Revista Facultad de Ingeniería

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DOI: **10.17533/udea.redin.20240619**

To appear in: *Revista Facultad de Ingeniería Universidad de Antioquia*

Received: March 10, 2023
Accepted: June 11, 2024
Available Online: June 11, 2024



Please cite this article as: A. M. Paredes-Rodríguez, A. F. Toro-Pedroza, D. S. González-Tenorio and J. T. Martínez-Ávila. Stochastic linear programming model for the shelter's location in small Colombian cities, *Revista Facultad de Ingeniería Universidad de Antioquia*. [Online]. Available: https://www.doi.org/10.17533/udea.redin.20240619

# Stochastic linear programming model for the shelter's location in small Colombian cities

## Modelo de programación lineal estocástico para la localización de albergues en pequeñas ciudades colombianas

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**KEYWORDS**
Disaster relief; humanitarian assistance; optimization; decision making
Atención a desastres; asistencia humanitaria; optimización; toma de decisiones

**ABSTRACT:** This article addresses the problem of locating temporary shelters in small Colombian cities through the construction of a stochastic linear programming model that considers different scenarios where the affected population is a factor that generates uncertainty in the location of shelters and the respective flows in the humanitarian supply chain. The model is validated through the construction of a case study referring to the floods presented in a city in the center of the department of Valle del Cauca, which constantly causes the need to relocate the affected population, seeking to reduce attention times to the victims while considering restrictions associated with the budget available for emergency care. The generated proposal becomes a benchmark for the efficient management of shelters in similar disasters in small Colombian cities.

**RESUMEN:** En este artículo se aborda el problema de la localización de albergues temporales en pequeñas ciudades colombianas a través de la construcción de un modelo de programación lineal estocástico que considera distintos escenarios donde la población afectada es un factor que genera incertidumbre en la ubicación de los albergues y los respectivos flujos en la cadena de suministro humanitaria. El modelo es validado a través de la construcción de un caso de estudio referente a las inundaciones presentadas en una ciudad del centro del departamento del Valle del Cauca, lo que ocasiona constantemente la necesidad de reubicar la población afectada, buscando reducir los tiempos de atención a los damnificados al mismo tiempo que consideran restricciones asociadas al presupuesto disponible para la atención de las emergencias. La propuesta generada se convierte en un referente para la gestión eficiente de albergues en desastres similares que ocurran dentro de pequeñas ciudades colombianas

## 1. Introduction

In recent years, climate change has escalated damage and natural disasters affecting different regions worldwide. The International Federation of Red Cross and Red Crescent Societies (IFRC) defines a disaster as the occurrence of a hazardous event that severely affects members of an entire community, leading to various unfavorable life-threatening consequences and generating economic losses, exceeding its capacity to cope with such consequences using its own resources. [1]. Therefore, it is necessary for city administrations to establish strategies that mitigate the suffering of the population in the face of these emergencies.

Humanitarian supply chains have emerged as a strategy to reduce the suffering of populations affected by disasters [2]. These networks are responsible for the coordination, management, and planning of activities related to disaster response by controlling the flow of people, information, equipment, and materials. Currently, the management of humanitarian supply chains has a high degree of complexity due to a series of factors such as the unpredictability of the demand of victims, the environment with destabilized infrastructure characterized by limited access to roads or energy sources, time pressures and resource shortages [3], [4]. Despite the importance of humanitarian logistics, there is still little research on this type of issue in Latin America [5].

For this reason, [6] evaluate solutions to overcome the main barriers that arise in humanitarian supply chains; the study identifies 29 barriers and 20 solutions to overcome these drawbacks through a literature review and a brainstorming session held among experts. A fuzzy SWARA (Stepwise Weight Assessment Ratio Analysis) method is applied to calculate the weight of the barriers and evaluate their relative importance. The authors conclude that the solutions that provide the best results are long-term strategic planning for humanitarian operations, followed by collaboration, cooperation, and coordination by the actors in the humanitarian supply chain.

[7] carry out a multidimensional analysis of the literature, mainly from a scientific perspective, associated with the optimization of decisions in the context of humanitarian logistics. The authors found the need to integrate logistics decisions, including location and capacity, inventory management, distribution, routing, and fleet allocation, among other decisions, under a focus that is not exclusive to the mitigation or preparation, response, or recovery stages.

