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Presents

The ICAWMSCS Seminar Series

March 2026 (Every month on the first Monday)

Title:

Mathematical Modelling on Humanitarian Food Supply Challenges and Sorghum Deterioration Rate Under Boko Haram Controlled Areas.

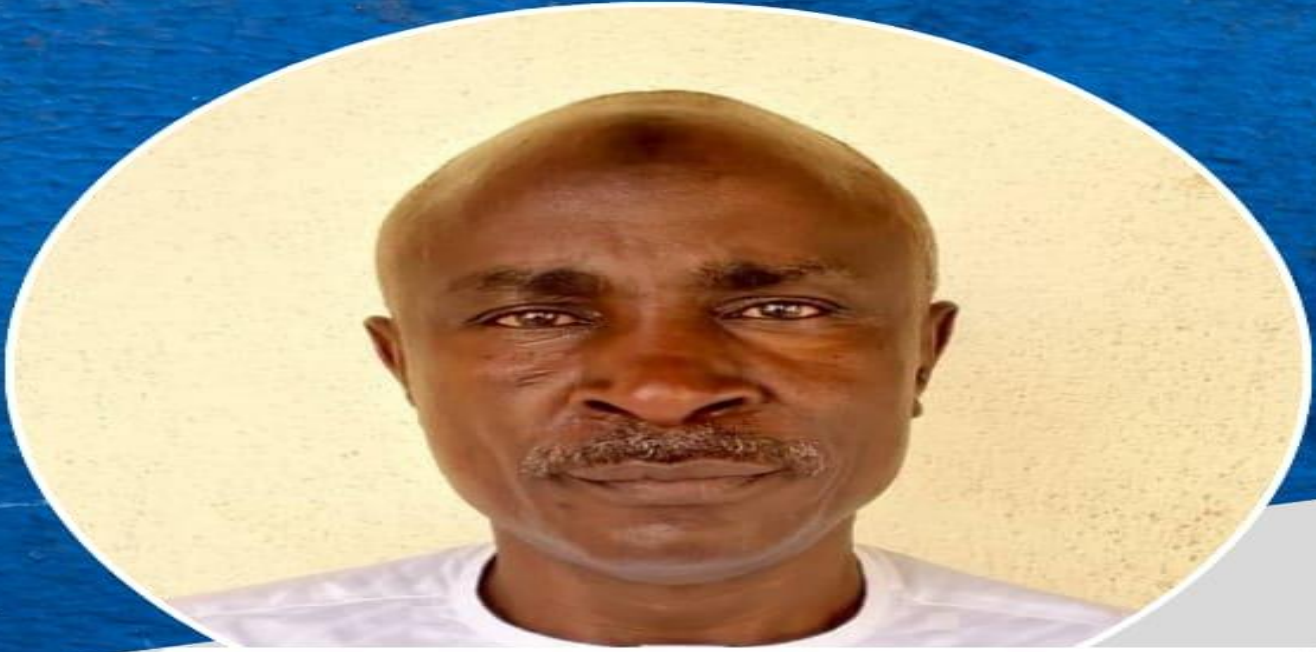
Affiliation:
Federal University Gashua. Faculty of Science. Mathematics Department. Yobe State, Nigeria.

Virtual Zoom Meeting

Zoom Link:
https://zoom.us/j/97592772965?pwd=i5N0uHHUa5qKWodS8g4ASLrKNviwHJ.1

Meeting ID: 975 9277 2965
Passcode: 359799

2nd March, 2026
12:00 pm WAT



DR BUBA MUSA TUNGA HAMBAGDA
LECTURER

Mathematical Modeling on Humanitarian Food Supply Challenges and Sorghum Deterioration Rate Under Boko Haram Controlled Areas

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INTRODUCTION

AS A GUIDING PRINCIPLE, IT CAN BE SAID:

"Effective inventory management is the backbone of humanitarian logistics, ensuring that the right resources reach the right people at the right time, especially when lives depend on timely delivery."

