportation costs due to the necessity of military escorts for securing food shipments and elevated holding and ordering expenses for essential items like sorghum. The safety of humanitarian workers and the integrity of food supplies are critical priorities in these areas. To address these complexities, the research proposes a specialized inventory model designed to optimize the distribution of sorghum, ultimately aiming to enhance the WFP's operational efficiency in conflict-affected regions.

Keywords: Inventory model, Deterioration, WFP, Boko Haram terrorist, Sorghum foodstuffs.

1. INTRODUCTION

The terrorist attacks on the World Trade Center in the United States on September 11, 2001, highlighted global concerns regarding insecurity and terrorism, particularly within democratic nations. This event, coupled with various sociopolitical crises, has played a significant role in the escalation of organized crime in Nigeria, notably marked by the rise of Boko Haram. Over the last decade, Nigeria's northeastern region has faced devastating consequences due to this insurgency, which has continued to pose substantial challenges despite numerous local and international initiatives aimed at combating the spread of terrorism.

In inventory management, deterioration refers to the natural decay or spoilage of products during storage, influenced by factors such as light exposure, oxygen levels, moisture, microorganisms, and temperature. Items like pharmaceuticals, chemical compounds, and food products, including grains and rice, are particularly vulnerable to deterioration, which reduces their value over time. This perishability is a vital consideration in formulating effective inventory policies.

The World Food Program (WFP), recognized as the largest global humanitarian organization, plays a crucial role in delivering relief materials and food supplies to regions affected by disasters and conflicts. Efficient inventory management within the WFP requires the optimization of procurement, storage, and distribution processes. This entails determining the economic order quantity (EOQ), establishing reorder levels, and implementing pricing strategies to strike a balance between cost efficiency and service effectiveness.

In crisis zones, the challenges of logistics operations are exacerbated by security risks and transportation issues, underscoring the necessity for strategic planning. By effectively addressing these complexities, the WFP can enhance its operational capabilities and ensure timely delivery of essential aid in vulnerable areas.

Numerous studies have examined inventory management challenges in comparable settings. Yang et al. [16] proposed an economic order quantity (EOQ) model specifically for temperature-sensitive deteriorating items within cold chain logistics. Concurrently, Jaggi and Singh [6] developed a model that addresses deterioration and disposal in relief supply chains. Önal et al. [10] designed an EOQ model that incorporates deteriorating items while considering self-selection constraints. Additionally, Jaggi et al. [5] investigated models for deteriorating items of imperfect quality under permissible delays in payment, and Yankah et al. [17] analyzed inventory models that

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account for price-dependent demand and deterioration, assessing their effects on manufacturing performance in Ghana.

Furthermore, Sindhuja and Arathi [14] proposed an inventory model specifically aimed at deteriorating products utilizing preservative technology. In another study, Gautam et al. [11] explored the impacts of inflation on inventory systems characterized by time-dependent quadratic demand. Banerjee and Agrawal [1] developed a model focusing on freshness-sensitive deteriorating items, while Kumar et al. [7] analyzed optimal ordering policies for retailers dealing with deteriorating inventory under pre-payment and post-payment strategies. Finally, Hambagda [3] introduced a food logistics model for the World Food Program (WFP) within regions controlled by Boko Haram, and Senapati [13] examined a marketing-oriented inventory model that incorporates time-dependent partial backlogging.

Additional studies have advanced the field of inventory management, such as Choudhury and Mahata's [2] model for fixed-lifetime products with hybrid prepayment and trade credit, and Mahapatra et al.'s [8] exploration of uncertain demand under preservation strategies. Mahata et al. [9] focused on optimal replenishment and credit policies under trade credit scenarios with default risks. Jaggi et al. [4] examined deterioration in two-warehouse models with imperfect quality, and Zhong et al. [18] analyzed food supply chain systems and their future developments. Schiraldi et al. [12] highlighted inventory control policies for humanitarian logistics, emphasizing warehouse safety in relief operations. Taheri-Tolgari et al. [15] extended an inventory model for imperfect items under inflation, incorporating inspection errors.

This paper presents an inventory model for the World Food Program (WFP), addressing the challenges posed by deteriorating items, transportation costs, and security risks in conflict zones. The model forecasts demand, incorporates deterioration rates, and accounts for transportation costs, including military escort requirements. The structure of this paper is as follows: Section 2 presents the model formulation, Section 3 discusses numerical experiments and results, Section 4 provides sensitivity analysis, and Section 5 concludes with recommendations for future research.