The main lines of research regarding humanitarian supply chains are framed within inventory management, demand, and capacity planning, location of shelters, and finally, activities related to transportation and distribution of resources [8]. However, the location of shelters is a strategic decision that influences the success of the response to the disaster and affects the safety of the victims [9].

Regions and countries face multiple natural disaster scenarios; for instance, floods are one of the most representative disasters in Colombia, mainly in the department of Valle del Cauca, due to the hydro-climatological and geographical conditions of the region. Currently, according to the Secretary of Risk and Disaster Management of Valle del Cauca, a total of 28 municipalities affected by this type of situation have been identified in this department. Due to this, the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM for its Spanish acronym) reported, in its most recent update, that the orange alert is maintained due to the level of the Cauca River.

This type of disaster frequently causes the deterioration of homes, making it necessary to transfer the population to temporary shelters to safeguard their lives. According to [10], over time, different refuge location models have been developed and tested for populations affected by natural disasters. However, there are still research gaps on the subject, like considering multi-disaster scenarios and systems that promote integrated disaster stage management [11]. This research aims to develop a model that supports decision making for the entity that manages risk and disaster management in a Colombian city.

The model is designed for a municipality situated in the central Valle del Cauca region, near the Cauca River. This geographic location is affected by a series of floods during periods of heavy regional rainfall. These floods impact the city's infrastructure and displace a significant number of families. Consequently, these families are compelled to evacuate their residences and relocate to temporary shelters for disaster response.

The primary challenge lies in the absence of a decision-support model for shelter location within the municipal administration. This deficiency frequently leads to the relocation of families to unsafe and remote areas with extended travel times. These relocations negatively impact the quality of care provided to the affected population and simultaneously contribute to elevated logistical costs associated with disaster response.

## 2. Literature review

In the context of natural disaster management and planning, the conceptualization and efficient design of temporary shelters is essential for preserving lives and mitigating adverse impacts. In this sense, a literature review was conducted in the Scopus database using keywords such as "location", "shelters", "disasters" and "models".

This study adopted the PRISMA protocol to guide the literature review process. Following this framework, key search terms were identified and incorporated into search equations used across relevant databases. Abstracts and conclusions of retrieved articles were then screened to refine the selection process and identify the most pertinent studies for inclusion. A selection of these key studies is presented below.

[12] analyze the shelter location decisions for the victims considering the assumption of the nearest shelter. The model was used for three North Carolina cities in the event of a Hurricane. The results of the study indicate that the choice of the closest shelter causes an imbalance between supply and demand of resources, and it is established that, in many cases, the second closest shelter is less than a mile away and helps to balance the use of resources. [13] propose a methodology for identifying the optimal location for temporary shelters during crisis events. The methodology leverages unmanned aerial vehicle (UAV) photography to calculate urban routing and assess facility accessibility, ultimately facilitating optimal shelter selection.

[14] present a two-part model for shelter location in response to various disaster scenarios within a mountainous village in India. The first stage focuses on risk assessment, employing the Random Forest algorithm and Google Earth data to generate a comprehensive risk map. The second stage leverages mathematical modeling to optimize shelter deployment. This model considers existing schools as potential shelters and residences as demand points for affected residents. Critically, the analysis reveals that the current shelter capacity is insufficient to accommodate all victims within a 60-minute timeframe, highlighting the need for improved disaster preparedness measures.

[15] propose a model for fixed shelter locations that specifically address the needs of an elderly population potentially affected by disasters. The model incorporates a set of parameters tailored to this demographic group. The model's efficacy is evaluated within a Chinese province, revealing that the current shelter capacity falls short of the anticipated demand from elderly disaster victims. This highlights the need for proactive measures by the city administration, such as promoting the construction of new shelters to ensure adequate emergency response capabilities.

[16] developed mathematical models to optimize the evacuation and sheltering of disaster victims, considering not only the costs of the operation but also those associated with psychological effects on the population due to the disaster. The developed model is tested in Wenchuan County, China, to evaluate different scenarios, find efficient solutions, and manage resources in disaster situations to minimize negative impacts on victims. [17] presents a multi-objective mathematical model for finding suitable locations for facilities such as hospitals, temporary care centers, shelters, and warehouses. The model considers population density, user suitability, road access, and site feasibility indices. The lexicographic method and GAMS software are used to solve the model and make informed decisions about the location of these facilities.

