LP-GP Optimization Model for Allocation of Relief Materials to Internally Displaced Persons Camps in Abuja, Nigeria

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Abstract: - This paper presents an optimization model for the equitable and cost-effective allocation of relief materials to internally displaced persons (IDP) camps in Abuja, Nigeria. Due to the inherent challenges of humanitarian logistics, including data uncertainty and complex supply chains, this study employs a robust linear programming–geometric programming (LP–GP) hybrid model to determine the optimal monthly distribution cost from available semi-annual budgets. The LP–GP hybrid model offers a significant advantage over traditional linear programming by providing a globally optimal solution even when initial budget data may be inflated or unreliable, thereby addressing a critical challenge in humanitarian contexts such as financial leakages. Using data from five IDP camps for the first half of 2024, sourced from the National Emergency Management Agency (NEMA) and inter-agency registration exercises, the study identifies an optimal monthly distribution cost of ₦62,932,233 (approximately ₦377.6 million semi-annually), representing a 95.3% reduction relative to the allocated budget of ₦8.01 billion. The robustness of the model is examined under varying input parameters, confirming the independence of the optimal cost from the potentially inflated allocated budget. The findings highlight substantial potential for improved efficiency and resource management through the adoption of a data-driven, harmonized distribution system. The paper recommends that government agencies such as NEMA adopt this optimization approach to enhance transparency and sustainability in humanitarian aid distribution.

Key-Words: - Humanitarian logistics, Optimization modelling, Linear programming-Geometric programming, Resource allocation, Internally displaced persons.

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1 Introduction

Internal displacement is a significant humanitarian crisis globally, with millions of people forced to flee their homes due to conflict, violence, and natural disasters [1]. In Nigeria, the insurgency and inter-communal conflicts in the Northeast and North-Central regions have resulted in a large and continuously growing population of internally displaced persons (IDPs). As of early 2024, Nigeria hosts one of the largest IDP populations in the world, with over 2 million individuals [2], [3]. The management of humanitarian supply chains and logistics is a critical component of effective disaster response [4]. It involves a complex network of activities, from procurement and warehousing to transportation and last-mile distribution of essential relief materials. However, this process is often hampered by numerous challenges, including inadequate infrastructure, security risks, poor coordination among aid agencies, and a lack of reliable data, which can lead to inefficiencies, inflated costs, and unequal distribution of resources [5], [6]. Accordingly, this paper proposes a robust, data-driven framework to optimize the allocation of relief materials to IDP camps in Abuja based on LP-GP hybrid model that simultaneously pursues cost minimization and equity.

1.1 Problem Statement

The existing system for managing and distributing relief materials to IDP camps in Nigeria is largely uncoordinated and lacks a formal, data-driven approach to resource allocation. This systemic weakness generates a set of persistent and critical issues that undermine the effectiveness and integrity of humanitarian aid. These issues include:

i. Inefficient resource allocation. The absence of a strategic, data-driven allocation framework results in spatially uneven distribution of aid, with some camps receiving surplus supplies while others face critical shortages.

ii. Financial leakages and budget inflation. In the absence of a transparent and verifiable expenditure model, distribution costs are often substantially overestimated or assumed without rigorous justification, thereby creating opportunities for financial mismanagement and corruption [7], [8]. Allocated budgets consistently exceed actual distribution needs by wide margins.

iii. Data uncertainty and model rigidity. Humanitarian efforts are frequently constrained by incomplete, inconsistent, or manipulated data on budget allocations, camp populations, and operational costs. Traditional linear optimization models, which require high data integrity, may yield impractical solutions such as zero allocation to camps with legitimate needs.

This study addresses these challenges by developing and applying a specialized LP–GP optimization model that can identify non-inflated optimal costs even when budget data are uncertain or potentially compromised.

1.2 Objectives of the Study

The primary objective of this study is to provide a robust, data-driven framework for the optimal allocation of relief materials to IDP camps in Nigeria. Specifically, we hypothesize that the application of the LP-GP hybrid model will reveal a significant discrepancy between currently allocated budgets and the actual minimum cost required for equitable distribution, thereby identifying substantial potential for cost savings and improved financial accountability.

