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RESEARCH ARTICLE

Optimization for Emergency Inventory Planning under Cyclone Uncertainty Using Neutrosophic Trapezoidal Fuzzy Modeling and Geometric Programming

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ABSTRACT

Cyclone-related disasters require effective inventory planning due to uncertain demand, disrupted logistics, and frequent shortages of essential supplies. This study develops a decision – support framework to help optimize the supply of emergency relief items, such as dry ration kits, drinking water, and first aid kits, within a short time of 60 hours. Cost parameters are represented as neutrosophic trapezoidal fuzzy numbers, which are converted into crisp values using a weighted average defuzzification method. The total cost function is expressed in a posynomial form and optimized using geometric programming. The optimal order quantity, shortage quantity and minimum total cost are determined for each relief kit. Sensitivity analysis was performed to evaluate the uncertainty in demand and cost parameters. The results show that combining neutrosophic trapezoidal fuzzy number and geometric programming makes effective inventory decisions in humanitarian logistics.

Keywords: Emergency Relief Items, Neutrosophic Trapezoidal Fuzzy Numbers, Weighted Average Method, Geometric Programming.

INTRODUCTION

Inventory management is essential for ensuring the availability of essential goods while minimizing operational costs. Economic Order Quantity (EOQ) model is a tool which provide an mathematical framework to determine optimal replenishment policies under various cost considerations. Later, Classical EOQ models have been extended to include real – world uncertainties such as perishability, shortages, uncertain demand and cost variations. Díaz et al. (2020) highlighted that inventory systems for perishable products require special care because

product decay and changing customer behaviour influence ordering decisions. In disaster situations, the importance of effective inventory planning becomes crucial. Humanitarian supply chains must operate under uncertainty, disrupted infrastructure, and time-bound demand. Stockouts can result in human suffering rather than financial loss. Humanitarian logistics literature suggests that traditional cost-oriented inventory policies are insufficient for disaster response, and decision-making must consider service levels, urgency, and shortage issues. Van Wassenhove (2006) emphasizes that humanitarian supply chains require approaches

that account for the distinctive challenges of disaster response. To capture uncertainty in inventory parameters, fuzzy set theory has been widely used in EOQ modelling. Poswal et al. (2022) demonstrated that incorporating imprecision in demand, holding cost, and ordering cost within fuzzy EOQ models can provide a more realistic framework for inventory decision-making.

Ye (2015) proposed the trapezoidal neutrosophic set as an extension of fuzzy set theory, incorporating truth, indeterminacy, and falsity components to represent uncertainty more comprehensively. Trapezoidal neutrosophic fuzzy number is suitable for aggregation and decision – making problems. Surya et al. (2024) integrated neutrosophic theory into EOQ models to address shortages, quality issues, and uncertainty in operational environments.

These studies show that neutrosophic EOQ models offer greater flexibility and robustness than classical inventory systems. The application of neutrosophic EOQ models in disaster management with short – term emergency horizons remains limited. Kotb and Fergany (2011) applied Geometric Programming (GP) to multi-item EOQ models with demand-dependent unit costs and varying lead times, demonstrating its usefulness for solving nonlinear inventory optimization problems. It guarantees global optimality for posynomial objective functions and offers closed-form analytical solutions, making it

suitable for emergency inventory planning where rapid decision-making is essential. Kalaichelvan et al. (2020) investigated inventory optimization using the Kuhn–Tucker method to address shortages under various constraints.

Motivated by these limitations, the present study develops a neutrosophic EOQ model for cyclone disaster management, focusing on a 60-hour emergency response horizon and multiple relief items, namely dry ration kits, drinking water, and first-aid kits. Holding cost, ordering cost and shortage penalty for each relief kit are modelled as trapezoidal neutrosophic fuzzy numbers to handle uncertainty, indeterminacy and conflicting assessments involved in disaster environments [6]. The neutrosophic model is defuzzified using the weighted average method and the resulting problem is optimized using geometric programming. This optimization technique is used to obtain closed-form expressions for optimal order quantity, optimal shortage quantity and minimum total cost.

ANALYSIS OF THE MODEL

The symbols represent demand characteristics, ordering decisions, shortage levels and cost parameters aligned with cyclone disaster relief inventory systems. All variables are assumed to be non – negative and decision variables are continuous.

