Model for location of temporary shelters and routing of specialized personnel for assisting vulnerable population in case sudden natural disasters

Modelo de localización de albergues temporales y ruteo de personal especializado para la atención de población vulnerable ante un desastre natural súbito

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***Abstract*— Natural disasters have long affected populations worldwide, resulting in significant consequences for both people and their environments. Most disasters occur suddenly, and several studies have highlighted logistical weaknesses in both the prevention and response to such events. In Colombia, flooding is the leading cause of death from hydrometeorological phenomena. Based on this context, the present research proposes a mixed-integer linear programming model for the location of temporary relief centers and the routing of specialized personnel. These decisions were addressed in two phases. In the first phase, the location of temporary shelters was determined, considering designated safe zones as candidate sites. In the second phase, route planning for specialized personnel was carried out, using a local distribution center as a reference point. The results indicate that addressing both decision-making processes and their interrelation contributes to minimizing response times for vulnerable populations.**

***Index Terms*— Aid distribution, Humanitarian logistics, Location of shelters, Mixed integer linear programming, Natural disasters.**

***Resumen*— Los desastres naturales han afectado a la población mundial, provocando consecuencias relevantes para las personas y su entorno. La mayoría de los desastres ocurren repentinamente, por lo que varios estudios han detectado deficiencias logísticas en el momento de prevenir y afrontar estos casos. En Colombia, las inundaciones son la principal causa de muertes por fenómenos hidrometeorológicos. Con base en lo anterior, la presente investigación propone un modelo de programación lineal entera mixta para la localización de albergues temporales y enrutamiento de personal especializado. Estas decisiones se abordaron en dos fases. En la primera fase se estableció la localización de albergues temporales considerando como sitios candidatos las zonas seguras destinadas para el emplazamiento de estas instalaciones. Los albergues seleccionados, permitió establecer en la segunda fase la configuración de rutas del personal especializado, considerando un centro local de distribución. Como resultado obtenido se pudo establecer que abordar ambos esquemas de decisión y su interrelación, contribuye a la minimización de los tiempos de respuesta a la población vulnerable.**

***Palabras claves*— Desastres naturales, Distribución de ayuda, Localización de albergues, Logística humanitaria, Programación Lineal Entera Mixta.**

I. INTRODUCTION

A natural disaster is defined as a phenomenon caused by nature, influenced by human activity. In 2011, there were more than 30,000 fatal victims, and 245 million people affected worldwide. This caused economic losses estimated at 386 trillion dollars, due to various disasters. In Colombia, 28 thousand events have been recorded in the last 40 years, 60% of which happened between 1990 and 2011; damage costs amounted to 623 billion dollars for the 2010-2011 winter season [1]. This shows that there has been an increase in the occurrence of disasters, which directly and indirectly affect the population and their environment.

From an engineering point of view, the most important challenge concerning humanitarian logistics is coordinating logistics activities [2] and managing resources in chaotic environments together with the uncertainty of emergency situations, which is a complex logistical task [1].

In Colombia, according to the National Risk and Disaster Management Unit, some of the most common disasters include floods, earthquakes, and landslides. These events have a negative effect on communities, and cause infrastructure damage and endanger human lives.

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Table 1 shows the distribution of these disasters that occurred in Colombia between 1906 and 2019. This also shows that floods, landslides, and earthquakes have the highest accumulated percentage of occurrences, totaling 81.77%.

TABLE I
DISTRIBUTION OF EVENTS IN COLOMBIA (1906-2019).

Type of Natural Disaster	Absolute Frequency (# events)	Relative Frequency	Accumulated Relative Frequency	Total frequency affected (# persons)	Total deaths (# persons)	Total damages (thousands of dollars)
Flooding	86	44.79%	44.79%	16.356,3	3.585	3.591,353
Landslide	43	22.40%	67.19%	76.082	3.460	102.400
Earthquake	28	14.58%	81.77%	1.460,39	3.972	2.318,666
Volcanic activity	11	5.73%	87.50%	56.964	22,826	1,000,000
Storm	9	4.69%	92.19%	140.415	49	53.050
Epidemic	6	3.13%	95.31%	121.194	672	0
Forest fire	3	1.56%	96.88%	200	31	0
Mass movement (dry)	3	1.56%	98.44%	2.411	247	0
Drougth	2	1.04%	99.48%	100.000	0	0
Insect infestation	1	0.52%	100%	0	0	104.000
Total	192	100%		18,314,58	34,842	7.169,469

Source: UNGRD

The most significant type of disaster is flooding, which occurs due to heavy or sudden rainfall, causing the rising and overflowing of rivers. These events happen abruptly and, in many cases, are difficult to control, causing material losses and affecting people's health. This may cause the loss of human lives. During a flood, the current of rivers often carries everything in its path such as animals, trees, rocks, and various debris.

