Optimizing Inventory Management for Humanitarian Aid: A Case Study of the World Food Program (WFP) in Boko Haram Terrorists Controlled Areas

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Abstract:

This paper examines the challenges faced by the World Food Program (WFP) on the forecast, procurement, and ordering policy to determine the required level of inventory management needed to satisfy future demands of internally displaced persons (IDPs). The deterioration rates of beans are high in this part of the geopolitical region due to the impact of climate, temperature, and the variety of the beans themselves. The paper also looked into the complex measures, that led to increased transportation costs for delivering food supplies to various destinations under military escort to safeguard against insurgent attacks. This situation also leads to a substantial rise in holding and ordering costs. Ensuring the safety of WFP humanitarian workers, foodstuff consignments, and other essential items is crucial. Given these challenges, this study attempts to develop an optimized inventory model for the distribution of beans to enhance the performance of WFP in Boko Haram caliphate states.

Keywords: *WFP, Ordering Policy, Inventory management, Deterioration, Boko Haram terrorist.*

1. INTRODUCTION

The World Food Program (WFP), the largest nongovernmental organization focused on global humanitarian services, is crucial in distributing relief materials and food supplies in crisis-affected regions. In 2020/21, the ongoing impacts of the COVID-19 pandemic, combined with escalating conflicts between Boko Haram terrorists and global increases in the cost of living, led to unprecedented levels of hunger and malnutrition in the northeastern states of Nigeria. Acute malnutrition nearly doubled where the World Food Program (WFP) operated, compared to pre-pandemic levels which include supply chain disruptions, and food procurement costs. Despite these challenges, progress was made in advancing United Nations development system reforms to help the internally displaced persons (IDPs) enhance cost efficiency and the ordering policy. The violent sectarian group popularly called Boko Haram, operation in northeastern Nigeria started having a disagreement and conflict with Nigerian security forces in early 2004. We also learned that the conflict emanated over the fishing rights of a pond located in a village called Kanamma in Yobe state Nigeria, shortly after the September 11 attacks on the World Trade Center in 2001. These had a profound impact on global concerns about insecurity and terrorism, particularly in democratic nations. These events, along with other forms of sociopolitical instability, have additional impact to the expansion of insurgency attack and some formation of an organized crime in Nigeria, which includes among the rise of Jihadist popularly known as Boko Haram terrorists. We must not deviate from the facts that over the past decade, Nigeria has faced severe challenges from Boko Haram insurgents, who have devastated the northeastern region of the country. In this context, inventory management simply refers to ordering and handling of beans foodstuff, goods, products, and any raw materials procured for distribution to internally displaced persons (IDPs) affected by the conflict of Boko Haram insurgent attack. This includes determining the economic order quantity (EOQ) for critical items, optimizing warehouse operations, and ensuring timely distribution. Essential considerations include deciding when to reorder, how much to order, and how to minimize costs while ensuring the effective and timely distribution of foodstuff assistance to those in need. The importance of effective inventory management has spurred extensive research into models that address key challenges. These include EOQ models for temperature-sensitive and perishable items, strategies for managing imperfect quality, and policies for inventory control under conditions such as payment delays or inspection requirements. Researchers have also developed models that incorporate factors like price-dependent demand, preservation technologies, and competitive dynamics in global markets. Such insights are invaluable for optimizing inventory systems, particularly for organizations like the World Food Program (WFP), which operate in complex and high-stakes environments. Deterioration, defined as the loss of original value due to decay, spoilage, or degradation of goods during storage on so many factors such as light, oxygen, moisture, microorganisms, and temperature, presents a significant challenge in inventory management and after initial inspections of goods such as beans, grains, rice, etc. Also, the simply definition of deterioration on the context of medical biodegradation or pharmaceutical products and chemical companies are the expiration of over time or lose of its value over time, while foodstuffs like beans, grains, and rice