Symbols	Description
q_i	Order quantity per replenishment cycle
$q_{s,i}$	Shortage (backorder) quantity
h_i	Holding cost
s_i	Shortage cost
o_i	Ordering cost
D_i	Total demand
d_i	Demand rate per hour

ASSUMPTIONS

1. The study considers a cyclone disaster event with a fixed 60-hour emergency response horizon, representing the critical initial relief phase.
2. The inventory system consists of three essential relief items, such as dry ration kits, drinking water, and first-aid kits, where each item is managed independently with item-specific parameters.
3. Shortages are permitted and fully backlogged, acknowledging unavoidable supply disruptions during the cyclone while ensuring all unmet demand is satisfied.

4. A shortage penalty cost is imposed to capture both operational and humanitarian consequences of unmet demand.

5. Holding cost, ordering cost, and shortage penalty are uncertain due to infrastructure damage and volatile conditions and are therefore modelled as trapezoidal neutrosophic fuzzy numbers.

6. Decision variables (order quantity and shortage quantity) are treated as crisp, ensuring implementable and actionable inventory policies.

MATHEMATICAL MODEL

The total cost function is derived from Kalaichelvan et al. (2020) as,

$$TC = \frac{h(q-q_s)^2}{2q}d + \frac{sq_s^2}{2q}d + \frac{oD}{q} \quad (1)$$

After evaluating and expressing the demand rate in terms of total demand over the 60-hour horizon and normalizing the cost components over a replenishment cycle, the total cost for a single relief item is formulated as,

$$\text{Taking } d = \frac{D}{60}$$

$$TC = \underbrace{\frac{hD}{120}q}_{\text{holding cost}} - \underbrace{\frac{hD}{60}q_s}_{\text{inventory relief due to shortages}} + \underbrace{\frac{(h+s)D}{120}\frac{q_s^2}{q}}_{\text{shortage penalty}} + \underbrace{\frac{oD}{q}}_{\text{ordering cost}} \quad (2)$$

Cyclone disaster relief operations involve the management of multiple essential items, such as dry ration kits, drinking water and first-aid kits. The model is extended to a multi-item framework by introducing an index i to represent individual relief items.

The overall total cost is obtained by summing the item-wise total costs across all relief items,

$$TC_i = \sum_{i=1}^3 \left[\frac{h_i D_i}{120} q_i - \frac{h_i D_i}{60} q_{s,i} + \frac{(h_i + s_i) D_i}{120} \frac{q_{s,i}^2}{q_i} + \frac{o_i D_i}{q_i} \right] \quad (3)$$

To determine the optimal shortage quantity for each relief item, the total cost function is partially differentiated with respect to the shortage quantity while keeping the order quantity fixed.

$$\frac{\partial TC_i}{\partial q_{s,i}} = -\frac{h_i D_i}{60} + \frac{2(h_i + s_i) D_i}{120} \frac{q_{s,i}}{q_i} \quad (4)$$

$$\frac{\partial TC_i}{\partial q_{s,i}} = 0 \quad (5)$$

$$q_{s,i}^* = \frac{h_i}{h_i + s_i} q_i \quad (6)$$

The optimal shortage quantity is obtained. Substituting the optimal shortage expression into the total cost function to reduce the problem to a single-variable optimization in terms of the order quantity.

$$TC_i = \frac{h_i s_i D_i}{120(h_i + s_i)} q_i + \frac{o_i D_i}{q_i} \quad (7)$$

$$\frac{\partial TC_i}{\partial q_i} = \frac{h_i s_i D_i}{120(h_i + s_i)} - \frac{o_i D_i}{q_i^2} \quad (8)$$

$$\frac{\partial TC_i}{\partial q_i} = 0 \quad (9)$$

$$q_i^* = \sqrt{\frac{120 o_i (h_i + s_i)}{h_i s_i}} \quad (10)$$

$$q_{s,i}^* = \frac{h_i}{h_i + s_i} \sqrt{\frac{120 o_i (h_i + s_i)}{h_i s_i}} \quad (11)$$