Since floods are difficult to be controlled, in necessary to have a contingency plan for efficient and timely post-disaster response. To achieve this purpose, it is important to know the affected area and its limitations. Help centers and resource distribution centers should be strategically located, and trained personnel efficiently deployed so that they can respond to emergencies of this nature.

To fulfill this purpose, it is necessary to go to a branch of logistics that is responsible for providing timely aid to populations that may be affected before, during and after a disaster. This branch is called Humanitarian Logistics, which have the same fundamental principles logistics: planning, implementing and controlling the flow of information, resources or personnel from a point of origin to a destination. While logistics aims to meet customer needs, humanitarian logistics aims to alleviate the suffering of affected populations in a timely manner.

Based on this, this project aims to develop a mixed-integer linear programming model whose objective is to minimize response time for victims by optimizing the distribution of resources between relief centers and temporary shelters. Specialized personnel are also present to provide timely assistance to victims in a municipality of the Valle del Cauca department, Colombia. Thus, a diagnosis of the area will be conducted to assess the effects of natural disasters and identify the most relevant dangers, which will be the bases for formulating the mathematical model.

II. LITERATURE REVIEW

Humanitarian logistics according to [3] is the process of planning, implementing and efficiently controlling the flow of products, materials and information from individuals and donor organizations to victims, so that their survival needs are met. Humanitarian logistics emerged as a response to the increase of natural disasters worldwide, which have affected some populations. According to data from the International Strategy Program for Disaster Reduction (ISDR), in 2004, there were 305 natural disasters in the world. As these natural disasters continue to increase, and consequently the survival needs of affected populations increase as well. Populations affected by these adversities face such multiple problems as inadequate shelter, lack of food, limited access to medical care, insufficient drug supply and the need for psychological support, particularly in cases of family loss. [4].

The authors [4] identify the challenges facing humanitarian logistics today are increasing, and they are much more complex; these issues are the speed aid of delivery, the movement of affected populations in conflict areas, the influence of humanitarian teams, deficiencies in ONG`s capabilities, lack of knowledge, limited investment in technology and communication.

Humanitarian logistics is generally divided into three stages, which are aligned with the well-known traditional risk management model: pre-disaster, during the disaster, and post-disaster. These stages have several subcategories [5]. These are shown in Fig.1.

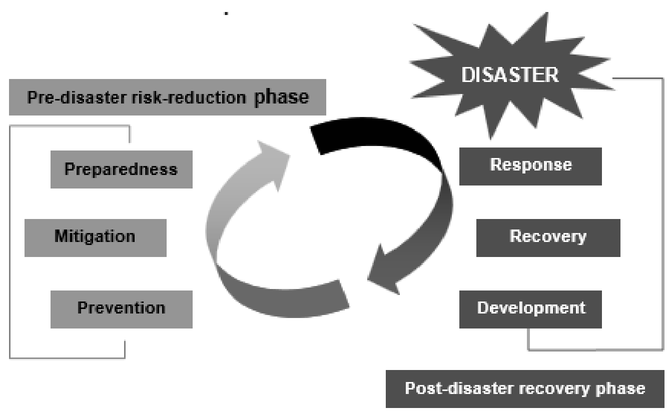

Fig. 1. Traditional Risk Management Model Source: Adapted of [5]

Authors such as [6] state that in natural disasters such as floods, the affected population is partially isolated and vulnerable. Research in Colombia highlights the importance of providing timely post-disaster support. According to IFRC (2010), cited by [7], such "organizations as the Red Cross in Colombia play an important role in developing training programs for both the population and institutions: These organizations have also established a series of protocols and guidelines to effectively manage crisis situations".

The post-disaster situation occurs in an environment characterized by uncertainty regarding aid resources and shelters for victims. The latter is critical, since many houses are damaged or destroyed. Therefore, families are forced to seek alternative accommodation until a permanent housing solution can be found [8].

Regarding humanitarian logistics [9], this presents a qualitative analysis of inventory management strategies in the humanitarian logistics operations. They state that, each year, many natural and human-induced disasters affect thousands of people around the world. During these disasters, both government agencies and humanitarian organizations face logistical challenges; their main objective is to meet the needs of affected people and alleviate their suffering. To achieve this, an effective inventory management strategy plays a crucial role at every stage of the supply chain.

In terms of routing trained personnel and vehicles for the care of vulnerable populations, some authors have researched this topic, including:

In the emergency logistics planning, natural disaster [10] pose one of the most common problems in logistics: the Vehicle Routing Problem (VRP), which involves a set of clients (each represented as a destination node) that must be served by *m* identical vehicles located at a warehouse. Each vehicle is to return to the depot after completing its route, and its load cannot exceed its capacity at any point of the trip. Additionally, each client can be visited only once, and it is assumed that the vehicle's carrying capacity exceeds the demand of any individual client. Thus, the main objective is to minimize the total distance traveled on each route.