Inventory

Inventory is the total amount of goods and materials that an organization or company keeps for resale, manufacturing or consumption. It encompasses of raw materials, machines, spare parts, semi-finished items, finished goods and operational supplies that are vital to the operation of the production or service delivery system. Managing inventory helps ensure that the right products are available at the right time, without overstocking or running into shortages or stockouts.

Inventory management

Inventory management essentially deals with the process of procurement, ordering, storing, tracking, and use of raw materials and materials management either as a semi-finished product or as finished process products. The main goal is to ensure that the right quantity of items is available at the appropriate time and locations, avoiding both excess stock levels and shortages. Effective inventory control helps to reduce unnecessary costs and ensures products are always available, thereby enhancing customer satisfaction. A widely recognized method for optimizing inventory management is the economic order quantity (EOQ) model, which is the method that determines the ideal order quantity that minimizes total inventory costs.

World Food Programme (WFP)

The World Food Programme (WFP) simply stands for the food assistance sub-unit of the United Nations. It is the largest humanitarian organization in the world, saddled with the functions and responsibilities of addressing hunger and promoting food security, established in 1961 with headquarters in Rome, Italy. The WFP plays a crucial role in providing food aid to vulnerable populations, particularly during emergencies such as armed conflicts, natural disasters, man-made disasters and pandemics. Its mission includes supporting affected communities, including displaced individuals, malnourished children and nursing mothers.

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THE SENATE · FEDERAL REPUBLIC OF NIGERIA

OFFICE OF THE
SENATE CHIEF WHIP
FEDERAL REPUBLIC OF NIGERIA

9th February 2024

Malam Buba Musa Tunga

APPOINTMENT AS CHAIRMAN, BORNO SOUTH PALLIATIVE DISTRIBUTION MONITORING COMMITTEE

I am pleased to inform you of your appointment as the Chairman of the Palliative Distribution Monitoring Committee of Borno South Senatorial District. Your role is vital in overseeing the fair and transparent distribution of the resources. You are to liaise with the **Secretary of the Committee (Junaid Jibrin Maiva)** to nominate two persons from each of the nine Local Governments as members of the Committee to assist you.

While wishing you success in the task ahead, please accept the assurances of my esteemed regards.

Senator Mohammed Ali Ndume
The Senate Chief Whip
Senator Borno South

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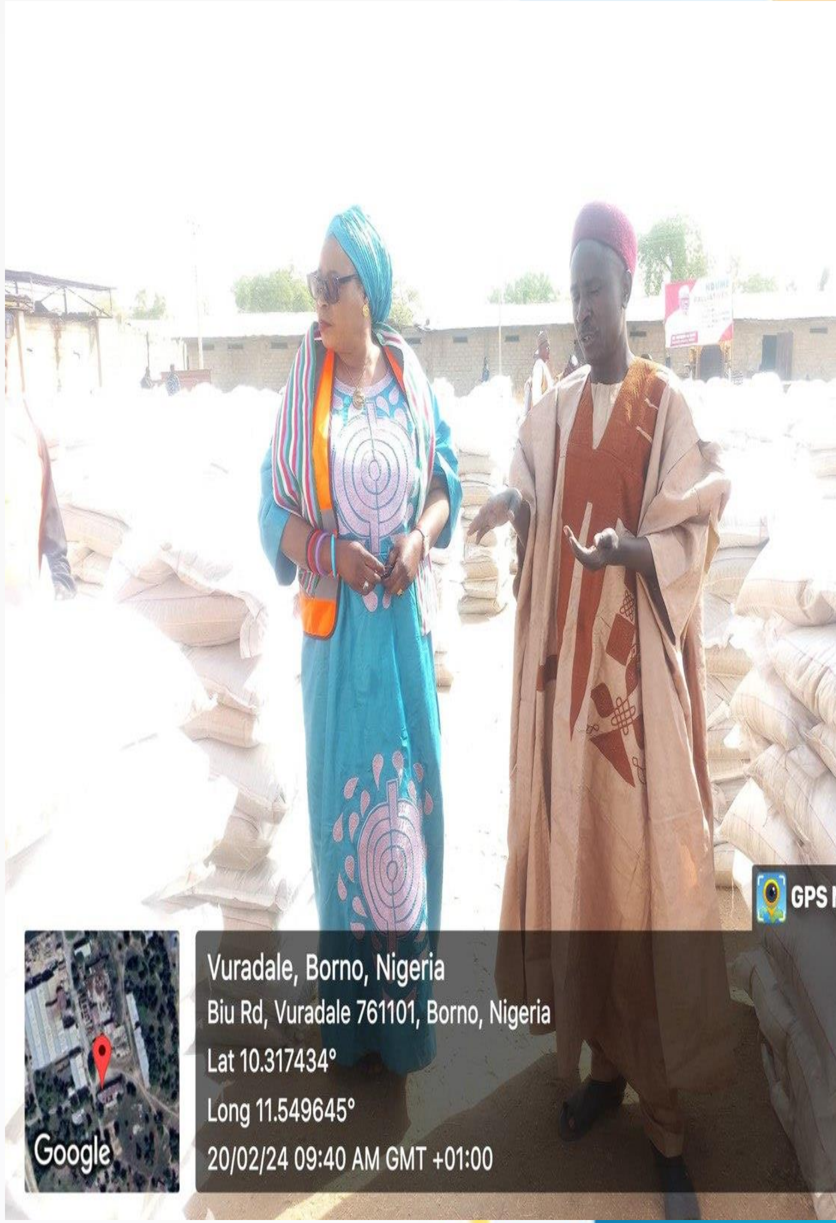