2. MODEL FORMULATION

The data below was collected from a reputable company and one of the NGOs sublated with the responsibility of dis tributing 10.5 kg of sorghum foodstuffs to each person(s). The demand focus is based on the data obtained from the company.

Distribution of Sorghum 10.5kg to each Person for The Period of Jan. 2020 to Dec. 2020 Through the Global Commodity Management by the World Food Program (WFP)

MONTH	People who received Foodstuff	10.5kg Sorghum Distributed	DAY 1 Distribution	DAY 2 Distribution	DAY 3 Distribution	DAY 4 Distribution
Jan 2020	1,201,998	12,620,979	3,155,245	4,164,923	3,407,665	1,893,146
Feb 2020	1,258,792	13,217,316	2,907810	2,379,117	4,890,410	3,039,979
March,2020	1,157,379	12,152,480	3,159,645	4,982,517	2,795,070	1,215,248
April,2020	1,260,096	13,231,008	4,101,612	5,557,023	1,323,102	2,249,271
May,2020	1,201,041	12,610,931	2,143,858	4,113,826	2,817,187	3,531,060
June, 2020	1,264,496	13,277,208	2,589,056	3,126,529	4,514,250	2987,373
July, 2020	1,369,306	14,377,713	4,744,645	5,463,531	2,587,988	1,581,549
Aug 2020	1,323,818	13,900,089	4,480,028	3,336,021	2,502,017	3,614,023
Sept 2020	1,395,456	14,652,288	4,542,209	5,567,870	1,465,229	3,076,980
Oct 2020	1,503,559	13,688,420	4,106,526	4,790,947	3,832,758	959,189

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Nov 2020	1,379,398	14,483,679	4,055,430	4,345,103	3,186,409	2,896,737
Dec, 2020	1,365,270	14,335,335	5,734,134	4,474,250	4,126,951	--

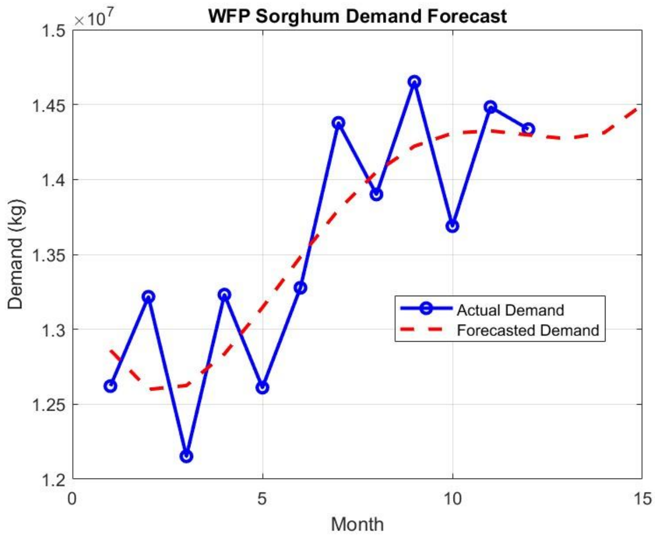

Figure 1: Graphical representation of Demand Forecast

Figure 1 illustrates the demand forecast function, modeled by the polynomial $687.24\,t^4 - 23982t^3 + 270418.12t^2 - 915141.22t + 13528381.70$

2.1. Notations and Assumptions

An inventory model for sorghum foodstuff to internally displaced persons (IDPs) in the World Food Program (WFP) considering deterioration under the impact of Boko Haram Terrorism in Borno State Nigeria.

2.1.1. Notations.

C_p is the Purchasing Cost per unit.

C_h is the Holding Cost per unit per unit of time.

A is the Ordering Cost per order.

S(t) is the inventory level at any time.

T Length of each cycle (decision variable).

φ is the Deterioration rate.

D_o is the Deterioration value per order.

SS is the Safety stock.

TC is the Total Inventory Cost.

S_0 is the Total Ordered Quantity.

Z is the service level factor (1.65 for 95% service level).

σ_L is the Lead time demand variability (10% of monthly demand).

D Demand rate, quadratic as $at^4 + bt^3 + ct^2 + dt + e$

M_f Military Escorts Transportation/logistics cost of the unit item.