According to [11], specialized literature has enough information on the application of metaheuristics in route planning route. However, most research in this field have been conducted under normal conditions (e.g., standard weather conditions). The problem of route planning for repairing electrical faults can be basically modeled Capacitated Multiple Traveling Salesman Problem (CMPS)**,** due to some significant similarities with this well-known variant of the theoretical VRP. These similarities are related to the dispatching of a homogeneous fleet of vehicles (with repair technicians deployed in vulnerable areas), where each vehicle is assigned a set of nodes (affected areas) similar to MTSP (Multi-Traveling Salesman Problem). Each node is once visited by a single vehicle (or salesman).

Other authors as [12] have developed a structured plan for distributing humanitarian aid through vehicle routing in the event of a major earthquake in Lima Metropolitan and Callao. They use the Great Route method together with Linear Programming, as this minimizes the actual distance traveled and reduces transportation costs. The number of victims was also considered to optimize the allocation of resources and supplies to be used for each trip by the terrestrial vehicular fleet.

In the work of [13], a bi-level optimization model is presented for sending, receiving and distributing in-kind assistance after a natural disaster has occurred. This aims to determine the optimal configuration of shipments and the most efficient distribution method for delivering supplies affected areas through various transportation modes.

A key issue in humanitarian logistics, widely recognized by researchers, is the strategic location of temporary relief or facilities to provide timely resources and specialized assistance in affected areas.

Concerning this issue, [14] propose an approach to the problem of locating temporary relief facilities for households affected by severe natural disasters. They characterize both the demand and supply of temporary relief, identifying high-risk areas based on the type of disaster that may occur. The model's performance function seeks to minimize the weighted distances between temporary relief facilities and affected households, considering constraints such as ensuring full demand from each household type, facility capacity limitations, and the maximum number of temporary shelters that can be built.

Similarly, author [15] propose a bi-criteria model for the location of temporary relief centers. This model includes the design an evacuation plan to support and ensure the safety of the affected population in case of a flood. This includes the opening of a temporary relief and distribution centers, pre-positioning of aid package inventories, and the assignment of individuals to temporary shelters and evacuation routes.

Some of the optimization models in humanitarian logistics used for facility location, which is the focus of this research, include deterministic single-objective modes developed by [16-19], and stochastic models developed by [20-22], among others.

Based on the analyses of previous studies, it is necessary to analyze the interrelationship between decisions related to the location of distribution points and temporary shelters, and the distribution of humanitarian aid. This analysis is to consider limitations in the availability and capacity of humanitarian assistance or support units in affected areas.

Unlike the reviewed literature on humanitarian logistics this research considers the following:

- ✓ A mathematical formulation with hierarchical approach that allows integrating decisions on the location of temporary relief centers and the routing of specialized personnel.
- ✓ The allocation of temporary shelters and assignment of homeless individuals to the temporary shelters.
- ✓ Supplies allocation according to the number of victims assisted by open temporary shelters
- ✓ The routing of specialized personnel and their assignment to open temporary shelters
- ✓ Capacity constraints in temporary shelters and limitations in specialized personnel availability.

Therefore, this research proposes a two-level mode. The first level aims to determine the optimal location of a distribution point and temporary shelters to assist populations that have been affected by a sudden natural disaster. The second level has to do with decisions on the distribution of humanitarian aid in the last-mile by considering limited resources and capacity issues in care units.

III. METHODOLOGY

A review of the literature on location and routing models will be conducted by various authors who have addressed these topics related to natural disasters. This review will be of great help as a basis for developing mathematical models to achieve an optimal post-disaster solution Fig. 2.

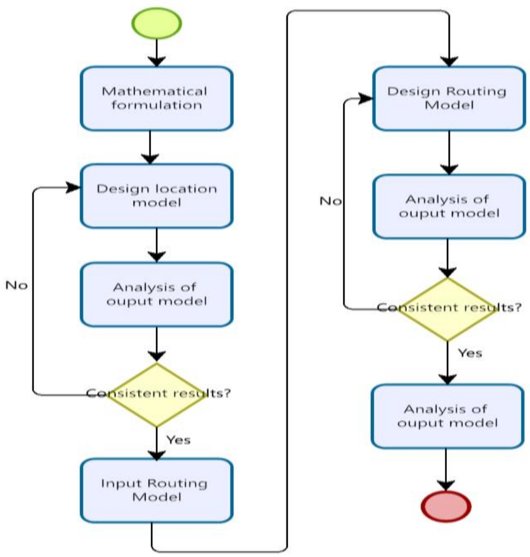

Fig. 2. Description of Methodology. Source: Authors

The formulation of mathematical models will be presented, defining input parameters, decision variables, the objective function, and constraints. These models are validated through a case study to determine whether the results are aligned with real-world contexts.