suffer quality degradation during extended storage. Effectively managing the perishability of these items is crucial for developing robust inventory policies. The demand forecasting method uses trend patterns of data collected from the field to predict future demand inventory. Priyadharshini et al., [1] examines an optimal inventory policies for deteriorating items with expiration dates and dynamic demand under two-level trade credit. Sahoor et al., [2] did a thorough work on inventory management and its impact on the firm performance. Swami et al., [3] developed an inventory model for decaying items with Multivariate demand and variable holding cost under the facility of trade credit. Hambagda et al., [4] developed a model on humanitarian food logistics: An inventory model for World Food Program (WFP) operations in Boko Haram-Controlled areas. Jaggi and Mittal., [5] focused on retailer ordering policy for deteriorating items with initial inspection and allowable shortage under the condition of permissible delay in payments. Jaggi and Verma., [6] reviewed a retailer's ordering policy for deteriorating items in a supply chain with varying deterioration rates. Jaggi and Singh., [7] put a beautiful contribution on inventory relief chain model with deterioration and disposal of relief commodity. Mahato and Mahata., [8] examines the optimal inventory policies for deteriorating items with expiration dates and dynamic demand under two-level trade credit. Paciarotti et al., [9] investigate the humanitarian logistics and supply chain standards. Literature review and view from practice. Ferreira et al., [10] examines inventory management of perishable items in long-term humanitarian operations using Markov decision processes. Yang et al., [11] proposed and discussed an EOQ model for temperature-sensitive deteriorating items in cold chain operations. Onal et al., [12] developed an EOQ model with deteriorating items and self-selection constraints. brahim Abdul and Atsuo Murata, [13] developed an inventory model for deteriorating items with varying demand pattern and unknown time horizon. Gautam et al., [14] focused on Investigating the impact of inflation on inventory systems: Time-Dependent quadratic demand, Time-Variable deterioration, and Shortage. Zhon g, Xu and Wang., [15] investigated the food supply chain management: systems, implementations, and future research. R. Uthayakumar and A. Ruba Priyadharshini., [16] examines optimal strategy on inventory model under permissible delay in payments and return policy for deteriorating items with shortages. The research work focused on humanitarian logistics supply chain with safety in warehouses. Sindhuja and Arathi., [17] proposed an inventory model for deteriorating products under preservation technology with time-dependent quality demand Jiang et al., [18] discussed a note on optimal replenishment policies for non-instantaneous deteriorating items with price and stock sensitive demand under permissible delay in payment. D. Chitra and Dr. P. Parvathi., [19] focus on fuzzy inventory model for non-instantaneous deteriorating items with stock and time dependent demand with partial backlogging and permissible delay in payments. In real life, actual situations may vary with increasing or decreasing demand due to the time and nature of the disaster. Researchers' efforts have been made in the development of decision models related to problems in supply chains. In support of these models, they have been integrated with decision support systems and optimization of these models, the researchers aim is to introduce or demonst rate how mathematical analysis can be applied to develop optimal strategies for managing invent ory systems. Once products deteriorate due to climate, temperature, spoilage, etc the customer int erest declines, prompting sellers to reduce prices before the product's shelf life expires. The goal is to create a reliable and cost-effective inventory model using data gathered from wholesale com panies. A comprehensive inventory model has been developed that focuses on the actual monthly demand pattern. Additionally, a deteriorating inventory model for WFP foodstuffs has been prop osed, incorporating a price-dependent demand rate and a time-proportional deterioration rate. Th e numerical solution indicated that the cost of military escort transportation is relatively high. Th e aim of this research is to incorporate the military escort transportation cost and enhance the exi sting EOQ model for deteriorating items, while forecasting the monthly demand of internally dis placed persons (IDPs), assuming a nonlinear demand. The structure of the paper is as follows: an abstract, followed by a combined introduction and literature review. Section 2 covers the model f ormulations, while Section 3 elaborates on the model. Sections 4 and 5 present the numerical sol utions and sensitivity analysis of key parameters. Section 6 concludes the study.