[9] propose a multi-objective programming model that seeks to determine the location of shelters reducing operating costs, the number of shelters needed, and the total travel time of the affected population. On the contrary, [10] established a multi-criteria decision model for the selection and spatial location of community or collective temporary shelters, with which they developed a management tool for these disasters in Brazil.

[18] present a bi-objective mathematical programming model that determines suitable locations for temporary medical care shelters, minimizing the logistical costs of the humanitarian relief operation while ensuring medical coverage of the affected population. In contrast, [19] propose a model for the optimal location of temporary shelters for the medical care of disaster victims, considering criteria such as patient severity, geographic location, and budget limitation.

[20] develop a mixed integer linear programming model to determine the pre-disaster location of storage areas for supplies needed to care for the affected population during an earthquake, considering uncertainty. The model minimizes three aspects simultaneously: the total expected distance, the risk of damage to the storage areas, and the cost of not caring for victims during the disaster. [1] establish that stochastic programming models must be incorporated into shelter location decisions to manage the uncertainty present in disasters. Based on this need [10], they developed a probabilistic programming model for the location of shelters in a case applied to Istanbul, Turkey.

[21] explores a multi-criteria decision-making approach for selecting and assigning emergency shelters. The approach leverages network analysis and incorporates various attributes into the selection process. These attributes include proximity to disaster zones, fire stations, hospitals, and major roads. The findings demonstrate that, within a consistent service delivery radius, simply increasing the number of shelters does not necessarily guarantee a higher level of service delivery.

In the Colombian context, efforts have been made to propose models to support the location of temporary shelters in disaster situations. [22] use a multi-criteria tool built from criteria defined by experts to identify suitable areas for the location of shelters in disaster situations. Besides, [23] evaluate the suitability of various public infrastructures that serve as shelters, building an indicator that can be used in future research.

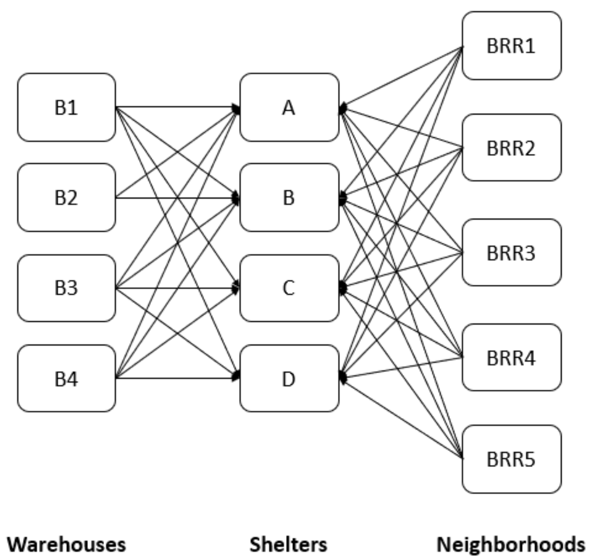
On the contrary, in the present investigation, a stochastic linear programming model is proposed that reduces the attention time to the victims, considering budget restrictions, which are common limitations in small cities of developing countries. The developed model is tested in a city in the Valle del Cauca department, where it is possible to find a solution that guarantees a window of attention to the victims by determining the opening of the temporary shelters considered and establishing the flow of food and families from each one of the affected areas.

## 3. Mathematical model

In the explored literature, various documents have addressed the problem of locating shelters in disaster scenarios [1], [9], [10], [24], [25]. However, the developed mathematical model establishes a configuration of a humanitarian supply chain for victims of a flood disaster in a small Colombian city in the presence of uncertainty about the affected population.

**Figure 1** shows the links to the proposed network, within the neighborhoods in which the affected families reside, a set of response kit warehouses ready to respond to the emergency, and the potential sites where the shelters can be temporarily located. It is necessary to consider that in this supply chain, both the family and the food flow to the shelters to provide timely care and reduce the suffering of the victims.