The methodology is structured in two phases. First, the location model is solved by using information provided by the case study; thus, output variables are obtained, which serve as input parameters for the routing model following a hierarchical approach. This produces output variables or model results that are to be analyzed to verify if they meet the objectives of each component. Finally, conclusions are reached based on these findings.

A. Model of location for temporary relief centers

This location model is a mathematical model formulated as a mixed-integer linear programming (MILP), which has been designed to determine the best location of a distribution center and different temporary relief centers. This done to minimize travel time for delivering supplies from the distribution center to temporary shelters, ensuring timely assistance to vulnerable populations.

Assumptions.

- The municipality in this study case lacks specialized and adequate infrastructure for establishing temporary relief centers during a flood disaster. Therefore, some educational facilities in both urban and rural areas are used instead.
- The areas affected and requiring evacuation due to such disasters are known with certainty.
- The victims are not relocated to the homes of relatives, friends or neighbors.
- Victims arrive at the assigned temporary relief.
- Supplies include temporary kits (including a pillow, mat and blanket), which is required by each victim.
- It is assumed that each victim uses only one kit.
- The kits are donated and managed by national and departmental institutions.
- The kits are pre-positioned at the Distribution Center.
- Travel times and number of victims are considered deterministic.

Main Sets

- CNS: *set of secure nodes in the region*
- CD: *subset safe nodes CNS secure zones for the*
- *installation of the distribution center indexed by i*
- CA: *subset of secure nodes CNS secure zones for*
- *the installation of temporary relief indexed by j*
- CV: *set of flooded areas of the region where they are*
- *the victims indexed by k*

Parameters

- $TIEMPCV_{kj}$: *tranfer time from the regions where victims are located in zone k to the temporary relief center in zone j*
- $DAMN_k$: *DVictims in the area k who require assistance*
- C_j: *capacity of the temporary relief center in zone j Number of victims who can be assisted*
- U: *number of arbitrary supplies*
- $CONSD$: *consumption of supplies (kits)required per victim*
- N_i: *capacity of the distribution center (supplies)*

Decision Variables

- M_i *Binary*: 1 if the distribution center is located in zone i; 0 otherwise.
- W_j *Binary*: 1 if the temporary relief center is located in zone j; 0 otherwise
- G_{ij} *Binary*: 1 if the distribution center serves the temporary relief center j; 0 otherwise
- D_{kj} : number of victims in area k who are served

in the temporary relief center in zone j

- Y_{kj} $Binary$: 1 if the victims of the area k are assigned to the temporary relief center in zone j; 0 otherwise
- Q_{ij}: quantity of supplies sent from the distribution center in zone j

Objective Function

Minimize travel time from the distribution center to the temporary relief centers so that affected victims can be assisted [minutes].

$$\sum_{\forall i,j} TIEMPCD_{ij} * G_{ij} + \sum_{k,j} TIEMPCV_{k,j} * Y_{kj}$$

Constrains

$$M_i + W_j \leq 1 \quad \forall i \in CD, j \in CA, i = j \quad (1)$$
$$\sum_{i \in CD} M_i = 1 \quad (2)$$
$$\sum_{i \in CD} G_{ij} = W_j \quad \forall j \in CA \quad (3)$$
$$\sum_{k \in CV} D_{kj} \leq \sum_{k \in CV} DAMN_k * W_j \quad \forall j \in CA \quad (4)$$
$$D_{kj} = Y_{kj} * DAMN_k \quad \forall j \in CA, k \in CV \quad (5)$$
$$\sum_{j \in CA} Y_{kj} = 1 \quad \forall k \in CV \quad (6)$$
$$\sum_{k \in CV} D_{kj} \geq 0.1 * C_j * W_j \quad \forall j \in CA \quad (7)$$
$$\sum_{k \in CV} DAMN_k * Y_{kj} \leq C_j * W_j \quad \forall j \in CA \quad (8)$$
$$Q_{ij} \leq G_{ij} * U \quad \forall i \in CD, j \in CA \quad (9)$$
$$\sum_{j \in CA} Q_{ij} \leq N_i * M_i \quad \forall i \in CD \quad (10)$$
$$\sum_{i \in CD} Q_{ij} \leq CONSD * C_j * W_j \quad \forall j \in CA \quad (11)$$
$$\sum_{j \in CA} D_{kj} \geq DAMN_k \quad \forall k \in CV \quad (12)$$
$$\sum_{j \in CA} W_j \geq \frac{\sum_{K \in CV} DAMN_k}{\sum_{j \in CA} C_j} \quad (13)$$
$$\sum_{i \in CD} Q_{ij} \geq CONSD * \sum_{k \in CV} D_{kj} \quad \forall j \in CA \quad (14)$$
$$M_i \in \{0,1\} \quad \forall i \in CD \quad (15)$$
$$W_j \in \{0,1\} \quad \forall j \in CA \quad (16)$$
$$G_{ij} \in \{0,1\} \quad \forall i \in CD, j \in CA \quad (17)$$
$$Y_{kj} \in \{0,1\} \quad \forall k \in CV, j \in CA \quad (18)$$
$$D_{kj} \geq 0 \quad \forall k \in CV, j \in CA \quad (19)$$
$$Q_{ij} \geq 0 \quad \forall i \in CD, j \in CA \quad (20)$$