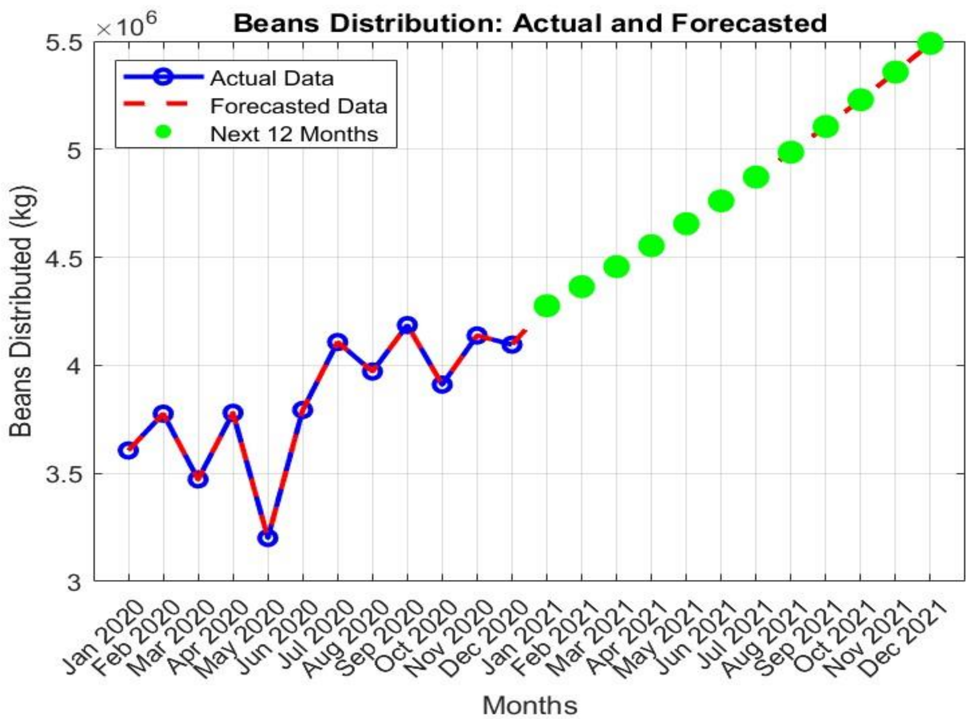
2. MODEL FORMULATION

The data was obtained from a reliable wholesaler to the World Food Program (WFP) and a vendor company responsible for the distribution of 3kg of beans to each person(s). The demand forecast is based on the data obtained from the company. `

Beans Distribution of 3kg to each Person for the Period of January 2020 to December 2020 Through The Global Commodity Management Under the World Food Program (WFP).

MONTH	People who received the Beans.	3kg Beans for each person	DAY 1 Distribution	DAY 2 Distribution	DAY 3 Distribution	DAY 4 Distribution
Jan 2020	1,201,998	3,605,994	901,499	1,153,918	973,618	576,959
Feb 2020	1,258,792	3,776,376	830,806	679,750	1,397,265	868,555
March, 2020	1,157,379	3,472,137	902,756	1,423,137	798,592	347,652
April,	1,260,096	3,780,288	1,171,889	1,587,721	378,029	642,649

2020						
May,2020	1,201,041	3,603,123	544,191	1,056,371	704,247	1,298,314
June, 2020	1,264,496	3,793,488	758,698	910,437	1,289,786	834,567
July, 2020	1,369,306	4,107,918	1,355,613	1,602,088	739,425	410,792
Aug 2020	1,323,818	3,971,454	1,270,865	953,147	714,862	1,032,580
Sept 2020	1,395,456	4,186,368	1,297,774	1,590,820	418,636	879,138
Oct 2020	1,503,559	4,510,677	1,173,293	1,290,622	1,095,074	951,688
Nov 2020	1,379,398	4,138,194	1,158,694	1,241,458	910,403	827,639
Dec, 2020	1,365,270	4,095,810	1,638,324	1,269,701	1,187,785	=



2.1. Notations and Assumptions

Retailer ordering policy and the deteriorating rates of inventory management of beans foodstuff distributions to internally displaced persons (IDPs) in the World Food Program (WFP) under the impact of Boko Haram terrorist-controlled areas.