RESEARCH GAP

Relatively enough researchers took some deterministic parameters in their investigations, but we intend to take a demand pattern based on realistic data to investigate further and use a numeriacal illustration and sensitivity analysis by using nonlinear integer programming on the inventory model by the World Food Programme (WFP) on humanitarian food logistics challenges in some disaster regions.

OBJECTIVES

(i) To develop inventory models with more realistic parameters for humanitarian logistics challenges in crisis-affected regions faced by the World Food Programme.

(ii) To develop an inventory model to meet unexpected future demand and suggest suitable models for supply chain on the operations of the World Food Programme in crisis-affected regions.

(iii) To apply sensitivity analysis on different parameters for efficiency and cost effective performances by the world Food Programme.

PROBLEM STATEMENT

Inventory management in humanitarian relief logistics explores a unique set of challenges that differ significantly because its circumstances like natural disasters, man-made disasters, local and international political conflicts, pandemics, drought and those in commercial supply chains which are not comparable. Humanitarian operations often take place in highly volatile, unpredictable and unstable environments, where food and shelter demand is uncertain, infrastructure may be damaged or destroyed and a timely response is critical to saving lives.

Mathematical Modeling on Humanitarian Food supply challenges and Sorghum Deterioration Rate Under Boko Haram Controlled Areas

The operational difficulties entailed in the humanitarian supply of sorghum to communities and internally displaced persons (IDPs) in conflict areas, done by ad-hoc personnel of the United Nations World Food Programme (WFP). The unstable nature of the security situation in these areas makes logistics more difficult, which results in high transportation costs, specifically due to military escort requirements, as well as holding and ordering expenses for vital commodities such as sorghum. To solve these problems, the research suggests an adapted inventory model that is made to maximize sorghum distribution and increase the operational efficiency of the WFP in conflict-affected regions.

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DATA OBTAINED FOR THE DISTRIBUTION OF SORGHUM IN 2020 THROUGH THE GLOBAL COMMODITY MANAGEMENT/ UNITED NATIONS WORLD FOOD PROGRAMME https://executiveboard.wfp.org **SUMMARY REPORT-NIGERIA 13TH JANUARY, 2023**

Table 3.1: Sorghum Distribution and Demand Forecast in 2020

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
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	------------