Where (1) is a zone that can only be used to locate a distribution center or temporary relief center; (2) Ensures the opening of a single distribution center i; (3) The distribution center can serve a temporary relief center j only if the temporary relief center is open; (4) Ensures that victims from each zone k are accommodated in a temporary relief center only if it is open; (5) The temporary relief center can serve the victims of a zone only if it has been designated to do so; (6) Victims from each affected area k must be assigned to a single temporary relief center j; (7) A temporary relief is opened only if the number of victims to be served exceeds 10% of its capacity; (8) Each open temporary relief center must have sufficient capacity to accommodate the victims from an affected area k; (9) supplies are sent from a distribution center to the temporary relief center only if the distribution center serves the temporary relief center; (10) The amount of supplies sent from a distribution center to a shelter should not exceed the distribution center's capacity; (11) The quantity of supplies sent from distribution centers for to temporary relief centers should not exceed the temporary relief center's capacity; (12) The total number of victims accommodated in temporary relief centers in zone j of k must be at least equal to the total number of victims in that area; (13) Ensures that the number of temporary relief centers is sufficient to serve the affected population; (14) Ensure that sufficient supplies are sent to meet the demand of the shelter; (15), (16), (17), (18), (19) and (20) Define the range of values that variables can take.

B. *Specialized Personnel Routing Model*

To develop the model shown below, the Capacitated Vehicle Routing Model with a homogeneous fleet was used as aa reference.

Assumptions

- Three support groups (Red Cross, Civil Defense and Fire Department) have the same skill and capacity to serve the victims of such disasters and are equipped with all necessary tools.
- Specialized people form a single support unit.
- The capacity for assistance is determined based on the number of victims and available staff.
- Restrictions on access roads are not considered.
- All specialized personnel are available at the distribution center.
- Travel times are deterministic
- Support unit transport all specialized personnel required to assist victims.

Main Sets

- CDA: Set of input vertices(distribution center and temporary relief centers indexed by i and j
- UA: Set of available support units indexed by k

Parameters

- T_{ij}: Travel time from the CDA i to the CDA j (Minutes)
- C: $Capacity\ for\ assistance\ by\ specialized\ personnel$)
- A_i: Shelter demand associated with each CDA i (Victims)
- NP: Number of specialized personel available in each support unit (Personnel)

Decision Variables

- P_{ijk} $Binary$: 1 if support unit k travels through the route from i to j; 0 otherwise
- D_{ik}: Demand at the Temporary Relief Center supplied by the support unit (Personnel)
- S_i: Additional variable that represents the unit's load capacity

of the support unit after visiting the temporary relief center i (Personnel)

Objective Function

Minimize travel time from the distribution center to all temporary relief centers.

$$\sum_{\forall i,j,k\ i\neq j} T_{ij} * P_{ijk}$$

Constraints

$$\sum_{i,k\ \ i\neq j} P_{ijk} \geq 1 \quad \forall\, j \in CDA \qquad (1)$$

$$D_{ik} = \frac{A_i}{C} * \sum_{j\in CDA} P_{ijk} \quad \forall i \in CDA, k \in UA: i \geq 1 \qquad (2)$$

$$\sum_{k\,\in\,UA:i\geq 1} D_{ik} = \frac{A_i}{C} \quad \forall\, i \in CDA \qquad (3)$$

$$\sum_{i\,\in\,CDA:i\geq 1} D_{ik} \leq NP \quad \forall\, k \in UA \qquad (4)$$

$$\sum_{i\,\in\,CDA\ \ i\neq n} P_{ink} - \sum_{j\,\in\,CDA\ \ j\neq n} P_{njk} = 0$$
$$\forall\, n \in CDA, k \in UA \qquad (5)$$

$$S_i - S_j + NP * P_{ijk} \leq NP - \frac{A_i}{C}$$
$$\forall i,j \in CDA, k\ \in UA: i \neq j, i \neq 0\,, j \neq 0 \qquad (6)$$