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2.1.2 Assumptions

(1) Shortage and back ordering are not allowed in this model.

(2) The inventory system involves only one item.

(3) Deteriorated products are not replaceable or repairable.

3. MODEL DEVELOPMENT

In the current inventory system, S items are procured during the World Food Program's (WFP) relief material distribution and the demand rate D, where T is the length of each cycle. Considering φ as the rate of defective or deteriorating items, Figure 2 illustrates the behavior of the inventory level

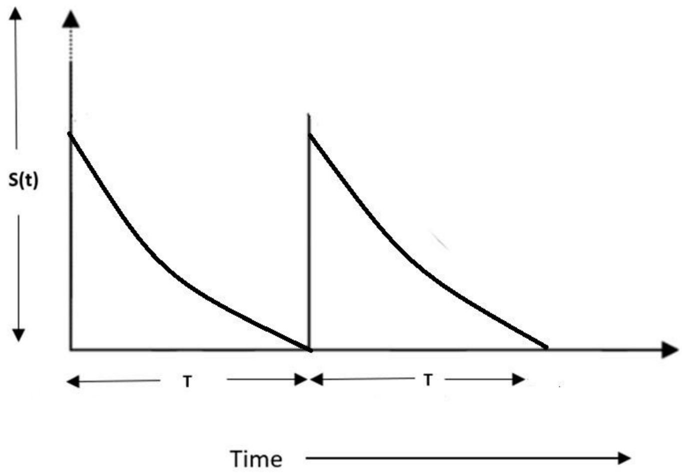

Figure 2: Inventory Level at time t

$$\frac{dS(t)}{dt} + \varphi . S(\mathrm{t}) = -(at^4 + bt^3 + ct^2 + dt + e) \qquad t \in [0, T] \qquad (1)$$

With boundary condition $S(0) = S_0 \; and \; S(T) = 0$

The solutions to equation (1) are obtained below.

$$S(t) = \frac{1}{\varphi^5}\{(-at^4\varphi^4 - 24a + 6b\varphi - 2c\varphi^2 + d\varphi^3 - e\varphi^4 + t^3\varphi^3(4a - b\varphi) + t^2\varphi^2(-12a + 3b\varphi - c\varphi^2) + t\varphi(24a - 6b\varphi + 2c\varphi^2 - d\varphi^3) + (T^4 a\varphi^4 + T^3\varphi^3(-4a + b\varphi) + T^2\varphi^2(12a - 3b\varphi + c\varphi^2) - T\varphi(24a - 6b\varphi + 2c\varphi^2 - d\varphi^3) + 24a - 6b\varphi + 2c\varphi^2 - d\varphi^3 + e\varphi^4)e^{\varphi(T-t)}\} \qquad (2)$$

Total Purchase Cost $\mathrm{CP} = C_p S(0)$

$$CP = C_p \; e^{\varphi T}\left\{\frac{Td + T^3 b + T^4 a}{\varphi} + \frac{-2Tc - 3T^2 b - 4T^3 a}{\varphi^2} + \frac{6Tb + 12T^2 a}{\varphi^3} - \frac{24Ta}{\varphi^4}\right\} \qquad (3)$$

Total Deterioration Cost $DO = C_p D_0 = C_p\left(S(0) - \int_0^T D(t)dt\right)$

$$D_0 = C_p\left\{ e^{\varphi T}\left\{\frac{Td + T^3 b + T^4 a}{\varphi} + \frac{-2Tc - 3T^2 b - 4T^3 a}{\varphi^2} + \frac{6Tb + 12T^2 a}{\varphi^3} - \frac{24Ta}{\varphi^4}\right\} - \frac{T^5 a}{5} - \frac{T^4 b}{4} - \frac{T^3 c}{3} - \frac{T^2 d}{2} - T.e \right\}$$
(4)