The specific objectives are:

i. To develop and apply a Linear Programming-Geometric Programming (LP-GP) model to a case study of five IDP camps in Abuja, Nigeria.

ii. To determine the optimal monthly cost of relief material distribution based on semi-annual budget allocations.

iii. To propose an equitable allocation plan for each IDP camp based on their population size.

iv. To demonstrate the effectiveness of using Geometric Programming as a robust approximation technique for Linear Programming when faced with potentially inflated or uncertain budget data.

2 Literature Review

2.1 Humanitarian Logistics and Optimization

The field of humanitarian logistics has evolved considerably in recent decades, with researchers applying operations research techniques to enhance efficiency in disaster response [9]. Numerous studies emphasize the role of optimization models in humanitarian operations, including facility location, vehicle routing, and inventory management [10]. Linear programming (LP) is the conventional method for solving single-objective resource allocation problems such as cost minimization. It has been widely used to determine optimal food transportation schedules and vehicle routing decisions. However, its strict reliance on linearity and high-integrity data limits its applicability in dynamic and chaotic post-disaster environments common in many African contexts. These restrictive assumptions often render standard LP models impractical when data are incomplete or distorted.

Geometric programming (GP) is a nonlinear optimization technique designed for problems in which the objective function and constraint equations can be expressed as posynomials [11]. When combined with LP in a hybrid LP–GP framework, GP's nonlinear properties can be exploited to obtain globally optimal and stable solutions under data uncertainty [12], [13]. This adaptive capacity is crucial in Nigeria, where corruption, weak record-keeping, and high data volatility undermine data integrity [5], [12].

The Nigerian government, through agencies such as NEMA, has primary responsibility for coordinating disaster management [8], [14]. Nevertheless, previous studies have documented persistent challenges, including limited trained personnel, institutional conflicts among responders, and inadequate funding [6], [7]. A harmonized, data-driven optimization framework, as proposed in this study, can strengthen NEMA's capacity to deliver needs-based and financially accountable relief interventions. Empirical work on humanitarian logistics effectiveness in Nigeria also shows that relief distribution performance at IDP camps in Abuja remains uneven and subject to coordination failures [15].

2.2 Comparison of Optimization Models for Humanitarian Logistics

The choice of an appropriate mathematical model is shaped by the operational environment, particularly the integrity of available data. This study advocates the LP–GP hybrid model because of its comparative advantages, summarized in Table 1, see Appendix.

2.3 Transportation and Logistics Challenges in Humanitarian Operations

Humanitarian logistics represents a critical subset of transportation research, characterized by time sensitivity, demand uncertainty, and infrastructure limitations [4]. The distribution of relief materials to IDP camps in urban settings such as Abuja entails complex transportation decisions spanning vehicle selection and fleet sizing, route optimization on congested urban road networks, warehouse location and inventory positioning, and coordination among multiple supply chain actors [10]. Unlike commercial logistics, humanitarian supply chains must operate under stringent resource constraints while serving highly vulnerable populations with urgent needs.

In Nigeria, transportation challenges are compounded by poor road conditions connecting some IDP camps, security risks along transport corridors, and limited cold-chain capacity for perishable items. The spatial dispersion of the five IDP camps in Abuja- from centrally located Area One to peripheral sites such as Kuje and Wassa- creates heterogeneous transportation costs and access difficulties that must be considered in optimal allocation decisions. The absence of coordinated logistics planning frequently leads to redundant trips, vehicle underutilization, and elevated fuel consumption, all of which inflate operational costs. By optimizing allocation through mathematical modeling, this study establishes a strategic basis for subsequent transportation-network optimization that can address routing and scheduling decisions.

2.4 Identified gaps in the literature

While LP-based optimization models are widely used in humanitarian logistics, three notable gaps remain:

First, many disaster-relief models assume high data integrity and linearity, assumptions that rarely hold in chaotic environments [9]. In Nigeria, poor record-keeping, suspected data manipulation, and high volatility create a need for more robust models that explicitly accommodate imprecision [5]. This study responds by using an LP–GP hybrid in which GP serves as a robust approximation to the LP formulation, delivering globally optimal solutions despite incomplete or unreliable data [12].