$$\frac{A_i}{C} \leq S_i \qquad \forall i \in CDA: i \neq 0 \qquad (7)$$

$$S_i \leq NP \qquad \forall i \in CDA: i \neq 0 \qquad (8)$$

$$P_{ijk}\ \in \{0,1\} \quad \forall i,j \in CDA\,, k\ \in UA \qquad (9)$$

$$D_{ik} \geq 0 \quad \forall i \in CDA, k \in UA \qquad (10)$$

$$S_i \geq 0 \quad \forall i \in CDA \qquad (11)$$

$$S_j \geq 0 \quad \forall, j \in CD \qquad (12)$$

Where (1) ensures that the specialized personnel arrives at the temporary relief center; (2) indicates that the temporary relief center i can be served by specialized personnel if k passes *i*; (3) Ensures that the demand of each open temporary relief is fully satisfied ; (4) determines that the quantity of specialized personnel assigned to each temporary relief center does not exceed the available personnel; (5) Flow balance, which indicates that the support unit leaving the distribution center returns; (6), (7) and (8) Avoid sub-routes; (9), (10), (11) and (12) define range of values that the variables can take.

IV. CASE STUDY

The case study is framed within the municipality of Tuluá is located in southwestern Colombia, in the center of Valle del Cauca department between the Central Mountain Range and the Cauca River (CVC, 2017). It has territorial area 1,014.96 km^2. The total land area of the municipality is 910.55 km^2 of which 98.78% corresponds to the rural sector and the urban sector 1.22% (Municipality of Tulua, 2017).

According to figures from DANE, Tuluá has a population of 216,619 inhabitants, 187.121 live in the municipal capital and 29,483 in rural areas. (Tuluá Chamber of Commerce, 2016).
To validate the proposed models, the municipality of Tuluá was chosen as a reference, particularly those areas affected by the 2022 rainy season. Floods occur during the winter season due to the overflow of Tuluá River, which initially affects the following neighborhoods: Tomas Uribe (CV1), La Trinidad (CV2), Siete de Agosto (CV3), San Antonio (CV4), La Inmaculada (CV5), Villa Nueva (CV6), Casa Huertas (CV7), Portales Rio in urban area (CV8), the village of Bocas de Tulua (CV9), Tres Esquinas (CV10); Morales River affecting neighborhoods: Urbanizacion Villa (CV11), El Bosque (CV12) and Santa Rita (CV13). (CMGR, Consejo Municipal de Gestión del Riego de Desastres Municipio de Tuluá – disaster risk managment -, 2012). These places can be seen in fig. 3.

The proposed models provide an optimal solution that meet the needs of the affected population, safe areas were identified, where temporary relief centers could possibly be located. These safe places are: Coliseo de Ferias Manuel Victoria Rojas(CA1), Salesiano High School San Juan Bosco (CA2), Coliseo Benicio Echeverry (CA3), Stadium Doce de Octubre (CA4), Institución Educativa Aguaclara (CA5) Institución Educativa Técnica Occidente Tulua (CA6), Health Center La Independencia (CA7), Rubén Cruz Vélez (CA8), Institución Educativa Julia Restrepo (CA9), Gimnasio del Pacifico School (CA10), Institución Educativa Julio Cesar Zuluaga, Tres Esquinas Village (CA11), Institución Educativa Julio Cesar Zuluaga in the village Bocas de Tulua (CA12). These places can be seen in Figure 4. A distribution center was also identified, which has become a safe potential place: these are Coliseo de Ferias Manuel Victoria Rojas (CD1) and Salesiano High School San Juan Bosco (CD2), which can be seen in Figure 5 as well; the municipality of Tulua Secretary of government lacks suitable facilities of temporary relief centers; that is the reason why some state-owned educational institutions and some health centers are used. Although it is known that, when an emergency occurs, these centers should not be used since doing do would disrupt academic and labor activities, these have been used in this study due to the lack of alternative facilities.

They can be observed in Fig. 4; in the municipality of Tulua Secretary of government lacks suitable for the location of temporary shelter facilities, which is why we make use of official educational institutions and some health centers, although it is known that when an emergency that requires locating temporary relief should not resort to educational institutions and health centers, because this way we would be intervening in academic and labor activities, but as mentioned above the city and this work they will resort to facilities because they are not they have other available. The entities or groups equipped with specialized disaster relief personnel include the Fire Department, Civil Defense, and Red Cross.