**Figure 1.** Supply chain scheme for the care of victims in a disaster situation in a small Colombian city




The constructed mathematical model considers the following assumptions:

• The demand of victims is uncertain. Various factors contribute to the uncertainty of demand, including the type of disaster, the severity of the event, the population affected, and the availability of resources. The construction of three scenarios, pessimistic, most probable, and optimistic, is used to validate the effect of this parameter on the configuration of the network.
• The decisions considered by the model are related to the opening of temporary shelters and the flow of kits and the affected population towards the shelters.
• Temporary shelters have a fixed capacity to serve a specific number of families. To quantify this parameter, the potential shelter capacity within a predefined set of safe locations was approximated. This estimation considered the available floor area at each site and adhered to the minimum space requirements and shelter standards established by the International Red Cross and Red Crescent Movement for sheltering displaced populations and managing non-food items. Shelter capacity constitutes a critical parameter within the model as it directly ensures the ability to accommodate and care for the affected population, thereby mitigating their suffering during disaster events. The model is not required to transfer the entire affected population; however, it penalizes not transferring an affected family to the shelter.

• Warehouses that house kits have an initial inventory; however, supply decisions are not considered.
• Shelters can receive the number of kits sent from the warehouses
• A transportation cost associated with moving vehicles with kits and families to the temporary shelter is considered. Transportation costs are determined by considering the capacity and type of vehicles employed, the travel distance, and prevailing road conditions. This cost element represents a significant factor within disaster response operations and directly impacts the budgetary allocation.
• There is a limited budget for disaster response operations, which limits the decisions to open shelters and flow in the network. Disaster response operations are financed through a combination of governmental and non-governmental funding sources. However, due to budgetary constraints, this parameter directly influences the selection of temporary shelters and logistical decisions concerning resource and evacuee movement through the network.
• The number of trips between the network nodes depends on the number of families and kits to be transported.
The elements considered within the mathematical model are detailed below.

**Sets**

$B = Warehouses\ i: 1 \dots n$
$BR = Neighborhoods\ j: 1 \dots m$
$V = Kits\ k: 1 \dots o$
$R = Shelters\ s: 1 \dots l$
$E = Scenarios\ e: 1 \dots p$

**Parameters**

$CV = Number\ of\ kits\ required\ per\ family$
$CT = Volume\ of\ the\ truck\ to\ transport\ kits$
$PD = Vehicle's\ capacity$
$N = Number\ of\ simulated\ scenarios$
$PR = Budget\ for\ disaster\ response$
$CNA = Cost\ of\ no\ attending\ a\ family$
$DT_{je} = affected\ families\ in\ a\ neighborhood\ j\ in\ escenarios\ e$
$TC_{js} = Transportation\ cost\ of\ a\ vehicle\ between\ neighboord\ j\ and\ shelter\ s$
$CBR_{is} = Transportation\ cost\ of\ a\ vehicle\ from\ warehouse\ i\ to\ shelter\ s$
$TA_{js} = Travel\ time\ between\ neighborhood\ j\ and\ shelter\ s$

$VM_k = Volume\ of\ the\ kit\ k$
$DV_{ki} = Availability\ of\ kit\ k\ in\ warehouse\ i$
$CR_s = Accommodation\ capacity\ of\ a\ shelter\ s$
$CA_s = Cost\ of\ opening\ the\ shelter\ s$

**Variables**

$P_{kise} = Quantity\ of\ kits\ k\ to\ be\ transferred\ from\ warehouse\ i\ to\ shelter\ s\ in\ scenario\ e$
$L_{jse} = Number\ of\ affected\ families\ to\ be\ transported\ from\ neighborhood\ j\ to\ shelter\ s\ in\ scenario\ e$
$M_{ise} = Trips\ made\ from\ warehouse\ i\ to\ shelter\ s\ in\ scenario\ e$
$V_{ise} = Trips\ made\ from\ neighborhood\ j\ to\ shelter\ s\ in\ scenario\ e$
$X_{je} = Number\ of\ affected\ families\ from\ neighborhood\ j\ that\ are\ not\ transferred\ to\ scenario\ e$
$W_{se} = 1\ if\ shelter\ s\ is\ opened\ in\ scenario\ e\ and\ 0\ otherwise$

**Objective Function**

**Equation 1** presents the objective function of the proposed linear programming model, which is intended to reduce the average transfer time of affected families to shelters, considering the three defined scenarios, taking into account the SAA (Sample Average Approximation) method. , which is used to solve stochastic programming models [26].

$$Min\ Z = \frac{1}{N} * \sum_{j,s,e} TA_{js} * V_{jse} \quad (1)$$

**Constraints**

As can be seen in **Equation 2**, the number of trips made by trucks between the kit warehouses and the shelters directly depends on the number of kits to be transported, the volume of each kit, and the capacity of the vehicle.