2.1.1. Notations.

S/No.	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 cycle.
$S(t)$	is the inventory level at any time.
T	length of each cycle (decision variable)
φ	is the Deterioration rate constant and high
Do	is the deterioration value per order per cycle.
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% if monthly demand).
D	demand rate $at^2 + bt + c$
Mf	military escorts logistics cost per unit per cycle.

2.1.2 Assumptions

(1). Lead time is zero

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

(3). Replenishment is instantaneous.

(4). The time horizon of the inventory system is infinite.

(5). Deteriorated products are not replaceable or repairable.

3. MODEL DEVELOPMENT

In the current inventory system, $S(t)$ are procured level of beans foodstuff by the World Food Program (WFP) relief material distribution, and the demand rate D, where T is the length of each cycle. We take φ as the rate of defective or spoiled items during storage time. Figure II illustrates the behavior of the inventory level

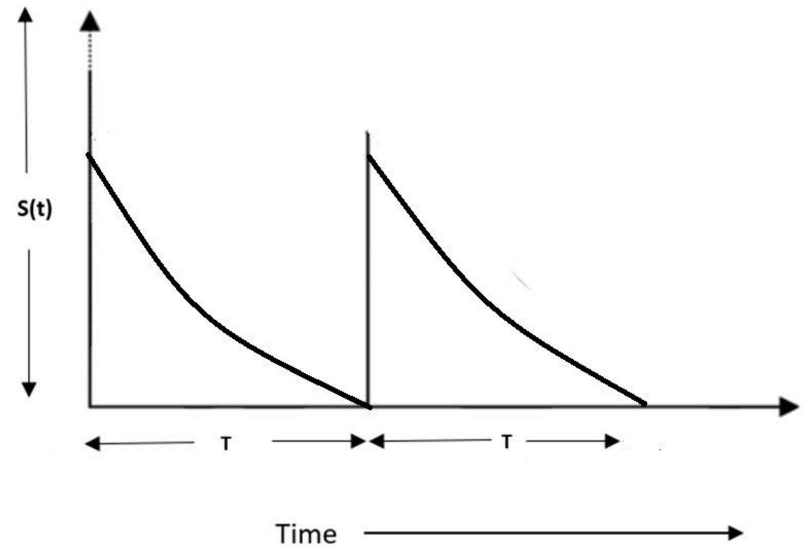


Figure II: Inventory Level at time t.

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

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

The solutions to equation (1) are obtained below.

$$S(t) = \frac{1}{\varphi^3}(2a + 2a(T-t)\varphi + (T^2a - bT - at^2 - bt)\varphi^2)e^{\varphi(T-t)} \qquad (2)$$

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

$$CP = C_p \, \frac{1}{\varphi^2}(T^2 a\varphi - bT\varphi + 2aT)e^{\varphi T} \qquad (3)$$

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

$$Do = \; C_p \; e^{\varphi T} \left\{ \frac{T^2b - bT}{\varphi} + \frac{2aT}{\varphi^2} \right\} - \frac{T^3 a}{3} - \frac{T^2 b}{2} - T.c \qquad (4)$$

Ordering Cost $\mathrm{CO} = \frac{A}{T}$

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

$$CH = -Ch\{2a - 2ae^{\varphi T} - \varphi^2 - ce^{\varphi T} - T^2 a\varphi^2 e^{\varphi T} - T^2 b\varphi^2 e^{\varphi T} + b\varphi e^{\varphi T} + 2Ta\varphi e^{\varphi T} + (c\varphi^2 + \frac{T^3 a\varphi^3}{3} + \frac{T^2 b\varphi^3}{2} + cT\varphi - b\varphi))/\varphi^4 \qquad (5)$$

Military Escorts transportation $MF = M_f S_0$

$$MF = Mf\ \frac{1}{\varphi^2}(T^2 a\varphi - bT\varphi + 2aT)e^{\varphi T} \tag{6}$$

Safety Stock cost $SS = LC_h Z$.

