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Supplying aid products to affected regions by a natural phenomenon in Chiapas, Mexico

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Abstract: Natural phenomena affect differently in the world. It comes first from the geographical location, followed by the economic characteristics of each region. The objective of the case study presented is to design a supply network of essential products to victims in the state of Chiapas, located within the Mexican Republic, which is one of the states most affected by the appearance of natural phenomena. The vehicular routing problem with capacity is applied as a solution for the supply of aid products to 120 of 124 municipalities impacted by natural phenomena of a hydrometeorological type during the period 2015-2022. Evaluating the different municipalities that are home to the state under study through various Infrastructure and service factors, the municipality of Tuxtla Gutiérrez is determined as the origin of the routing, obtaining with it a total of 44 routes with an average of 2.7 municipalities to be supplied per route and an average of 402 km travelled. A second municipality is located, Tapachula, which obtains a second place in evaluating factors, providing the longest route in the distance travelled.

1 Introduction

Natural disasters are a serious threat worldwide. In the last 20 years, they have caused more than 1.2 million deaths and direct losses above 3.3 trillion dollars [1]. According to their origin, natural disasters are classified as meteorological and biological, with meteorological being hydrological or geophysical [2].

The appearance of natural phenomena and the degree of impact they have on human beings is not the same in all regions of the world. For example, we can mention Latin America and the Caribbean, the second most prone region to suffer disasters due to natural phenomena in the world. From 2000 to 2020, there were 1,205 disasters, including floods, hurricanes and storms, earthquakes, droughts, avalanches, fires, extreme temperatures, and volcanic events. Mexico is among the countries most affected by storms. Likewise, because it is located along the "ring of fire," it is exposed to volcanic activity [3]. In the same way, the degree of affectation of these phenomena is not the same; this is partly a consequence of the levels of economic development, which, among other factors, is reflected in the region's infrastructure.

There are various classifications of the disaster care phases; in general, they fall within one of the following moments: 1. before the disaster, 2. during the disaster, and 3. after the disaster. That is why it is worth mentioning that, through a great diversity of tasks and activities carried out at different times, humanitarian logistics is in charge of valuing, providing, storing, transporting, and distributing the personnel and services required in some areas affected by a disaster. It aims to provide emergency supplies to the affected areas quickly and on time, minimizing deaths and human suffering [4].

A helpful tool in the area of humanitarian logistics is the model of the Vehicle Routing Problem (VRP) in its different variants, which is used to design the routes that allow, among other things, the interest of this document, the delivery of products people affected by a natural disaster.

The *capacity vehicle routing problem (CVRP)* is the classic version of the vehicle routing problem (VRP). It is a problem where each vehicle has a known capacity, and loading it above said capacity is not permissible. Two aspects emerge from CVRP: *a)* ACVRP when the cost matrix is asymmetric, and *b)* SCVRP when the cost matrix is symmetric [5].

The formulation of integer linear programming of ACVRP proposed by [6] is presented through 1. Table 1 shows the assumptions, inputs, and outputs accompanying the formulation of the problem, and Table 2 shows the set of equations that form the mathematical formulation.

Table 1 Assumptions, inputs, and outputs

	Description
Assumptions	The demand is deterministic.
	The demand is not split.
	The vehicles are similar.
	The vehicles are located in a central depot.
	Vehicle capacity restrictions are assigned.
Inputs	$G = (V, A)$: *a complete graph.*
	$V = \{0, \ldots, N\}$: *the vertices set.*
	A: *the arc set.*
	D_j: *the demand of each client* $(D_o = 0)$.
	C_{ij}: *the travel cost (from vertex i to verte* .
	SCV: *set of client.*
	$d(S) = \sum d_i$: *the total demand of the set.*
	K: *the number of identical vehicles.*
	C: *the capacity of each vehicle.*
	$Kmin, r(S)$: *the minimum number of vehicl required.*
Outputs	$X_{ij} = 1$ *if the arch* (i, j) $\in A$ *if the arc belongs to the optimal soluti and* 0 *otherwise.*

$$min \quad \sum_{i \in V} \sum_{j \in V} C_{ij} X_{ij}$$

Subjects:

$$\sum_{j \in V} X_{ij} = 1 \qquad \forall\, i \in V \,/\, \{0\} \qquad (1)$$

$$\sum_{j \in V} X_{ij} = 1 \qquad \forall\, i \in V \,/\, \{0\} \qquad (2)$$

$$\sum_{i \in V} X_{i0} = K \qquad (3)$$

$$\sum_{j \in V} X_{0j} = K \qquad (4)$$

$$\sum_{i \notin S} \sum_{j \in S} X_{ij} \geq r(s) \qquad \forall S \subseteq V/\{0\}, S \neq \emptyset \qquad (5)$$

$$X_{ij} = \{0,1\} \qquad \forall i, j \in V$$

Equations (1) and (2) are input and output, respectively; equations (3) and (4) establish the deposit requirements; Equation (5) is the capacity constraint, which stipulates that each cut *(V/S, S)* defined by a set of customers S is traversed by a number of arcs greater than r*(S)*.

Throughout the world, researchers have carried out studies based on the VRP, combining it with other techniques to provide solutions to the various variables that arise from the impact of natural phenomena. Among these, we can mention those presented in point 1.1.

The present investigation is made up in this introductory section with concepts and definitions in humanitarian logistics. Many studies were carried out by researchers from all over the world using the vehicular routing model. The problem arises in Chiapas, Mexico. The methodology shows the set of actions carried out to evaluate and give a solution to the problem of delivery of products to victims of a natural event. Lastly, the results obtained through graphs and images are shown, and a comparison is made, allowing the discussion of the results and the conclusions.