$$\sum_k VM_k * P_{kise} \leq CT * M_{ise} \quad \forall i,s,e \quad (2)$$

The total number of families affected in the neighborhoods can be transferred to a temporary shelter or remain at the disaster site (see **Equation 3**).

$$\sum_s L_{jse} + X_{je} = DT_{je} \qquad \forall j, e \qquad (3)$$

**Equation 4** guarantees that the number of trips made between the neighborhoods and the shelters depends on the flow of families to be transferred and the capacity of the vehicle.

$$V_{jse} \geq \frac{1}{PD} * L_{jse} \quad \forall j, s, e \qquad (4)$$

The survival kits sent to the shelters cannot exceed the availability in the warehouses (see **Equation 5**). Likewise, the number of kits sent to each shelter depends on the number of families that have been transferred and the consumption per family of the kits (see **Equation 6**).

$$\sum_s P_{kise} \leq DV_{ki} \qquad \forall k, i, e \qquad (5)$$

$$\sum_i P_{kise} \geq \sum_j CV_k * L_{jse} \quad \forall k, s, e \qquad (6)$$

The number of families sent to each shelter is directly related to whether the shelter has been opened and depends on its installed capacity (see **Equation 7**).

$$\sum_j L_{jse} \leq CR_s * W_{se} \qquad \forall s, e \qquad (7)$$

As seen in **Equation 8**, the cost of moving kits and families, added to the cost of opening the shelters and the cost of penalties for not caring for families, must not exceed the budget allocated for the disaster response.

$$\sum_{j,s} TC_{js} * V_{jse} + \sum_{i,s} CBR_{is} * M_{ise} + \sum_s CA_s * W_{se} + \sum_j CNA * X_{je} \leq PR \quad \forall e \qquad (8)$$

Finally, in **Equations 9,10,11,12, 13, and 14,** the obvious restrictions of the model are presented.

$$P_{kise} \geq 0 \qquad (9)$$
$$L_{jse} \geq 0 \qquad (10)$$
$$M_{ise} \geq 0 \qquad (11)$$
$$V_{jse} \geq 0 \qquad (12)$$
$$X_{je} \geq 0 \qquad (13)$$
$$W_{se} \in \{0,1\} \qquad (14)$$

## 4. Results

### 4.1.Generation and collection of model input data

In this research, a case study is built from the information shared by the risk secretary of the Colombian city's municipal administration. The constructed model considers a predefined set of temporary shelters of the community type, i.e., infrastructures already built, such as schools, stadiums, coliseums, and churches, among others [27]. The case study initially considers 4 shelters (A, B, C, D) that can be used for disaster relief; at the same time, 4 warehouses are defined (B1,B2,B3,B4) for the supply of 3 kits (K1: food, K2: blanket, and K3: cleaning) and 5 neighborhoods (BRR1, BRR2, BRR3, BRR4, BRR5), which are historically the most affected by floods in the small city under study.

All data used for the model can be found in Appendix 1. For the definition of travel times between warehouses, shelters, and neighborhoods, the Google Maps app was used, where values were increased by 25%, considering that in disruptive scenarios, travel times within the city are longer due to the deterioration of roads due to the disaster. In this research, Sample Average Approximation (SAA) is applied, considering that the scenarios constructed are identically distributed.

Demand data for each scenario considered were estimated through the collection of records of the number of families affected during the period 2018 - 2022, which was granted by the risk management secretariat, together with the budget used for victim assistance.

### 4.2.Description of computational environment

The model was formulated under the AMPL programming language and was run on a 10th-generation Intel Core i5 computer with 4GB RAM. The model manages to find an optimal solution in a solution time of less than 1 minute, guaranteeing its scalability to larger instances.

### 4.3.Description of the experiment and analysis of the results

The objective function of the proposed model yields a result of 17,216 minutes on average for the care and transportation of affected families during the three scenarios considered.

Regarding the result of the variables, the model opens shelters A, C, and D in all the proposed scenarios and only sees the need to open shelter B in the scenario where there is a more significant number of affected families.