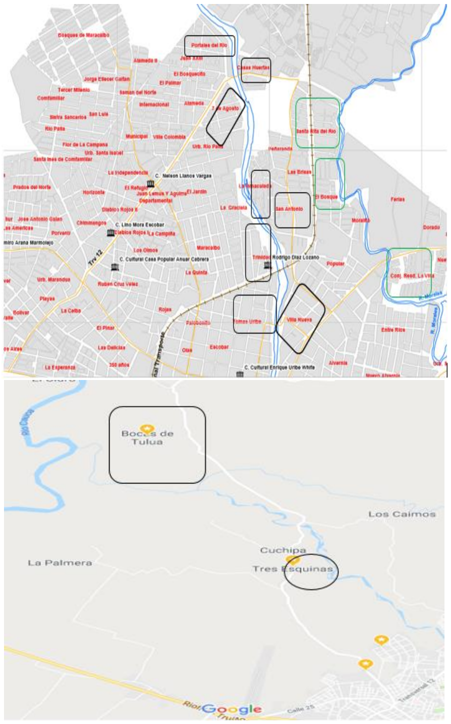

Fig. 3. Areas Flood irrigation. Source: Google Maps

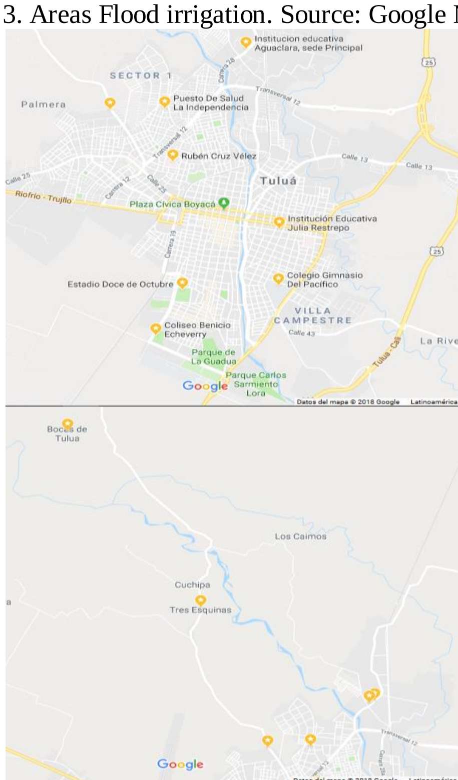

Fig. 4. Safe Zones for the location of temporary relief centers Source: Google Maps

Fig. 5. Safe areas for the location of distribution centers. Source: Google Maps

V. RESULTS

This section presents the results obtained based on the methodology developed. The results thrown by the CPLEX software in the NEOS Server platform and the mathematical programming language AMPL, indicate that the location model determined the opening of a Distribution Center No. 1 (CD1) and Temporary Relief Centers No. 5 and 11 (CA5, CA11). These temporary locations ensure a minimum travel time of 93 minutes while guaranteeing assistance for the entire vulnerable population.

Fig. 6 shows the location of the distribution center and temporary relief centers, while Figures 7 and 8 show the assignment of affected areas to each of the temporary relief center.

Fig. 6. Location of the distribution center and temporary relief Source: Google Maps

Fig. 7. Mapping affected areas to CA5.Source: Google Maps

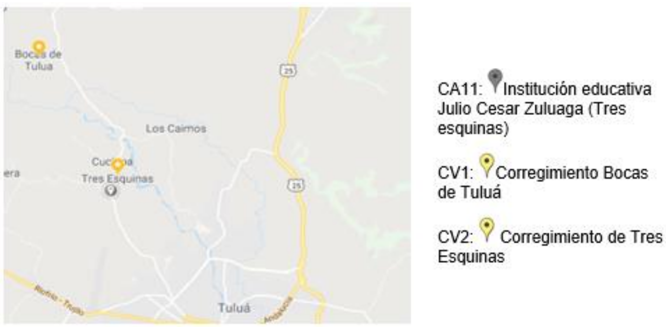

Fig. 8. Allocation of areas affected by CA11. Source: Google Maps

The number of victims and supplies assigned to each temporary relief center are shown in Table 2. Table 3 presents the results of supplies allocation from the distribution center to each temporary relief center.

TABLE II
VICTIMS OF EACH AFFECTED SITE THAT WILL BE TREATED AT EACH TEMPORARY RELIEF

CV \ AC	5	11
1	0	47
2	0	21
3	27	0
4	32	0
5	21	0
6	25	0
7	25	0
8	30	0
9	16	0
10	32	0
11	26	0
12	27	0
13	25	0

Source: Authors

TABLE III
SUPPLIES ALLOCATED FROM THE DISTRIBUTION CENTER FOR EACH TEMPORARY RELIEF

AC \ CD	1
5	286
11	68

Source: Authors

These results show that all affected areas within where the victims are in the municipal head are assisted by Institución Educativa Aguaclara Sede principal (CA5), which is also located in the city center and close to the distribution center Coliseo de Ferias Manuel Victoria Rojas (CD1). Meanwhile, affected rural areas are served by Institución Educativa Julio Cesar Zuluaga (CA11), which also receives supplies from the same distribution center (CD1).