Ordering Cost (CO)= $\frac{A}{T}$

Inventory holding cost $CH = C_h \int_0^T S(t)dt.$

$$C_h\left\{\frac{24ae^{\varphi T}-1}{\varphi^6}+\frac{1}{\varphi^5}(6b(1-e^{\varphi T})-24ae^{\varphi T})+\frac{1}{\varphi^4}(-2c(1-e^{\varphi T})+6Tbe^{\varphi T}+12T^2ae^{\varphi T}+\frac{1}{\varphi^3}(d(1-e^{\varphi T})-2Tce^{\varphi T}-4T^3ae^{\varphi T}-3T^2be^{\varphi T})+\frac{1}{\varphi^2}(-e(1-e^{\varphi T})+Tde^{\varphi T}+T^4ae^{\varphi T}+T^3be^{\varphi T}+T^2ce^{\varphi T})-\frac{T^5a}{5\varphi}-\frac{T^4b}{4\varphi}-\frac{T^3c}{3\varphi}-\frac{T^2d}{2\varphi}-\frac{Te}{\varphi}\right\} \quad (5)$$

Military Escorts transportation $MF = M_f S_0$

$$MF = M_f\, e^{\varphi T}\left\{\frac{Td+T^3b+T^4a}{\varphi}+\frac{-2Tc-3T^2b-4T^3a}{\varphi^2}+\frac{6Tb+12T^2a}{\varphi^3}-\frac{24Ta}{\varphi^4}\right\} \quad (6)$$

Safety Stock cost $SS = LC_hZ$.

$TC(0,T)$ = Ordering Cost + Purchase Cost + Holding Cost + Deterioration Cost + Military Escorts Transportation Cost + Safety Stock Cost

$$TC(T) = \frac{1}{T}\{CO + CH + CP + DO + MF + SS\}$$

$$TC = \frac{1}{T}\{C_0 + C_h\left\{\frac{24ae^{\varphi T}-1}{\varphi^6}+\frac{1}{\varphi^5}(6b(1-e^{\varphi T})-24ae^{\varphi T})+\frac{1}{\varphi^4}(-2c(1-e^{\varphi T})+6Tbe^{\varphi T}+12T^2ae^{\varphi T}+\frac{1}{\varphi^3}(d(1-e^{\varphi T})-2Tce^{\varphi T}-4T^3ae^{\varphi T}-3T^2be^{\varphi T})+\frac{1}{\varphi^2}(-e(1-e^{\varphi T})+Tde^{\varphi T}+T^4ae^{\varphi T}+T^3be^{\varphi T}+T^2ce^{\varphi T})-\frac{T^5a}{5\varphi}-\frac{T^4b}{4\varphi}-\frac{T^3c}{3\varphi}-\frac{T^2d}{2\varphi}-\frac{Te}{\varphi}\right\}+e^{\varphi T}\left\{\frac{Td+T^3b+T^4a}{\varphi}+\frac{-2Tc-3T^2b-4T^3a}{\varphi^2}+\frac{6Tb+12T^2a}{\varphi^3}-\frac{24Ta}{\varphi^4}\right\}(C_p+M_f)+C_p\left\{e^{\varphi T}\left\{\frac{Td+T^3b+T^4a}{\varphi}+\frac{-2Tc-3T^2b-4T^3a}{\varphi^2}+\frac{6Tb+12T^2a}{\varphi^3}-\frac{24Ta}{\varphi^4}\right\}-\frac{T^5a}{5}-\frac{T^4b}{4}-\frac{T^3c}{3}-\frac{T^2d}{2}-T.e\right\}+LC_hZ\} \quad (7)$$

4. NUMERICAL SOLUTION

The parameters for the mathematical model have been provided by a reputable company in collaboration with an NGO.
C_h= ₦100; a = 687.24; b = -23982.00; c = 270418.12; d = -915141.22; e = 13528381.7; φ=0.001; C_p=₦2000; M_f=₦1500; C_0=₦2000; Z=1.65; L=0.1*e;

The optimal values obtained are T = 51.2132 days, TC = ₦ 46,550,484,517.4504, and S_0=2,177,792 kg.