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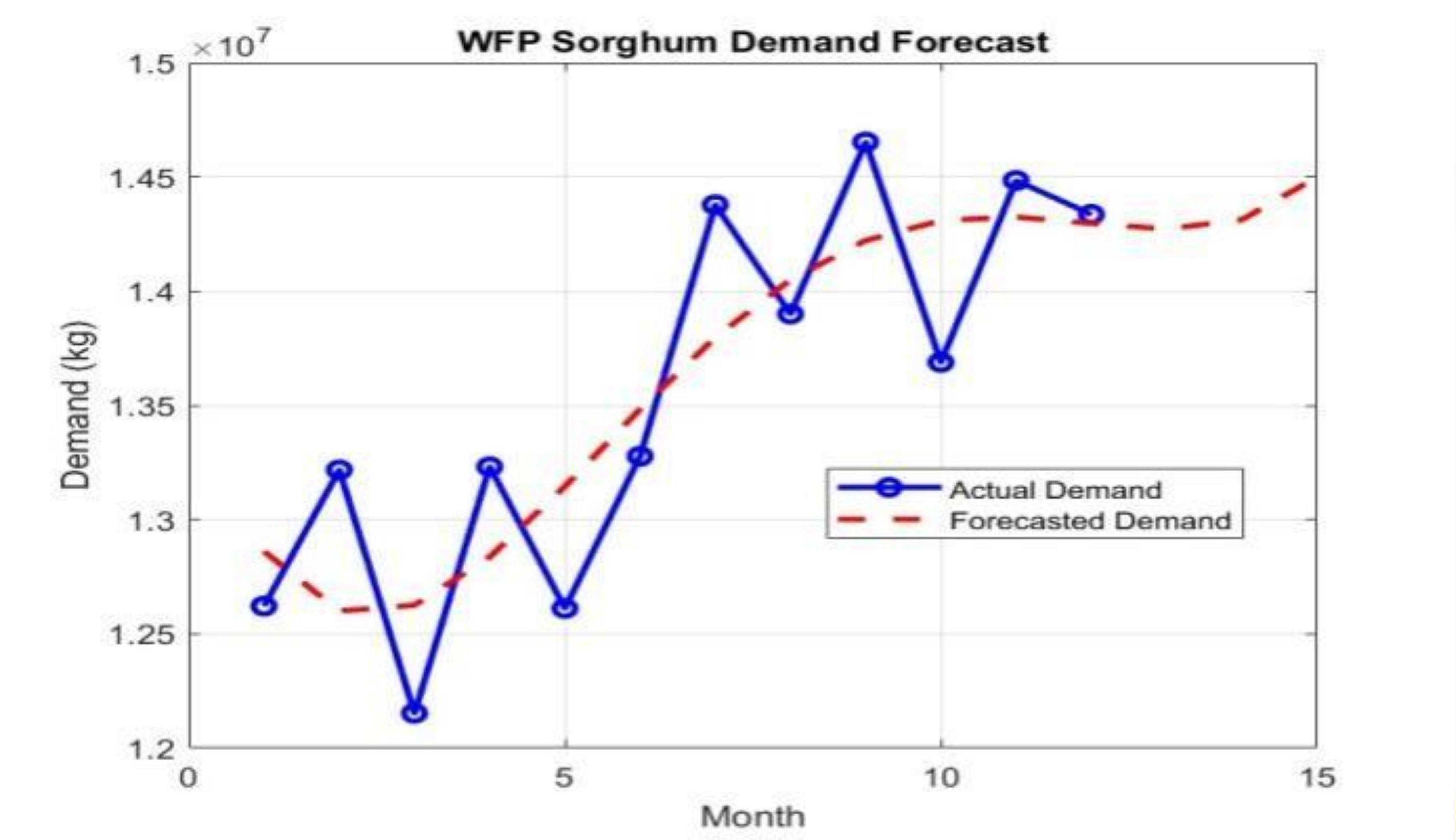


Figure 3.1 illustrates the demand forecast function, modeled by the polynomial

$$687.24t^4 - 23982t^3 + 270418t^2 - 915141.22t + 13528381.70 = 0$$

Cont.,

ASSUMPTIONS.

(1) Stockouts and backorders are not permitted in the model.

(2) The inventory system considers a single product type.

(3) Items that deteriorate cannot be repaired or replaced.