The routing model that has been designed to minimize travel time and provide timely assistance to victims, determined that the support unit with specialized personnel leaves the Coliseo de Ferias Manuel Victoria Rojas (CD1), goes to the Institución Educativa Aguaclara temporary relief (CA5), where 96 specialized personnel are left. After that, it goes Institución Educativa Julio Cesar Zuluaga (CA11), where other 23 specialized personnel are left. Finally, it returns to point of departure (CD1). Table 4 shows the results produced by the model.

TABLE IV
RESULTS MODEL ROUTING OF SPECIALIZED PERSONNEL.

Specialized personnel (D) temporary relief (CA) open		
AC	CA5	CA11
D	96	2. 3

Source: Authors

- Travel time: 40 minutes
- Route: CD1 → CA5 → CA11 → CD1

It is observed in the base model of routing that the path that specialized staff starts at the distribution center CD1, there is going to lodge to CA5 where 80% of specialist staff meets the demand of the temporary relief because most (+ - 80%) of the victims are concentrated there, so that is necessary more specialist staff to alleviate the suffering of those affected by a disaster natural, thence he goes to meet the other temporary shelter open CA11 which has 20% of victims, generating a time minimum of 40 minutes of transfer from support unit with specialized personnel to temporary relief.

These models determine the number of temporary relief centers that are to be opened by, identify optimal locations and distribution centers with good capacity, assign victims to shelters, and also identify the routing of specialized personnel. This is aimed to seek a solution that generates the shortest possible time in assisting the affected victims. The combined results related to Location and Routing are shown in Fig. 9.

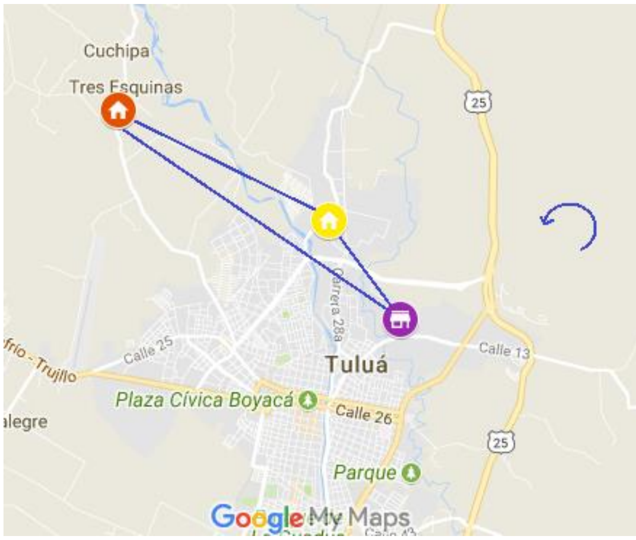

Fig. 9. Results Model Location and routing of specialized personnel.Source: Google Maps

Although the location model provides a decision-making decision solution for placing temporary relief centers to assist flood victims in the municipality of Tulua, and the routing model ensures a solution that meets the objective of minimizing travel time for the support unit and specialized personnel. Thus, further scenario analysis is required based on the variation of parameters of interest, so that the behavior of the location and routing model can be evaluated to improve response strategies and optimize decision-making in the event of a flood.

Addressing the decisions about the location of temporary shelters and the configuration of routes for specialized personnel together recognizes the connection between both decision-making processes. This integrated approach helps improve response times for affected populations compared to tackling these decisions separately, as shown in the studies conducted by [8], [16], and [17]. Treating these decisions individually may lead to suboptimal solutions [2].

VI. Conclusion

In emergency situations caused by natural disasters, the most important issue is to have a well-structured emergency response to meet victims' needs and assist them as soon as possible. The objective of this study is to minimize time from the occurrence of a disaster to the arrival of aid in affected areas.

To achieve this, a location model was proposed to determine the number and location of temporary shelters, which should be served by a single distribution center. This model also took into account allocation of victims and necessary supplies; this also accounts for the capacity of both shelters and the distribution center. A routing model was also designed to optimize the movement of specialized personnel to provide timely assistance to vulnerable population and the assignment of personnel, according to the needs of each shelter.For this purpose, the mathematical programming language AMPL was used, as well as the NEOS Server platform and the CPLEX solver to obtain and analyze quantitative results of the proposed models.

Unlike previous studies in humanitarian logistics, this research employs a mathematical hierarchical approach, which allows the integration of location decisions for distribution centers and temporary shelters with the routing of specialized personnel. This model considers issues related to victim assignment to shelters, supply assignment according to the number of victims served by open shelters, and assignment of specialized personnel, while accounting for the limited capacity of relief units.

For future research, it is necessary to improve models for temporary relief centers and routing of specialized personnel by incorporating stochastic travel and setup times and number of victims. Future studies could also include cost models related to opening and operating a temporary shelter and distribution centers. Furthermore, the impact environmental factors in the performance function are considered as well.

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Declaration of Interests

The authors declare no conflict of interest.

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