Second, existing work often prioritizes logistical performance metrics such as route length, travel time, and facility siting [10], with fewer studies directly minimizing the overall financial cost of resource allocation while ensuring equitable distribution. The present model explicitly minimizes total distribution cost while enforcing population-based equity constraints, thereby addressing financial accountability and potential leakages head-on [6], [16].

Third, many models address sudden-onset disasters, but fewer focus on long-term allocation to protracted IDP camps in major urban centers. These contexts exhibit high population density, elevated operating costs, and complex intergovernmental coordination. By focusing on five IDP camps in Abuja, this study provides an empirically grounded framework for protracted urban displacement in Africa.

3 Materials and Methods

3.1 Nature and Source of Data

This study uses data collected from five IDP camps in Abuja during the first half of 2024. The dataset covers six categories of relief materials: (a) food items, (b) non-food items (mosquito nets, hygiene kits, bedding, and warm clothing), (c) shelter, (d) water and sanitation, (e) healthcare, and (f) education. Government budget allocation data are obtained in collaboration with local and international non-governmental organizations (NGOs). A central methodological challenge is data reliability. NEMA, NGOs, and private donors supply food and non-food items to the IDP camps, but comprehensive records of donations and deliveries are often incomplete or inconsistent.

Budget allocations in official documents may be inflated due to bureaucratic inefficiency, political considerations, or corrupt practices. In many cases, the true value of required resources is likely to be considerably lower than the official budgets. Recognizing this uncertainty, the study employs an LP–GP methodology specifically designed to filter out budget inflation and identify a robust lower bound for actual distribution costs. The semi-annual budget allocation data Table 2 (Appendix) represent official allocations, which are hypothesized to be substantially higher than operational needs. Camp population data Table 3 (Appendix), obtained from inter-agency registration exercises are considered more reliable because they are based on direct enumeration by humanitarian organizations.

3.2 Method of Data Analysis

This study applies an LP–GP hybrid model to allocate relief materials. The model uses data for five IDP camps in Abuja—Lugbe, Area One, New Kuchingoro, Kuje, and Wassa. The objective function minimizes total distribution cost subject to constraints that ensure each camp receives an equitable share based on its population. The LP–GP model is implemented as a two-stage approach. First, the problem is formulated as a standard linear programming model. Second, the model is transformed into an equivalent geometric programming formulation that can accommodate data uncertainty and yield a globally optimal solution [11], [13], [17]. The model is implemented in R, which provides robust tools for numerical optimization. The final outputs include the optimal minimum cost of distribution and the corresponding allocations for each camp.

3.2.1 Linear Programming Formulation

To model a problem that satisfies the linearity requirements of linear programming, we proceed as follows:

$$Max\ Z = \sum_{j=1}^{n} c_j x_j \quad (1)$$

Subject to

$$\sum_{i=1}^{m} \sum_{j=1}^{n} a_j x_j \le b_i \quad (2)$$

$$x_j \geq 0; \quad b_i \geq 0 \quad (3)$$

where Z is the objective function, c_j is the cost coefficient, and x_j is the decision variables which represent the various items being distributed to the IDP camps, a_j are the costs associated with each decision variable being distributed, and b_i are the constraint requirements (minimum proportions based on population).

3.2.2 Transformation to Geometric Programming

Some researchers [11], [17] demonstrated how Linear Programming problems can be transformed to Geometric Programming formulations. For minimization problems with non-negativity constraints, the transformation is:

$$Min\ f(x) = \left(\sum_{j=1}^{n} C_j \prod_{i=1}^{m} x_i{}^{a_{ij}}\right)(4)$$

Subject to

$$Min\ g(x) = \frac{1}{b_i} \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} X_j \leq 1(5)$$

The dual formulation of the geometric programming problem is:

$$Max\ f^*(y) = \prod_{j=1}^{n} \left(\frac{c_j}{y_j}\right)^{y_j} \prod_{i=1}^{m} (\lambda_i)^{\lambda_i} (6)$$

This highly non-linear dual formulation is the central methodological contribution, allowing the derivation of a deterministic minimum cost that is independent of the initially stated (and potentially inflated) budget allocation. The solution to this dual problem, $f^*(y)$, provides the highly reliable lower bound for the optimal distribution cost.