	%	T	T in Days	TC	Total Inventory
C_h	-40%	1.7071	51.2132	46114532278.1140	22175744.0000
	-20%	1.7071	51.2132	46338241697.3499	22177792.0000
	0%	1.7071	51.2132	46550484517.4504	22177792.0000
	+20%	1.7071	51.2132	46762727337.5510	22177792.0000
	+40%	1.7071	51.2132	46974970157.6515	22177792.0000
C_p	-40%	1.6633	49.8988	36068362929.1476	21618688.0000
	-20%	1.7071	51.2132	41350065599.4086	22177792.0000
	0%	1.7071	51.2132	46550484517.4504	22177792.0000
	+20%	1.7071	51.2132	51694765340.7159	22175744.0000
	+40%	1.7071	51.2132	56936321306.2370	22177792.0000
M_f	-40%	1.5310	45.9310	38703576424.6403	19947520.0000
	-20%	1.7071	51.2132	42653049586.4173	22177792.0000
	0%	1.7071	51.2132	46550484517.4504	22177792.0000

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	+20%	1.7071	51.2132	50447919448.4836	22177792.0000
	+40%	1.7071	51.2132	54345354379.5167	22177792.0000
C_0	-40%	1.7071	51.2132	46550484048.8213	22177792.0000
	-20%	1.7071	51.2132	46550484283.1358	22177792.0000
	0%	1.7071	51.2132	46550484517.4504	22177792.0000
	+20%	1.7071	51.2132	46550484751.7650	22177792.0000
	+40%	1.7071	51.2132	46550484986.0796	22177792.0000

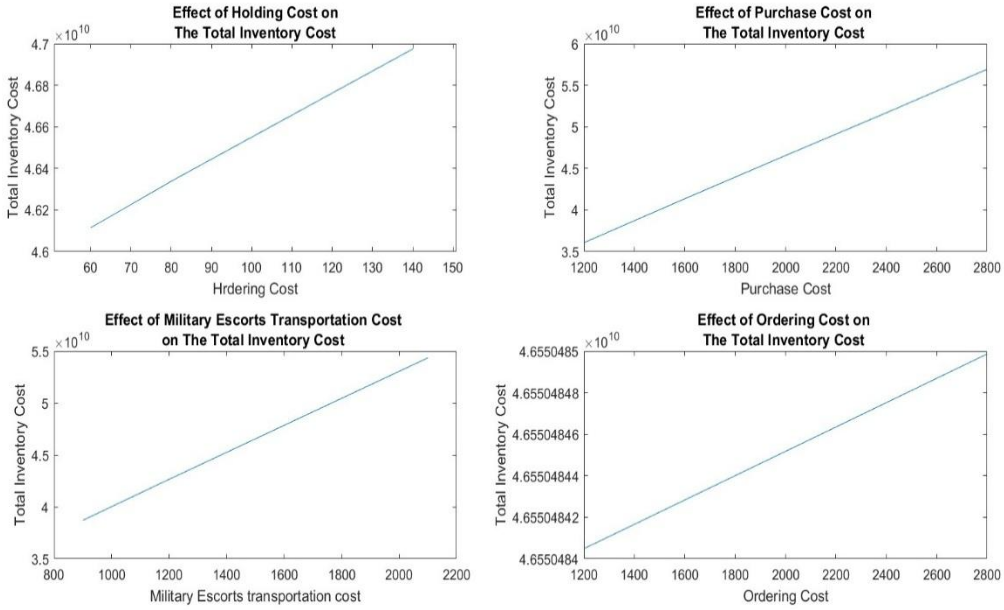

Figure 3: Representation of Sensitivity Analysis for Cost Parameters

5. CONCLUSION

The analysis underscores the significant influence of key cost parameters on the inventory model's performance. Purchase cost (C_p) and military escort costs (M_f) exhibit a substantial impact on total costs (TC), with notable increases as these parameters rise. While holding cost (C_h) moderately affects TC, and ordering costs (C_0) has minimal impact. Total inventory and time intervals (T) remain stable across most parameter variations. These findings highlight the critical importance of strategically managing C_p and M_f to achieve cost-efficient and effective inventory management in humanitarian logistics.

These findings emphasize the importance of strategic management of C_p and M_f to minimize costs and ensure effective inventory control. By addressing the most sensitive parameters, the proposed model is a valuable tool for optimizing resource distribution in humanitarian logistics, particularly in challenging and resource-constrained environments.

REFERENCES

[1] Banerjee, S., Agrawal, S., 2017. Inventory model for deteriorating items with freshness and price dependent demand: Optimal discounting and ordering policies. Appl. Math. Model. 52, 53–64.

[2] Choudhury, M., Mahata, G.C., 2024. Non-instantaneous deteriorating items inventory models with fixed lifetime products under hybrid partial prepayment and trade credit in the supply chain. J. Ind. Manag. Optim.

20, 221–259. https://doi.org/10.3934/jimo.2023075.