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

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

Hence, the total cost for the World Food Program (WFP) per cycle unit.

$$TC(0,T) = \frac{1}{T}\left\{Co - Ch\left\{2a - 2ae^{\varphi T} - \varphi^2 - ce^{\varphi T} - T^2 a\varphi^2 e^{\varphi T} - T^2 b\varphi^2 e^{\varphi T} + b\varphi e^{\overset{\varphi}{T}} + \right.\right.$$
$$2Ta\varphi e^{\varphi T} + (c\varphi^2 + \frac{T^3 a\varphi^3}{3} + \frac{T^2 b\varphi^3}{2} + cT\varphi - b\varphi))/\varphi^4 + \frac{1}{\varphi^2}(T^2 a\varphi - bT\varphi + 2aT)e^{\varphi T}\left(C_p + \right.$$
$$\left.\left. M_f\right) + C_p\, e^{\varphi T}\left\{\frac{T^2 b - bT}{\varphi} + \frac{2aT}{\varphi^2}\right\} - \frac{T^3 a}{3} - \frac{T^2 b}{2} - T.c + LC_h Z.\right\} \tag{7}$$

4. NUMERICAL SOLUTIONS.

The parameters for the mathematical model have been provided by a reputable company in collaboration with an NGO.
C_h=250; a = 2212.75; b = 28478.63; c = 3531709.91; φ=0.15; C_p=2500; M_f=1500; C_0=2500; Z=1.85; L=0.15*c;
The optimal values obtained are T = 11.83 days, TC = 15,615,413,701.2900 , and S_0=1,183,151.5800kg.

	%	T	T in Days	TC	Total Inventory
	-40%	0.26	7.93	15231154951.13	954044.64
	-20%	0.30	8.95	15430489884.21	1079323.70
C_h	250	0.33	9.79	15615413701.29	1183151.58
	+20%	0.35	10.50	15790714733.12	1271622.91
	+40%	0.37	11.12	15959142787.90	1348538.90
	-40%	0.37	11.23	11890299877.29	1362974.31
	-20%	0.30	8.95	15430489884.21	1079323.70
C_p	2500	0.33	9.79	15615413701.29	1183151.58
	+20%	0.31	9.25	17469020659.92	1116275.02
	+40%	0.29	8.79	19317955605.58	1059637.36
	-40%	0.39	11.83	15360755934.81	1506798.41
	-20%	0.36	10.67	15493842289.97	1307454.71
φ	0.15	0.33	9.79	15615413701.29	1183151.58

	+20%	0.30	9.09	15728063989.54	1093691.06
	+40%	0.28	8.52	15833538744.46	1024284.11
M_f	-40%	0.34	10.17	13439662538.98	1230779.71
	-20%	0.33	9.97	14527816100.04	1206228.82
	1500	0.33	9.79	15615413701.29	1183151.58
	+20%	0.32	9.61	16702486511.35	1161306.56
	+40%	0.31	9.44	17789062893.80	1140642.80
C_0	-40%	0.33	9.79	15615410636.13	1183149.13
	-20%	0.33	9.79	15615412168.71	1183150.36
	2500	0.33	9.79	15615413701.29	1183151.58
	+20%	0.33	9.79	15615415233.87	1183152.80
	+40%	0.33	9.79	15615416766.45	1183154.02