INVENTORY MODEL FOR FUZZY INTEGRATED EMERGENCY RELIEF ITEMS

In the Inventory model h_i, s_i, o_i are represented as trapezoidal fuzzy numbers, which are modelled as $h_{ik} = (h_{i1}, h_{i2}, h_{i3}, h_{i4})$, $s_{ik} = (s_{i1}, s_{i2}, s_{i3}, s_{i4})$, $o_{ik} = (o_{i1}, o_{i2}, o_{i3}, o_{i4})$

$$TC_{1i} = \sum_{i=1}^3 \left[\frac{h_{1i} D_i}{120} q_i - \frac{h_{1i} D_i}{60} q_{s,i} + \frac{(h_{1i} + s_{1i}) D_i}{120} \frac{q_{s,i}^2}{q_i} + \frac{o_{1i} D_i}{q_i} \right] \quad (12)$$

$$TC_{2i} = \sum_{i=1}^3 \left[\frac{h_{2i} D_i}{120} q_i - \frac{h_{2i} D_i}{60} q_{s,i} + \frac{(h_{2i} + s_{2i}) D_i}{120} \frac{q_{s,i}^2}{q_i} + \frac{o_{2i} D_i}{q_i} \right] \quad (13)$$

$$TC_{3i} = \sum_{i=1}^3 \left[\frac{h_{3i} D_i}{120} q_i - \frac{h_{3i} D_i}{60} q_{s,i} + \frac{(h_{3i} + s_{3i}) D_i}{120} \frac{q_{s,i}^2}{q_i} + \frac{o_{3i} D_i}{q_i} \right] \quad (14)$$

$$TC_{4i} = \sum_{i=1}^3 \left[\frac{h_{4i} D_i}{120} q_i - \frac{h_{4i} D_i}{60} q_{s,i} + \frac{(h_{4i} + s_{4i}) D_i}{120} \frac{q_{s,i}^2}{q_i} + \frac{o_{4i} D_i}{q_i} \right] \quad (15)$$

The memberships $(T_{TC_i}, I_{TC_i}, F_{TC_i})$ are directly attached to the individual item-wise total cost and are not merged across items, thereby preserving item-specific uncertainty characteristics. The trapezoidal cost components propagate algebraically within each item's cost structure,

$$\widetilde{TC} = \sum_{i=1}^3 [TC_{1i}, TC_{2i}, TC_{3i}, TC_{4i}]; [T_{TC_i}, I_{TC_i}, F_{TC_i}] \quad (16)$$

The defuzzification process converts the neutrosophic trapezoidal total cost into a single representative crisp value using a weighted-average rule. In this approach, the trapezoidal cost components are first aggregated, while $(T_{TC_i}, I_{TC_i}, F_{TC_i})$ are retained as weights.

$$TC_i^* = \sum_{i=1}^3 \left[\frac{T_{TC_i}}{4(T_{TC_i} + I_{TC_i} + F_{TC_i})} \left[\sum_{K=1}^4 \left(\frac{h_{Ki} D_i}{120} q_i - \frac{h_{Ki} D_i}{60} q_{s,i} + \frac{(h_{Ki} + s_{Ki}) D_i}{120} \frac{q_{s,i}^2}{q_i} + \frac{o_{Ki} D_i}{q_i} \right) \right] \right] \quad (17)$$

$$TC_i^* = \sum_{i=1}^3 \left[\frac{D_i T_{TC_i}}{4(T_{TC_i} + I_{TC_i} + F_{TC_i})} \left[\frac{q_i}{120} \sum_{K=1}^4 h_{Ki} - \frac{q_{s,i}}{60} \sum_{K=1}^4 h_{Ki} + \frac{q_{s,i}^2}{120 q_i} \sum_{K=1}^4 (h_{Ki} + s_{Ki}) + \frac{1}{q_i} \sum_{K=1}^4 o_{Ki} \right] \right] \quad (18)$$

After the defuzzification of total cost, the crisp optimal shortage quantity and crisp optimal order quantity obtained.

$$q_i^* = \sqrt{\frac{120 (\sum_{K=1}^4 o_{Ki}) (\sum_{K=1}^4 (h_{Ki} + s_{Ki}))}{(\sum_{K=1}^4 h_{Ki}) (\sum_{K=1}^4 s_{Ki})}} \quad (19)$$

$$q_{s,i}^* = \frac{\sum_{K=1}^4 h_{Ki}}{\sum_{K=1}^4 (h_{Ki} + s_{Ki})} \sqrt{\frac{120(\sum_{K=1}^4 o_{Ki})(\sum_{K=1}^4 (h_{Ki} + s_{Ki}))}{(\sum_{K=1}^4 h_{Ki})(\sum_{K=1}^4 s_{Ki})}} \quad (20)$$