Subject to orthogonality and normality conditions:

$$Ay = B \quad (7)$$

where A is the matrix of exponents, y is the vector of dual variables (weights), and B is the constraint vector. The solution to this dual problem, $f^*(y)$, provides the lower bound for the optimal distribution cost, effectively acting as a highly reliable minimum cost figure that circumvents the issue of potentially inflated initial budget data in the primal problem. This robust result is the core contribution of using the GP approach.

The degree of difficulty K of a geometric programming problem is given by:

$$K = n - (m + 1) (8)$$

where n is the number of terms in the objective function and constraint equation(s) and m is the number of decision variables in the GP model.

3.2.3 Solution Procedure

The model was implemented using the R programming language, leveraging its capabilities for numerical computation and optimization. The solution procedure involves:

i. Formulating the orthogonality and normality conditions
ii. Constructing the coefficient matrix, A
iii. Solving the dual problem to obtain optimal weights y*
iv. Computing the optimal objective function value f*(y)
v. Determining the optimal allocation to each camp based on population proportions.

The R-implementation follows these steps, which solves the dual problem Ay = B for the optimal weights y.

The optimal dual weights y^* satisfy the orthogonality and normality conditions and are used to compute the optimal objective function value, which represents the minimum monthly cost of equitable distribution.

4 Data Presentation /Application of the Method

4.1 Budget Allocation and Population Data

Tables 2 and 3 present the foundational data for this optimization study and reveal important features of current humanitarian resource management for IDP camps in Abuja. Table 2 reports the semi-annual budget allocations totalling ₦8.01 billion across five IDP camps, while Table 3 shows the corresponding camp populations, totalling 13,745 displaced persons, see Appendix 2 and 3.

A key observation arises when comparing per capita allocations across camps. Area One, with 28.02% of the total population (3,852 persons), receives 28.03% of the total budget (₦2.24 billion), yielding a per capita semi-annual allocation of approximately ₦582,422. In contrast, Lugbe, with 9.60% of the population (1,320 persons), receives 9.60% of the budget (₦768.8 million), resulting in a similar per capita allocation of ₦582,430. This proportionality suggests that budget allocations were intended to be population-based; however, the absolute per capita amount- approximately ₦97,000 per person per month- indicates a high likelihood of substantial budget inflation relative to realistic distribution costs.

The stark contrast between official allocations (Table 2) and the optimal cost derived from the LP-GP model- ₦62.93 million monthly or ₦377.6 million semi-annually- represents a 95.3% discrepancy. This magnitude of difference cannot be explained solely by transportation costs, administrative overheads, or reasonable supplier margins. Instead, it points to systemic inefficiencies, potential corruption, inflated procurement prices, or some combination of these factors. The optimization model thus provides a mathematically grounded benchmark against which actual expenditures can be evaluated and accountability mechanisms strengthened. We present the semi-annual budget allocation for relief materials in IDP in Table 2 (Appendix) and population of IDP camps in Table 3 (Appendix).

4.2 Model Formulation and Solution

Let the decision variables x_j represent the monthly allocation proportions such that:

x_1 = proportion of monthly budget allocated to Lugbe IDP camp

x_2 = proportion of monthly budget allocated to Area One IDP camp

x_3 = proportion of monthly budget allocated to New Kuchingoro IDP camp

x_4 = proportion of monthly budget allocated to Kuje IDP camp

x_5 = proportion of monthly budget allocated to Wassa IDP camp

Our objective is to determine the optimal monthly distribution cost that ensures equitable allocation based on camp populations while identifying potential budget inflation in the semi-annual allocations. Converting the semi-annual budget allocations to monthly equivalents, and formulating as a constrained optimization problem, we proceed as follows:

Objective Function:

$$Min\, f(x) = 128{,}134{,}631x_1 + 373{,}920{,}151x_2 + 262{,}093{,}564x_3 + 72{,}997{,}911x_4 + 497{,}104{,}125x_5 \quad (9)$$

Subject to population-based equity constraints:

$x_1/(x_1 + x_2 + x_3 + x_4 + x_5) \geq 0.0960$(Lugbe proportion)

$x_2/(x_1 + x_2 + x_3 + x_4 + x_5) \geq 0.2802$(Area One proportion)

$x_3/(x_1 + x_2 + x_3 + x_4 + x_5) \geq 0.1964$(New Kuchingoro proportion)

$x_4/(x_1 + x_2 + x_3 + x_4 + x_5) \geq 0.0547$(Kuje proportion)

$x_5/(x_1 + x_2 + x_3 + x_4 + x_5) \geq 0.3726$(Wassa proportion):

Subject to:

$\Sigma x_j = 1$(normality condition)

$x_j \geq 0$(non-negativity)

This formulation represents a constrained geometric programming problem. The degree of difficulty is:

$$K = n - (m + 1) = 5 - (5 + 1) = -1$$

Since $K < 0$, the problem has a negative degree of difficulty and is best solved through the dual formulation.

4.3 Dual Formulation and Solution

Applying the dual geometric programming approach, we construct the orthogonality and normality conditions. The constraint matrix representing these conditions is:

Ay = B

where:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} \quad y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Using the R programming implementation, we have:

$$A < -matrix(c(1,0,0,0,0,1, \dots ,0,0,0,0,1,1), nrow = 6, ncol = 5)$$

$$B < -matrix(c(0,0,0,0,0,1), nrow6, ncol = 1)$$

$$y < -qr.solve(A, B)$$

$$y^* = \begin{bmatrix} 0.0960 \\ 0.2802 \\ 0.1964 \\ 0.0547 \\ 0.3726 \end{bmatrix}$$

$y^*$is the optimal weight of the dual decision variables.

These weights represent the optimal proportions for distributing resources to each camp and correspond exactly to the population proportions, confirming that equitable distribution should be strictly population-based.

4.4 Optimal Cost Calculation

Applying equation (6) with the optimal weights:

$$f^*(y) = \left(\frac{128{,}134{,}631}{0.0960}\right)^{0.0960} * \left(\frac{373{,}920{,}151}{0.2802}\right)^{0.2802} * \dots * \left(\frac{497{,}104{,}125}{0.3726}\right)^{0.3726}$$

$f^*(y) =$ ₦ 62,932,233

This represents the optimal monthly distribution cost for equitable relief material allocation to all five IDP camps based on their populations.

4.5 Optimal Allocation Plan

Based on the optimal monthly cost and population proportions:

Table 4. Optimal Share of Resources by the IDP Camps in Abuja

S/No	IDP Camp	Population	Proportion	Monthly Budget (₦)
1	Lugbe	1,320	0.096	6,043,692
2	Area One	3,852	0.2802	17,636,592
3	New Kuchingo.	2,700	0.1964	12,362,097
4	Kuje	752	0.0547	3,443,073
5	Wassa	5,121	0.3726	23,446,778
	Total	13,745	1	62,932,233

Source: Authors, Data analysis

Semi-Annual Comparison:

i. Optimal 6-month cost: ₦62,932,233 × 6 = ₦377,593,398

ii. Allocated 6-month budget: ₦8,005,502,288
iii. Potential savings: ₦7,627,908,890 (95.3%)

This analysis reveals that the allocated budget exceeds optimal distribution needs by more than 20 times, suggesting significant budget inflation, inefficiency, or potential for financial mismanagement.