5. SENSITIVITY ANALYSIS.

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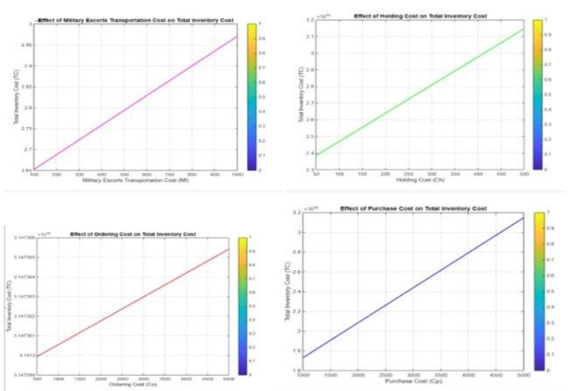

6. CONCLUSION.

In this paper, we develop an inventory model of beans distribution template by the World Food Program (WFP) in areas formerly under the controlled of Boko Haram terrorists' northeastern Nigeria. The model also considered the monthly forecast, procurement, and ordering policy to determine the required level of inventory management needed to satisfy future demands of internally displaced persons (IDPs). We provide numerical illustrations with some parameters and also carried out sensitivity analysis of several associated variables. Key findings include the following. The impact of C_p, M_f at -40% led to a decrease of total inventory without any effe ct at TC, and S. Conversely with the same decrease in T of days for C_h. Impact of C_h, at -20% revealed an increase in TC with little decrease on the total inventory. The impact of a $+20\%$ incr ease has a corresponding and simultaneous increase on TC and the stable level of total inventory.

The impact of a $+40\%$ increase has a corresponding and simultaneous increase on TC and the stable level of total inventory. Overall, parameters and φ significantly affect TC, and S, with φ having minimal influence. Effective management of and φ is essential for optimizing inventory performance. Figure 3 demonstrates that the military escort transportation cost as the demand rate increases, the total cost also rises, underscoring the importance of managing these parameters to control inventory expenses.

REFERENCES.

[1] A. R. Priyadharshini, C. Jayasankari, and R. Uthayakumar, "Impact of Learning on Ordering Policy for Deteriorating Imperfect Quality Items with Promotion Dependent Demand, Partial Trade-Credit and Shortages," *Indian J. Sci. Technol.*, vol. 17, no. SPI1, pp. 21–33, 2024, doi: 10.17485/ijst/v17sp1.143.

[2] A. Sahoo, D. Tandon, D. Jena, P. C. Mishra, J. R. Meher, and R. R. Panigrahi, "Inventory Management and Performance of Manufacturing Firms," *Int. J. Value Chain Manag.*, vol. 12, no. 2, p. 1, 2021, doi: 10.1504/ijvcm.2021.10033598.

[3] A. Swami, S. Pareek, S. R. Singh, and A. Singh Yadav, "Inventory Model for Decaying Items with Multivariate Demand and Variable Holding Cost under the Facility of Trade-Credit," *Int. J. Comput. Appl.*, vol. 113, no. 11, pp. 18–28, 2015, doi: 10.5120/19871-1858.

[4] Buba M.T. Hambagda, "Humanitarian Food Logistics: An Inventory Model for World Food Program (WFP) Operations in Boko Haram-Controlled Areas," *Commun. Appl. Nonlinear Anal.*, vol. 31, no. 6s, pp. 380–387, 2024, doi: 10.52783/cana.v31.1230.

[5] C. K. Jaggi and M. Mittal, "Retailer Ordering Policy for Deteriorating Items with Initial Inspection and Allowable Shortage Under the Condition of Permissible Delay in Payments," *Int. J. Appl. Ind. Eng.*, vol. 1, no. 1, pp. 64–79, 2012, doi: 10.4018/ijaie.2012010106.

[6] C. K. Jaggi and M. Verma, "Retailer's ordering policy for deteriorating items in a supply chain with varying deterioration rates," *Int. J. Adv. Oper. Manag.*, vol. 1, no. 2/3, p. 250, 2009, doi: 10.1504/ijaom.2009.030675.