By substituting the optimal shortage quantity $q_{s,i}^*$ back into the total cost function, the item-wise cost is expressed solely in terms of the order quantity q_i^* . This substitution eliminates the negative and quadratic shortage terms, reducing the total cost to a sum of a linear and an inverse term in q_i^* . The resulting expression is a posynomial in open form, satisfying the structural requirements of geometric programming.

$$TC_i^* = \sum_{i=1}^3 \left[\frac{D_i T_{TC_i}}{4(T_{TC_i} + I_{TC_i} + F_{TC_i})} \frac{(\sum_{K=1}^4 h_{Ki})(\sum_{K=1}^4 s_{Ki})}{120 \sum_{K=1}^4 (h_{Ki} + s_{Ki})} q_i + \frac{1}{q_i} \sum_{K=1}^4 o_{Ki} \right] \quad (21)$$

INVENTORY MODEL FOR OPTIMIZED FUZZY INTEGRATED EMERGENCY RELIEF ITEMS

After identifying the reduced total cost as a posynomial in the decision variable q_i , the problem is formulated as a standard unconstrained geometric programming minimization. The objective function consists of one linear and one inverse monomial term, satisfying the structural requirements of GP with $q_i > 0$. The corresponding dual formulation yields equal dual weights, confirming the existence of a unique global optimum.

$$TC_i^*(q_i) \quad (22)$$

$$C_{1i} q_i + C_{2i} q_i^{-1} \quad (23)$$

$$\underbrace{\frac{D_i T_{TC_i}}{4(T_{TC_i} + I_{TC_i} + F_{TC_i})} \frac{(\sum_{K=1}^4 h_{Ki})(\sum_{K=1}^4 s_{Ki})}{120 \sum_{K=1}^4 (h_{Ki} + s_{Ki})}}_{C_{1i}} q_i + \underbrace{\frac{D_i T_{TC_i}}{4(T_{TC_i} + I_{TC_i} + F_{TC_i})} \sum_{K=1}^4 o_{Ki}}_{C_{2i}} q_i^{-1} \quad (24)$$

To obtain the optimal solution, the geometric programming problem is formulated as a dual problem by associating a dual variable with each monomial in the primal objective function. The dual feasibility and normality conditions impose equality and balance constraints on these variables, guaranteeing convexity and global optimality.

Dual Feasibility Condition:

$$\delta_{1i} \rightarrow C_{1i} q_i \quad (25)$$

$$\delta_{2i} \rightarrow C_{2i} q_i^{-1} \quad (26)$$

Dual Constraints:

$$\delta_{1i} + \delta_{2i} = 1 \quad (27)$$

$$\delta_{1i} - \delta_{2i} = 0 \quad (28)$$

$$\text{Solving: } \delta_{1i} = \delta_{2i} = \frac{1}{2} \quad (29)$$

Geometric Programming Optimality Condition,

$$C_{1i} q_i = C_{2i} q_i^{-1} \quad (30)$$

$$q_i^* = \sqrt{\frac{120(\sum_{K=1}^4 o_{Ki})(\sum_{K=1}^4 (h_{Ki} + s_{Ki}))}{(\sum_{K=1}^4 h_{Ki})(\sum_{K=1}^4 s_{Ki})}} \quad (31)$$

$$q_{s,i}^* = \frac{\sum_{K=1}^4 h_{Ki}}{\sum_{K=1}^4 (h_{Ki} + s_{Ki})} \sqrt{\frac{120(\sum_{K=1}^4 o_{Ki})(\sum_{K=1}^4 (h_{Ki} + s_{Ki}))}{(\sum_{K=1}^4 h_{Ki})(\sum_{K=1}^4 s_{Ki})}} \quad (32)$$

At GP Optimum:

$$TC_i^{*min} = \sum_{i=1}^3 \left[\frac{D_i T_{TC_i}}{2(T_{TC_i} + I_{TC_i} + F_{TC_i})} \sqrt{\frac{(\sum_{K=1}^4 h_{Ki})(\sum_{K=1}^4 s_{Ki})(\sum_{K=1}^4 o_{Ki})}{120 \sum_{K=1}^4 (h_{Ki} + s_{Ki})}} \right] \quad (33)$$

After minimizing the total cost using geometric programming, the results indicate that the proposed neutrosophic EOQ model yields a unique, globally optimal solution under the given cyclone disaster constraints. The minimized total cost reflects an effective balance between holding cost, shortage penalty, and emergency ordering cost, ensuring reliable availability of critical relief items within the 60-hour response horizon.