[3] Hambagda, B.M.T., 2024. Humanitarian Food Logistics: An Inventory Model for World Food Program (WFP) Operations in Boko Haram-Controlled Areas. Commun. Appl. Nonlinear Anal. 31, 380–387. https://doi.org/10.52783/cana.v31.1230

[4] Jaggi, C.K., Tiwari, S., Shafi, A., 2015. Effect of deterioration on two-warehouse inventory model with imperfect quality. Comput. Ind. Eng. 88, 378–385.

[5] Jaggi, C., Goel, S., Mandeep, M., 2010. Economic order quantity model for deteriorating items with imperfect quality and permissible delay on payment. Int. J. Ind. Eng. Comput. 2, 237–248. https://doi.org/10.5267/j.ijiec.2010.07.003

[6] Jaggi, C., Singh, J., 2020. Inventory relief chain model with deterioration and disposal of relief commodity. Yugosl. J. Oper. Res. 30, 9–9. https://doi.org/10.2298/YJOR190310009J

[7] Kumar, B.A., Paikray, S.K., Padhy, B., 2022. Retailer's Optimal Ordering Policy for Deteriorating Inventory having Positive Lead Time under Pre-Payment Interim and Post-Payment Strategy. Int. J. Appl. Comput. Math. 8, 165. https://doi.org/10.1007/s40819-022-01374-6

[8] Mahapatra, A., Dasgupta, A., SHAW, A., Sarkar, B., 2022. An inventory model with uncertain demand under preservation strategy for deteriorating items. RAIRO - Oper. Res. 56. https://doi.org/10.1051/ro/2022145

[9] Mahata, P., Mahata, G.C., Kumar De, S., 2018. Optimal replenishment and credit policy in supply chain inventory model under two levels of trade credit with time- and credit-sensitive demand involving default risk. J. Ind. Eng. Int. 14, 31–42. https://doi.org/10.1007/s40092-017-0208-8

[10] Önal, M., Kundakcioglu, O.E., Jain, S., 2020. An EOQ model with deteriorating items and self-selection constraints. Optim. Lett. 14, 1491–1518. https://doi.org/10.1007/s11590-020-01566-3

[11] Gautam R., Gupta S., Srivastav S., and Khurana R. 2024. Investigating The Impact of Inflation on Inventory Systems: Time-Dependent Quadratic Demand, Time-Variable Deterioration, and Shortage. Commun. Appl. Nonlinear Anal. 31, 660–669. https://doi.org/10.52783/cana.v31.1406

[12] Schiraldi, M., Battista, C., Bianchi, P., 2009. Inventory Control Policies for Humanitarian Logistics Supply Chain. Proc. Conf. 'Sustainable Dev. Role Ind. Eng. Monop. BA Italy Sept. 2009 ISBNISSN 978-88-904625-0-4.

[13] Senapati, S., 2017. A Marketing-Oriented Inventory Model with Three-Component Demand Rate and Time-Dependent Partial Backlogging. Int. J. Adv. Eng. Manag. Sci. 3, 239794.

[14] Sindhuja, S., Arathi, P., 2023. An inventory model for deteriorating products under preservation technology with time-dependent quality demand. Cogent Eng. 10, 2176968. https://doi.org/10.1080/23311916.2023.2176968

[15] Taheri-Tolgari, J., Mirzazadeh, A., Jolai, F., 2012. An inventory model for imperfect items under inflationary conditions with considering inspection errors. Comput. Math. Appl. 63, 1007–1019. https://doi.org/10.1016/j.camwa.2011.09.050

[16] Yang, M.-F., Tsai, P.-F., Tu, M.-R., Yuan, Y.-F., 2024. An EOQ Model for Temperature-Sensitive Deteriorating Items in Cold Chain Operations. Mathematics 12, 775. https://doi.org/10.3390/math12050775

[17] Yankah, R., Osei, F., Owusu-Mensah, S., Agyapong, P.J., 2022. Inventory management and the performance of listed manufacturing firms in Ghana. Open J. Bus. Manag. 10, 2650–2667.

[18] Zhong, R., Xu, X., Wang, L., 2017. Food supply chain management: systems, implementations, and future research. Ind. Manag. Data Syst. 117, 2085–2114. https://doi.org/10.1108/IMDS-09-2016-0391