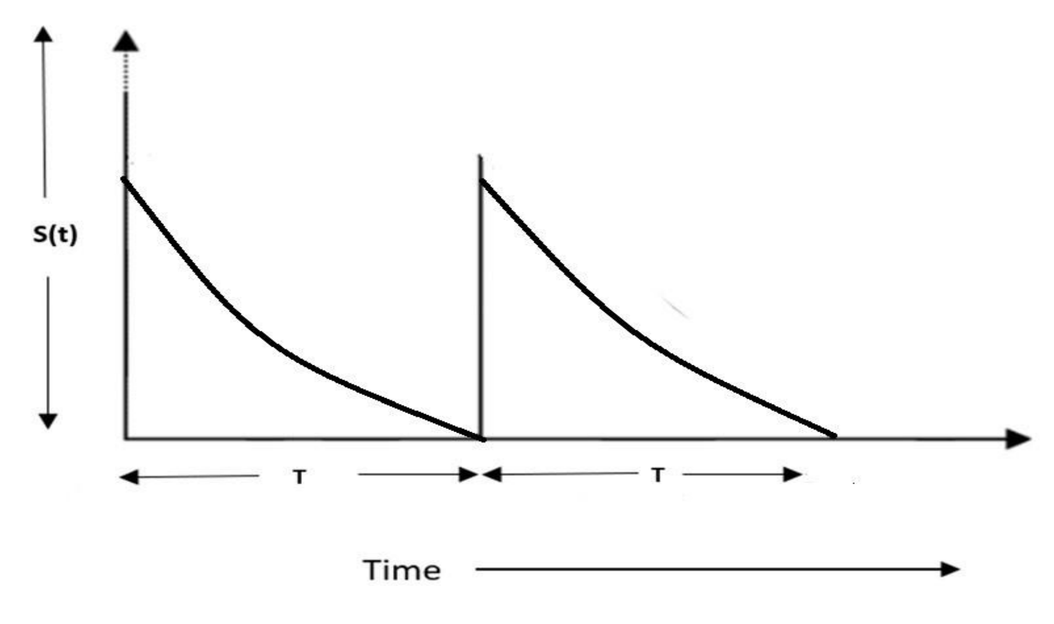
NOTATIONS.

- C_P Unit procurement cost.
- C_h Unit holding cost per period.
- A Ordering cost per replenishment.
- $S(t)$ Inventory level at time t.
- T length of each replenishment cycle (decision variable)
- φ Rate of deterioration.
- Do Rate of deterioration per cycle.
- SS Safety stock level.
- TC Total inventory related cost.
- S_0 Total order quantity per cycle.
- Z Service level coefficient (standard normal variable 1.65 for 95%).
- σ_L Standard deviation of lead time dependent (on monthly demand variability).
- D Time-dependent demand rate, quadratic as $at^4 + bt^3 + ct^2 + dt + e$
- M_f Military escorts transportation cost per cycle.

Cont.,

Model Development

The relief supplies of sorghum distribution to the communities dislodged by the armed group of people with a subversive activities, depletion is contineous at R per cycle. While the stock level and the deterioration rate is also constant and is infinite.



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

Total Purchase Cost

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

Total Deterioration Cost

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

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

Inventory holding cost

$$C_h \left\{ \frac{24ae^{\varphi T}-1}{\varphi^6} + \frac{1}{\varphi^5}(6b(1-e^{\varphi T}) - 24ae^{\varphi T}) + \frac{1}{\varphi^4}(-2c(1-e^{\varphi T}) + 6Tbe^{\varphi T} + 12T^2ae^{\varphi T} + \right.$$

$$\frac{1}{\varphi^3}(d(1-e^{\varphi T}) - 2Tce^{\varphi T} - 4T^3ae^{\varphi T} - 3T^2be^{\varphi T}) + \frac{1}{\varphi^2}(-e(1-e^{\varphi T}) + Tde^{\varphi T} + T^4ae^{\varphi T} + T^3be^{\varphi T} + T^2ce^{\varphi T}) -$$

$$\frac{T^5a}{5\varphi} - \frac{T^4b}{4\varphi} - \frac{T^3c}{3\varphi} \qquad \text{.....(4)}$$