In scenario 1, in which the lowest number of affected families is observed according to historical records of floods in the small Colombian city, 12 trips are made from warehouse B2 to Shelter A, 18 and 15 trips from Warehouse B3 to Shelter C and D, respectively. The detail of the number of survival kits sent is presented in **Table 1**

**Table 1.** Number of kits sent to shelters in scenario 1

| | **K1 – K3** | | | **K2** | | |
|---|---|---|---|---|---|---|
| | A | C | D | A | C | D |
| **B2** | 328 | 0 | 0 | 656 | | |
| **B3** | 0 | 505 | 410 | | 1010 | 820 |

**Table 2** shows the number of trips made between the neighborhoods and open shelters in scenario 1, which highlights the fact that Shelter A serves families from Neighborhoods 1 and 2; while Shelter D provides care to the victims of Neighborhood 3 and finally, C receives the affected population of Neighborhoods 4 and 5.

**Table 2.** Number of trips made between neighborhoods and shelters in Scenario 1

| | **A** | **C** | **D** |
|---|---|---|---|
| **BRR1** | 24 | 0 | 0 |
| **BRR2** | 42 | 0 | 0 |
| **BRR3** | 0 | 0 | 82 |
| **BRR4** | 0 | 26 | 0 |
| **BRR5** | 0 | 75 | 0 |

Regarding the results of Scenario 2, where the data of the victims that have most frequently occurred in the city under study is used, the model proposes that three supply warehouses be used to guarantee the delivery of survival kits to the shelters. (See **Table 3**), for which 21 trips were made from Warehouse B2 to Shelter A, and the same number of trips between Warehouse B3 and Shelters C and D, respectively. Finally, the need to make two trips between warehouse B4 and Shelter D is established.

**Table 3.** Number of kits sent to shelters in scenario 2

| | **K1 – K3** | | | **K2** | | |
|---|---|---|---|---|---|---|
| | A | C | D | A | C | D |
| **B2** | 580 | 0 | 0 | 1160 | 0 | 0 |
| **B3** | 0 | 590 | 610 | 0 | 1180 | 1220 |
| **B4** | 0 | 0 | 250 | 0 | 0 | 0 |

The number of trips between the neighborhoods and the shelters increases in Scenario 2, derived from the increase in affected families (See **Table 4**).

**Table 4.** Number of trips made between neighborhoods and shelters in Scenario 2

| | A | C | D |
|---|---|---|---|
| **BRR1** | 60 | 0 | 0 |
| **BRR2** | 56 | 0 | 0 |
| **BRR3** | 0 | 0 | 112 |
| **BRR4** | 0 | 35 | 0 |
| **BRR5** | 0 | 83 | 10 |

Finally, the results for Scenario 3 are shown, for which the number of victims increases compared to the two scenarios described above. In this scenario, the 4 potential shelters are opened, where 1 trip is made from Warehouse B1 to Shelter B, from warehouse B2, 21 trips are made to Shelter A and 1 trip to Shelter D; Starting from the Warehouse B3, the C and D shelters were visited 21 and 23 times, respectively. Finally, 23 trips are made between Warehouse B4 to Shelter B and 1 trip to Shelter D. **Table 5** details the number of kits sent between each warehouse and shelter.

**Table 5.** Number of kits sent to shelters in scenario 3

| | **K1 – K3** | | | | **K2** | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | A | B | C | D |
| **B1** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **B2** | 580 | 0 | 0 | 169 | 1160 | 0 | 0 | 0 |
| **B3** | 0 | 0 | 590 | 700 | 0 | 0 | 1180 | 1400 |
| **B4** | 0 | 629 | 0 | 171 | 0 | 1257 | 0 | 0 |

## 5. Conclusions

The mathematical model proposal reduces the attention time of the population affected by a flood disaster in a small Colombian city, thus contributing to the improvement of the response phase of the local administration, while reducing the suffering of the affected families.

As an innovative element of the proposed model, the consideration of three scenarios where there is a variation of the population to be served is proposed, with the aim of building a robust proposal for the location of shelters that serves as support for disaster risk management in the city under study. Besides, the authors expect that the mathematical model for shelter locations positively influences the effectiveness and efficiency needed to manage different decisions in disaster situations.

The model developed in this article becomes an input for decision-making process regarding the location of shelters and the mobilization of affected families and survival kits in scenarios where randomness in the affected population is considered.

Although the problem of locating shelters has been addressed in the literature, there are no references that have managed to apply a disaster management methodology considering the context of small cities located in developing countries. In contrast, randomness is considered in the generation of affected families.