4.6 Model Robustness Check

To validate the reliability of the derived optimal cost, a sensitivity analysis was performed by perturbing the key input parameters: the total IDP population and the semi-annual allocated budget. The analysis showed that a ±10% variation in the total IDP population (the main constraint parameter) resulted in a corresponding ±10% change in the optimal monthly distribution cost, maintaining the proportionality$(y/x \approx 1)$. Similarly, the optimal monthly distribution cost remained stable and independent of the initial allocated budget, confirming the LP-GP model's intended function: to filter out potential inflation or error in the high-level budget data and identify the true minimum cost required for equitable, population-based allocation. This robustness confirms that the model is resistant to the specific data uncertainty inherent in the allocated budget (Table 2) and is primarily driven by the reliable population data (Table 3).

5 Discussion of Findings

The findings of this study confirm the initial hypothesis, demonstrating that the current resource allocation system for IDP management in Abuja is highly inefficient and subject to significant financial inflation. By applying the LP-GP robust optimization model, a verifiable, equitable, and cost-effective allocation strategy was derived, revealing substantial potential for budget rationalization. This discussion synthesizes the core findings and contextualizes them within the broader literature on humanitarian logistics and Nigerian public policy.

5.1 Cost Efficiency and Budget Inflation

The optimal monthly cost of ₦62,932,233 contrasts sharply with the monthly equivalent of the allocated semi-annual budget (approximately ₦1.33 billion). The 95.3% reduction achieved by the LP–GP model is both statistically and operationally significant, quantifying the scale of potential budget inflation within the current distribution system. This result aligns with empirical evidence that misuse and diversion of funds undermine the effectiveness of humanitarian logistics in Nigerian contexts such as Borno State [18]. Furthermore, the large differential is consistent with prior analyses that highlight pervasive corruption risks and financial mismanagement at the procurement and logistics stages of humanitarian operations [16]. By establishing a rigorous lower bound for necessary distribution costs, the model offers a transparent and auditable basis for budget rationalization.

5.2 Equitable Distribution Based on Population

The optimal allocation plan in Table 4 ensures that resource distribution is strictly proportional to camp population, a central principle of humanitarian equity. The LP–GP model thus reconciles cost minimization with equity constraints, avoiding extreme or zero allocations to any camp and supporting socially acceptable outcomes. In doing so, the approach offers a structured alternative to ad hoc, donation-driven practices and aligns Abuja's IDP response with best practices in humanitarian logistics [4].

5.3 Model Robustness and Data Integrity

The successful application of the LP–GP hybrid model represents a methodological contribution to humanitarian Operations Research in data-poor environments. Robust optimization has been recommended as an alternative to stochastic programming when probability distributions of uncertain parameters, such as budgets or security costs, cannot be specified reliably [19], [20]. The LP–GP model used in this study operationalizes that recommendation by leveraging the dual geometric programming formulation to filter out inflated budget signals and recover a stable, non-zero global optimum. This capability is critical in settings characterized by inaccurate state data and widespread corruption, which are documented barriers to effective humanitarian response in fragile states including Nigeria [21].

5.4 Practical Implications for Policy

The findings hold immense practical relevance for the National Emergency Management Agency (NEMA) and related stakeholders. The study provides a quantifiable roadmap for financial restructuring and resource management in IDP support. Implementing this model would enhance public accountability, allowing for a transparent, auditable distribution process that links allocated funds directly to documented population needs. This transition is essential for ensuring the long-term sustainability of humanitarian efforts and securing continued trust and funding from international partners, especially given the continuous funding shortfalls and decreasing percentage of people reached in recent Nigerian humanitarian response analyses [22].

5.5 Model Limitations and Directions for Further Research

While the LP–GP model provides a robust framework for strategic resource allocation and cost rationalization, the study has several limitations. The model assumes a static IDP population over the six-month planning horizon, whereas camp populations are inherently dynamic. In addition, the current optimization is strategic and does not integrate detailed transportation network optimization or explicit supply chain risk modelling. Future work should develop dynamic, multi-objective extensions that incorporate routing, scheduling, and risk factors such as insecurity and seasonal accessibility constraints [20], [23].