Cont.,

Military Escorts transportation

$$MF = M_f\, e^{\varphi T}\left\{\frac{Td+T^3b+T^4a}{\varphi}+\frac{-2Tc-3T^2b-4T^3a}{\varphi^2}+\frac{6Tb+12T^2a}{\varphi^3}-\frac{24Ta}{\varphi^4}\right\}$$ …..(5)

Safety Stock cost $SS = LC_hZ.$

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

$$TC =$$

$$\frac{1}{T}\{C_0 + C_h\left\{\frac{24ae^{\varphi T}-1}{\varphi^6}+\frac{1}{\varphi^5}(6b(1-e^{\varphi T})-24ae^{\varphi T})+\frac{1}{\varphi^4}(-2c(1-e^{\varphi T})+6Tbe^{\varphi T}+12T^2ae^{\varphi T}+\right.$$

$$\frac{1}{\varphi^3}(d(1-e^{\varphi T})-2Tce^{\varphi T}-4T^3ae^{\varphi T}-3T^2be^{\varphi T})+\frac{1}{\varphi^2}(-e(1-e^{\varphi T})+Tde^{\varphi T}+T^4ae^{\varphi T}+T^3be^{\varphi T}+T^2ce^{\varphi T})-$$

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

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

(6)

Cont.,

NUMERICAL SOLUTIONS.

The parameters for the mathematical model have been provided by a reputable company in collaboration with an NGO. We also used MATLAB for accuracy in our computational numerical solutions.

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 in 12 months,

TC = ₦46,550,484,517.45 and S_0=22,177,792 units.

Table 3.1: Impact of Parameter Variation on T, T in days and TC

Parameters	%	Time	Time in Days within 12 months	Total Cost	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

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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
	+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

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SENSITIVITY ANALYSIS

We obtain the results of the sensitivity analysis on some parameters and the impact of changes to ascertain the level of responses.

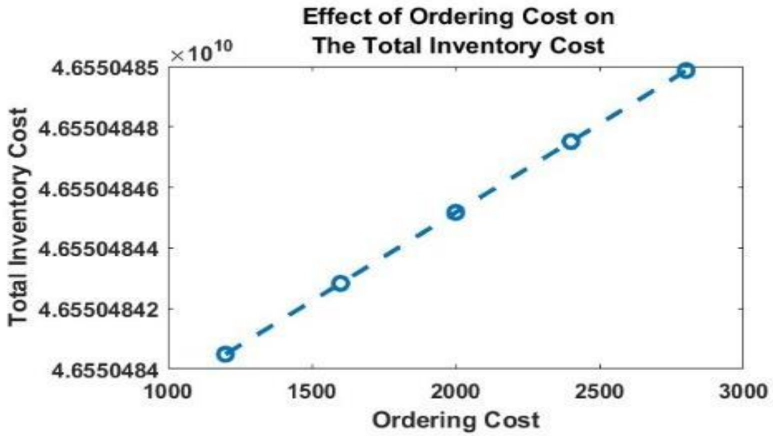

Figure 3.3(a)

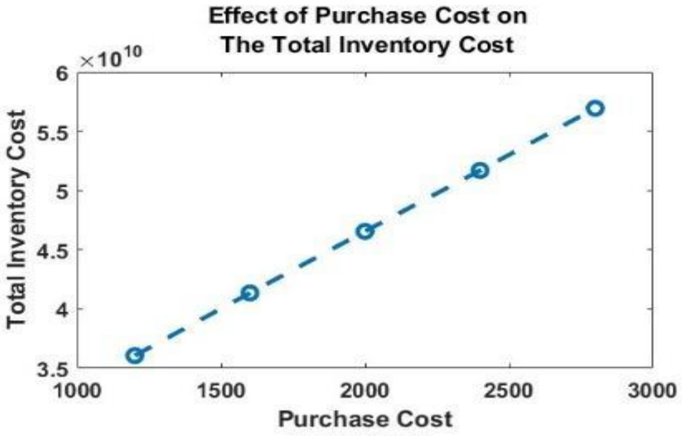

Figure 3.3(b)