This paper presents a novel model for disaster shelter siting tailored explicitly to the context of small cities.  In contrast to traditional models designed for large-scale disasters in expansive regions, the proposed model incorporates factors unique to smaller urban environments. These factors include shorter travel distances, stronger community ties, and limitations in logistical infrastructure.

In future research, the construction of a stochastic multi-objective model must be proposed, where not only is service time measured as a critical indicator of the process, but other elements of interest can be considered, such as service time in the shelter, disruptions in the roads access, among other elements that humanitarian logistics pose as challenges. Besides, research can also be conducted using sensitivity analysis to gauge the model's robustness under different disaster conditions and resource levels which will elucidate its reliability and effectiveness.

Furthermore, this model presents a promising avenue for future research. Its adaptability to various disaster types and urban contexts suggests its potential as a roadmap for advancements in disaster management, particularly within small cities. These cities often face significant challenges, such as limited resources and difficulty in accessing transparent and accurate data to support informed decision-making processes during disaster scenarios.

## 6. Declaration of competing interest

We declare that we have no significant competing interests including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

## 7. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

## 8. Author contributions

Andrés Mauricio Paredes-Rodríguez: Development of a mathematical model, analysis of results, writing - final draft preparation, validation.

Andrés Felipe Toro Pedroza: Conceptualization, methodology, literature review.

Diana Sofía González Toro: Conceptualization, methodology, literature review.

Jennifer Tatiana Martínez Avila: Conceptualization, methodology, literature review.

## 9. Data availability statement

The data that supports the application of the model was obtained from the databases of the risk management secretary of the city under study and is available in its internal databases. Appendix 1 show data used for mathematical model.

**Appendix 1**

| General parameters | Value |
|---|---|
| CT: Truck Volume | 2.000 |
| PD: Bus capacity (in families) | 5 |
| N: Number of scenarios | 3 |
| PR: Budget | 50.000.000 |
| CNA: Cost of not attending family | 150.000 |

| Kit | CV: Number of kits required per family | VM: Kit size |
|---|---|---|
| K1 | 1 | 10 |
| K2 | 2 | 25 |
| K3 | 1 | 11 |

| Shelter | CR: capacity | CA: Opening Cost |
|---|---|---|
| A | 580 | 1.120.000 |
| B | 650 | 1.350.000 |
| C | 590 | 1.550.000 |
| D | 700 | 1.300.000 |

| DT: Demand for scenario | 1 | 2 | 3 |
|---|---|---|---|
| **BRR1** | 345 | 420 | 480 |

| | | | |
|---|---|---|---|
| **BRR2** | 210 | 280 | 345 |
| **BRR3** | 412 | 560 | 710 |
| **BRR4** | 130 | 245 | 435 |
| **BRR5** | 375 | 465 | 650 |

| **DV: Kits inventory for warehouse** | **K1** | **K2** | **K3** |
|---|---|---|---|
| **B1** | 2480 | 2800 | 700 |
| **B2** | 1005 | 3400 | 1050 |
| **B3** | 1500 | 3100 | 950 |
| **B4** | 1100 | 3800 | 800 |

| **TA: Travel Time** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| **BRR1** | 50 | 60 | 180 | 100 |
| **BRR2** | 40 | 50 | 120 | 70 |
| **BRR3** | 100 | 130 | 110 | 40 |
| **BRR4** | 100 | 100 | 50 | 70 |
| **BRR5** | 80 | 75 | 45 | 55 |

| **TC: Transport Cost (families)** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| **BRR1** | 50.000 | 60.000 | 80.000 | 80.000 |
| **BRR2** | 40.000 | 50.000 | 80.000 | 70.000 |
| **BRR3** | 80.000 | 80.000 | 80.000 | 40.000 |
| **BRR4** | 80.000 | 80.000 | 50.000 | 70.000 |
| **BRR5** | 80.000 | 75.000 | 45.000 | 55.000 |

| **CBR: Transport cost (kits)** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| **B1** | 20.000 | 14.000 | 45.000 | 40.000 |
| **B2** | 15.000 | 45.000 | 25.000 | 35.000 |

| | | | | |
|---|---|---|---|---|
| **B3** | 25.000 | 35.000 | 10.000 | 25.000 |
| **B4** | 42.000 | 10.000 | 35.000 | 35.000 |

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