NUMERICAL EXAMPLE

Real-World Description

A severe cyclone strikes a densely populated coastal region, disrupting transportation infrastructure, electricity supply, and local markets. Relief agencies must ensure the uninterrupted availability of essential items during the initial response window, where delays or shortages can result in significant humanitarian consequences. In this study, three critical relief items are considered:

1. Dry ration kits ($i = 1$)
2. Drinking water units ($i = 2$)
3. First aid kits ($i = 3$)

Demand and cost parameters are highly uncertain due to damaged infrastructure and fluctuating availability. Hence, neutrosophic trapezoidal fuzzy costs are used. The total demand for each item over the 60-hour horizon is assumed to be known based on early damage assessments and population exposure estimates.

Table 1: The input parameter table for each relief kit.

Item i	Demand (D_i)	Holding cost ($h_{1i}, h_{2i}, h_{3i}, h_{4i}$)	$\sum h_{Ki}$	Shortage penalty ($s_{1i}, s_{2i}, s_{3i}, s_{4i}$)	$\sum s_{Ki}$	Ordering Cost ($o_{1i}, o_{2i}, o_{3i}, o_{4i}$)	$\sum o_{Ki}$
1	3,000	(1.5, 2.0, 2.5, 3.0)	9	(6, 8, 10, 12)	36	(9,000, 10,000, 11,000, 12,000)	42,000
2	5,000	(1.0, 1.5, 2.0, 2.5)	7	(10, 12, 15, 18)	55	(11,000, 12,000, 13,000, 14,000)	50,000
3	1,500	(1.0, 1.5, 2.0, 2.5)	11	(10, 12, 15, 18)	81	(8,000, 9,000, 10,000, 11,000)	38,000

The membership functions Truth, Indeterminacy and Falsity values are taken as $T_{TC_i} = 0.6$, $I_{TC_i} = 0.25$, $F_{TC_i} = 0.15$.

Using the neutrosophic EOQ model optimized via geometric programming, the optimal order quantity, optimal shortage quantity, and the corresponding minimum total cost are computed for each relief item under cyclone conditions.

Table 2: The output parameter table for each relief kit.

Item i	Relief items	Optimal quantity ($q_{s,i}^*$)	Shortage	Optimal Order Quantity (q_i^*)	Minimized Total Cost (TC_i^{*min})
1	Dry ration kits	167 units		836 units	₹45,180
2	Drinking water units	111 units		982 units	₹76,290
3	First aid kits	82 units		686 units	₹24,920

SENSITIVITY ANALYSIS

Sensitivity analysis is conducted to examine the robustness of the neutrosophic EOQ model under variations in key cost and demand parameters

during cyclone disaster response. The analysis provides insights into how changes in shortage penalties and demand severity influence optimal ordering decisions and the corresponding minimum total cost for each relief item.

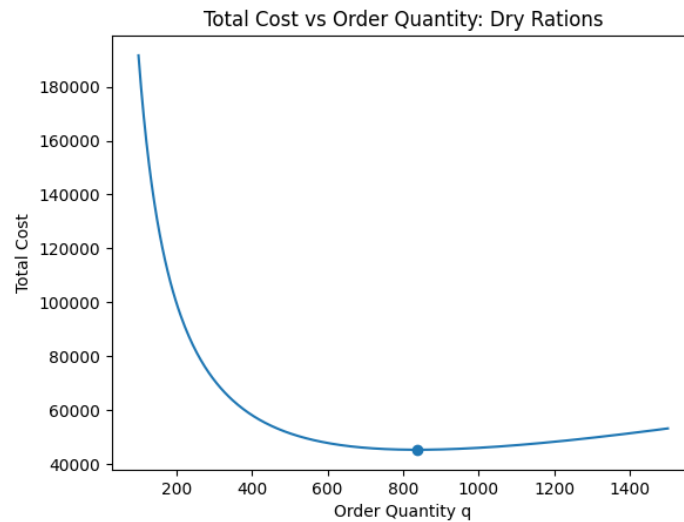


Figure 1: Total Cost vs EOQ for Dry Rations

Figure 1 shows the variation of total cost with respect to the order quantity for dry ration kits is illustrated to examine the trade-off between holding cost, shortage penalty, and emergency

ordering cost during the cyclone response period. The curve demonstrates a strictly convex behavior with a unique minimum corresponding to the optimal order quantity.