[7] C. K. Jaggi and J. Singh, "Inventory relief chain model with deterioration and disposal of relief commodity," *Yugosl. J. Oper. Res.*, vol. 30, no. 4, pp. 525–542, 2020, doi: 10.2298/YJOR190310009J.

[8] C. Mahato and G. C. Mahata, "Optimal inventory policies for deteriorating items with expiration date and dynamic demand under two-level trade credit," *Opsearch*, vol. 58, no. 4, pp. 994–1017, 2021, doi: 10.1007/s12597-021-00507-7.

[9] C. Paciarotti, W. D. Piotrowicz, and G. Fenton, "Humanitarian logistics and supply chain

standards. Literature review and view from practice," *J. Humanit. Logist. Supply Chain Manag.*, vol. 11, no. 3, pp. 550–573, 2021, doi: 10.1108/JHLSCM-11-2020-0101.

[10] G. O. Ferreira, E. F. Arruda, and L. G. Marujo, "Inventory management of perishable items in long-term humanitarian operations using Markov Decision Processes," *Int. J. Disaster Risk Reduct.*, vol. 31, no. May, pp. 460–469, 2018, doi: 10.1016/j.ijdrr.2018.05.010.

[11] M. F. Yang, P. F. Tsai, M. R. Tu, and Y. F. Yuan, "An EOQ Model for Temperature-Sensitive Deteriorating Items in Cold Chain Operations," *Mathematics*, vol. 12, no. 5, pp. 1–15, 2024, doi: 10.3390/math12050775.

[12] M. Önal, O. E. Kundakcioglu, and S. Jain, "An EOQ model with deteriorating items and self-selection constraints," *Optim. Lett.*, vol. 14, no. 6, pp. 1491–1518, 2020, doi: 10.1007/s11590-020-01566-3.

[13] I. Abdul and A. Murata, "An inventory model for deteriorating items with varying demand pattern and unknown time horizon," *Int. J. Ind. Eng. Comput.*, vol. 2, no. 1, pp. 61–86, 2011, doi: 10.5267/j.ijiec.2010.05.002.

[14] R. Gautam, S. Gupta, S. Srivastav, and R. Khurana, "Investigating The Impact of Inflation on Inventory Systems : Time- Dependent Quadratic Demand , Time-Variable Deterioration , and Shortage," Communication in Applied Nonlinear Analysis vol. 31, no. 7, pp. 660–669, 2024.

[15] R. Zhong, X. Xu, and L. Wang, "Food supply chain management: systems, implementations, and future research," *Ind. Manag. Data Syst.*, vol. 117, no. 9, pp. 2085–2114, 2017, doi: 10.1108/IMDS-09-2016-0391.

[16] R. Uthayakumar and A. Ruba Priyadharshini, "Optimal strategy on inventory model under permissible delay in payments and return policy for deteriorating items with shortages," *Malaya J. Mat.*, vol. 12, no. 01, pp. 71–84, 2024, doi: 10.26637/mjm1201/006.

[17] S. Sindhuja and P. Arathi, "An inventory model for deteriorating products under preservation technology with time-dependent quality demand," *Cogent Eng.*, vol. 10, no. 1, pp. 1–25, 2023, doi: 10.1080/23311916.2023.2176968.

[18] J. Wu, K. Skouri, J. T. Teng, and L. Y. Ouyang, "A note on 'optimal replenishment policies for non-instantaneous deteriorating items with price and stock sensitive demand under permissible delay in payment,'" *Int. J. Prod. Econ.*, vol. 155, pp. 324–329, 2014, doi: 10.1016/j.ijpe.2013.12.017.

[19] D. Chitra and P. Parvathi, "Fuzzy Inventory Model Fornon-Instantaneous Deteriorating Items With Stock and Time Dependent Demand with Partial Backlogging and Permissible Delay in Payments," IOSR Journal of Mathematics (IOSR-JM) e-ISSN: 2278-5728, p-ISSN: 2319-765X vol. 12, no. 1, pp. 36–49, 2016, doi: 10.9790/5728-12113649.