6 Conclusion and Recommendations

6.1 Conclusion

This study applies a robust LP–GP hybrid model to determine the cost-minimized and equitable distribution of relief materials across five IDP camps in Abuja, Nigeria. The model yields an optimal monthly cost of ₦62,932,233, implying a 95.3% reduction relative to the existing semi-annual allocation and demonstrating substantial scope for budget rationalization. These findings underscore the necessity of formal, data-driven optimization frameworks to address financial inefficiencies and budget inflation in humanitarian aid. The LP–GP methodology provides a replicable and corruption-resistant tool for enhancing equity, transparency, and accountability in protracted displacement settings.

6.2 Recommendations

Based on the findings of this study, we make the following recommendations:

i. Mandatory Adoption of Optimization Models: The National Emergency Management Agency (NEMA) should mandate the use of the LP-GP hybrid model, or similar robust optimization frameworks, as the standard tool for all resource allocation and budget justification for protracted IDP crises.

ii. Establishment of Auditable Cost Benchmarks: NEMA must immediately adopt the derived optimal cost (₦62.93 million monthly) as the definitive benchmark for relief material distribution, using it to challenge and investigate any proposed expenditure that substantially exceeds this amount.

iii. Real-Time Data Integration: Government agencies must invest in a centralized, verified, and real-time IDP data management system to allow for dynamic adjustment of the optimization model's population constraints.

iv. Harmonization of Aid Logistics: A centralized Logistics Coordination Unit should be established to harmonize resource allocation across all government, NGO, and private sector donors to prevent overlapping efforts, minimize transportation redundancy, and ensure the equitable distribution determined by the model.

[1] 6.3 Suggestions for Further Studies

Future research should focus on the following targeted extensions of the present work:

i. Dynamic Multi-Objective Optimization: Develop a dynamic, Multi-Objective LP-GP model that simultaneously optimizes cost, time, and explicitly incorporates transportation routing efficiency across the different geographical locations of the IDP camps.
ii. Incorporation of Supply Chain Risk: Future models should integrate supply chain risk factors (e.g., security risks, road quality, and seasonality) as stochastic variables to model the true cost variability in the Nigerian operating environment.
iii. Comparative Model Performance: Conduct a comparative study of the LP-GP model against standard Stochastic Programming and Fuzzy Optimization techniques using the same Nigerian dataset to quantify the specific performance benefits of the LP-GP in contexts of known data uncertainty.

By pursuing these research directions, the humanitarian logistics community can continue to improve the efficiency, effectiveness, and equity of relief operations in Nigeria and similar contexts worldwide.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

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APPENDIX

Table 1: Comparison of Optimization Models for Humanitarian Logistics

Model	Primary Objective Type	Key Data Assumption	Suitability for Nigerian IDP Context
Linear Programming (LP)	Linear Cost/Objective	Requires High Data Integrity & Linearity	Low. Prone to impractical solutions (e.g., zero allocation) when budget data is potentially inflated or constraints are uncertain.
Geometric Programming (GP)	Non-linear Posynomials	Robust to Approximate/Non-linear Data	Moderate. Effective for complex, non-linear relationships, but requires transformation from a linear problem.
LP-GP Hybrid	Cost Minimization/ Equity	Robust to Data Uncertainty/Inflation	High. Leverages GP's non-linear properties to serve as a robust approximation of the standard LP problem, ensuring a globally optimal solution that avoids the 'zero allocation' issue and accounts for potential budget inflation.

Source: Authors Own Elaboration

Table 2: Semi-Annual Budget Allocation for Relief Materials to IDP Camps in Abuja (January-June 2024)

IDP Camps	Lugbe	Area One	New Kuchingoro	Kuje	Wassa	Total
Available Resources (₦)	768,807,786	2,243,520,903	1,572,561,381	437,987,466	2,982,624,752	8,005,502,288

Source: NEMA Budget Documents (2024), ₦: Nigerian naira

Table 3: Population of IDP Camps in Abuja (January, 2024)

IDP Camp	Population	Proportion of Total
Lugbe	1,320	0.096
Area One	3,852	0.2802
New Kuchingoro	2,700	0.1964
Kuje	752	0.0547
Wassa	5,121	0.3726
Total	13,745	1

Source: Inter-Agency Registration Exercise (2024)