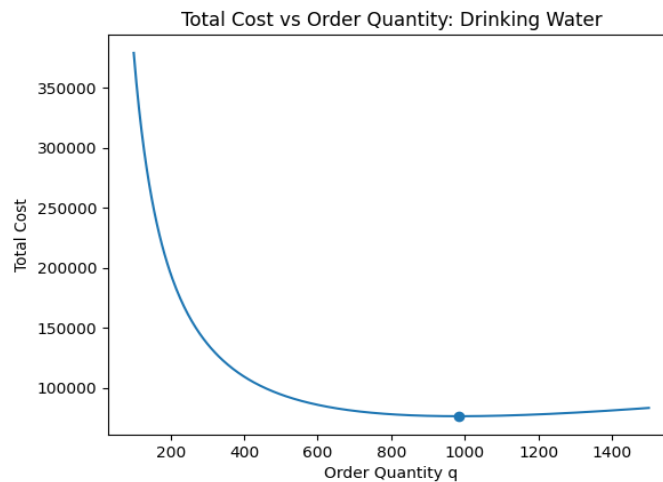


Figure 2: Total Cost vs EOQ for Drinking Water

Figure 2 presents the total cost versus order quantity relationship for drinking water is analyzed to capture the high sensitivity of life-critical supplies to shortage penalties under cyclone-induced uncertainty. The resulting

convex curve highlights a clearly defined minimum, indicating the globally optimal ordering policy derived through geometric programming.

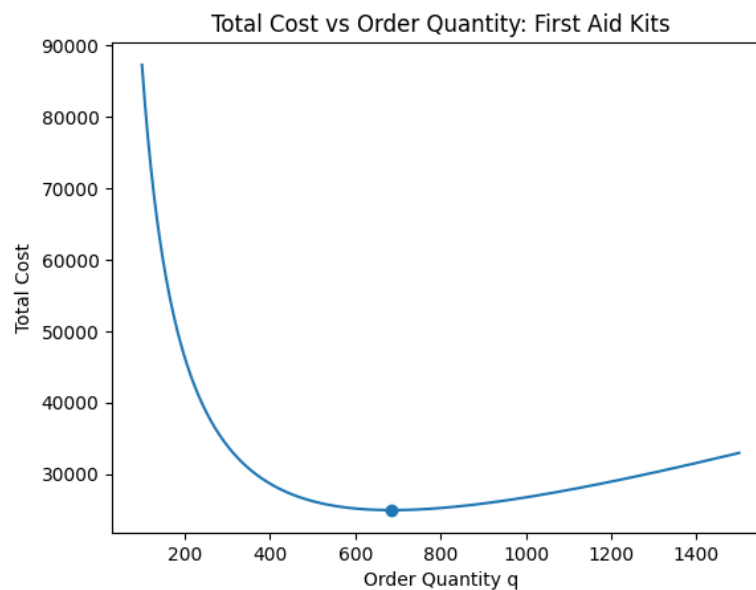


Figure 3: Total Cost vs EOQ for First Aid Kits

Figure 3 demonstrates the total cost variation with order quantity for first-aid kits to assess the impact of medical shortage penalties and storage limitations during emergency relief operations. The convex cost curve exhibits a distinct minimum, confirming the existence of an optimal order quantity that balances humanitarian risk and logistics cost.

CONCLUSION

This paper proposed a neutrosophic EOQ framework for managing relief inventory during cyclone disaster response under significant uncertainty. Holding cost, shortage penalty, and

ordering cost were modeled using neutrosophic trapezoidal fuzzy numbers and defuzzified through a weighted average approach. The resulting cost function was optimized using geometric programming, yielding closed-form solutions for the optimal order quantity, shortage quantity, and minimum total cost.

A numerical case study involving dry ration kits, drinking water, and first-aid kits over a 60-hour emergency horizon demonstrated the model's effectiveness. The results and sensitivity analyses highlighted the higher provisioning requirements and stricter shortage control for life-critical items such as drinking water and medical supplies. The

proposed approach provides a robust and analytically tractable decision-support tool for disaster management agencies, with scope for future extensions to multi-echelon systems and data-driven parameter estimation.

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