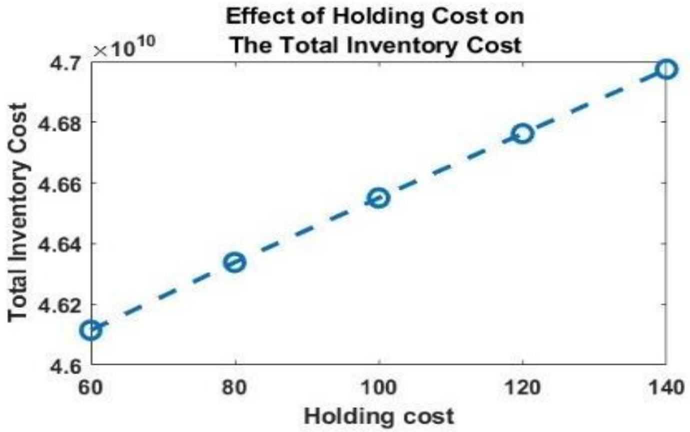

Figure 3.3(c)

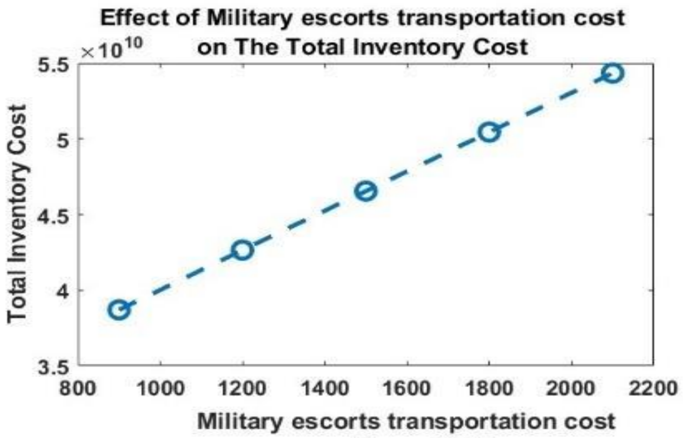

Figure 3.3(d)

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The analysis underscores the significant influence of key cost parameters on the inventory model's performance. The study indicates that purchase cost (C_p) and the cost of military escort (M_f) have a major impact on total cost (TC), holding cost (C_h) has a moderate impact, and ordering cost (C_o) has little impact. Interestingly, total inventory levels and time intervals (T) remain relatively unchanged amid parameter variation.

These results highlight the need to strategically manage C_p and M_f to realize cost-efficient inventory control. The suggested model is a pragmatic instrument for enhancing resource allocation in humanitarian logistics, particularly in high-risk, resource-scarce settings.

CONCLUSION

- As per our objectives, the research work was able to constructed and test a humanitarian inventory model specifically for WFP operations in insurgency-affected regions. Through the use of realistic data, unique and special parameters like military escort transportation cost, demand variability and deterioration, reflecting the difficult conditions faced in managing humanitarian supplies in unstable and insecure regions.

- The suggested models have provided a useful decision-making tool for the WFP, allowing them to plan, procure, and deliver critical supplies more effectively in challenging emergency environments, so that life-saving food assistance and supplies reach their intended beneficiaries even in the most unstable environments at a reasonable cost effective control.

CONCLUSION

- The suggested model and also a pragmatic instrument for enhancing resource allocation in humanitarian logistics, particularly in high-risk, resource-scarce settings. The results demonstrate the importance of accurate demand forecasting and cost management for the provision of effective nutritional support under challenging humanitarian conditions.

- In general, numerical illustrations and sensitivity analysis show that key parameters like the purchase price (C_p), military escort cost (M_f), and deterioration rate (φ) have major effects on total cost (TC) and the safety stock (S) on food supplies logistics challenges. The effect of deterioration rate φ, remains important in setting up optimal inventory levels for humanitarian logistics challenges.

THANK YOU

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