1.1 *Estate of the art*

The interest in studying applications of the vehicular routing problem within humanitarian logistics is growing daily. In the article of [7], the authors present a literary review of the 2009-2019 period of the vehicle routing problem (VRP) applied to natural disasters in South America; the results of their research are *a)* most of the models They are deterministic, with VRP being the most widely used; *b)* Its application phase is mainly in the post-disaster phase; *c)* A large number of them seek to minimize time and operating costs, and *d)* For small scenarios, the most used models are the exact ones. Similarly, the work of [8] addresses the application of vehicle routing models to solve problems arising from the appearance of a natural phenomenon that causes a disaster. In this same area, it is worth mentioning that the application of the VRP brings with it the use of software that allows its resolution [9] in, which the authors make a comparison of the software used as VRP resolution tools, finding 6 with the best characteristics in terms of feasibility.

The planning phase is highly relevant within the administration of any process; in the case of product delivery, various researchers have worked on generating schedules that minimize the disaster's impact on victims. We can mention [10], where the authors use multi-objective evolutionary optimization with greedy heuristics to generate item distribution schedules under heterogeneous vehicles. It allowed them to generate an efficient alternative to find effective distribution schedules minimizing time and operating costs.

In the same way, various researchers have proposed mathematical models as a basis for decision-making in the disaster response process. Such is the case of [11], in which the authors propose a mathematical model for planning the use of helicopters for logistics activities in disaster response operations; with a feasible result in the methodology, the authors minimize the total time operation and mobilization of air resources. However, heuristic models should not be left behind as a logistics tool, allowing the problem of reasonable computational time. In the case of [12], the authors propose a mathematical optimization model and a heuristic based on a genetic algorithm to solve the problem of routing and programming humanitarian assistance.

Regarding the application of the VRP to specific cases, we can mention [13] who determine the number and location of shelters, collection routes for evacuation, and attention time for victims in the event of an earthquake, by modeling the problem. Location-routing with time windows (LRPTW) in the same way, a phenomenon that has caused significant problems in item distribution is the appearance of the Sars-Cov-2 virus, increasing the opening of many supply centers to supply their products to remote areas. The researchers [14], based on modeling the routing problem for vehicles with capacity, redesigned the delivery routes of a store of social interest to their supply centers, decreasing about 24% the distance traveled by.

Continuing with the literary journey, it is worth mentioning the investigation of [15], the researchers applying the nearest neighbor (NN) heuristic technique and the capacity vehicle routing problem (CVRP), obtain and compare the delivery routes of necessities in the municipality of La Perla, Veracruz, Mexico. At the same time, the investigation of [16] evaluates a logistic model of the literature whose foundations are 1. The p-median problem for the location of a warehouse; 2. An extension of the model (qR) to calculate the products to be supplied, and 3. The problem of multiple vehicle routing with the capacity to deliver products to affected municipalities in Veracruz, Mexico.

Similarly, the research of [17] presents a new mathematical model for the Location Routing Problem with Private Fleets and Common Carriers (CLRPPC). The model can be adapted to solve the Vehicle Routing Problem with Private Fleets and Common carriers (VRPPC). And the Multi-Depot Vehicle Routing Problem with Private Fleet and Common Carrier (MDVRPPC). The models are validated with instances from the literature with satisfactory results. While the researchers [18] present a WEB application for the allocation of deposits and establishment of routes for the supply of distribution centers, considering population probabilities.

The paper in [19] presents a method to determine how to transport the maximum number of disaster victims to hospitals in metropolitan cities on time. The proposed method uses mathematical models, programming theory, heuristic methods, and the geometric Voronoi diagram. The goal is to transport the maximum number of patients on time, and the Voronoi diagram is used effectively to break down the complex problem. The article contains case studies of three hospitals in Tehran. Likewise, it is worth mentioning the work of [20], in which the researchers describe a study whose objective is to statistically evaluate the effects of various design factors on the performance of the casualty transport system in large-scale disasters. The authors propose a data-based decision support tool to improve casualty survival and ambulance transport times during the disaster response phase.

Continuing with the investigation of establishing transport routes in the event of a disaster, it is worth mentioning the investigation of [21], which has in its context the worst flood that occurred in Kelantan in 2014. The researchers evaluate and identify locations for shelters and routes relief. The simulation is performed using HEC-RAS and ArcGIS to map the best possible locations and modes of transportation for disaster relief. Likewise, the research of [22] proposes a mixed integer programming model and a two-stage hybrid metaheuristic method to solve the post-disaster humanitarian logistics problem. The model considers the medical assistance team and the distribution of relief supplies between the different demand points. The model is tested on problems of different sizes and a numerical example based on the 2016 Kyushu, Japan earthquake. Finally, the research of [23] addresses the importance of effectively managing relief supply operations and routing vehicles for delivery to help natural disaster victims.

1.2 Problem statement

Mexico is especially vulnerable to natural disasters. It is because its territory is located between the faults of the North American plate and the Cocos plate, which brings with it highly seismic regions. Likewise, it is surrounded by the Pacific Ocean and the Atlantic Ocean, thus having impacts from hydrometeorological phenomena. In addition to the above, critical human settlements are located in geographical areas with seismic activity or can suffer the impact of hurricanes of many categories [24].

The Chiapas state is in the southeast of Mexico, bordered to the north by Tabasco, to the west by Veracruz and Oaxaca states, to the south by the Pacific Ocean, and to the east by the Republic of Guatemala. It has a territorial area of 74,415 km^2; it occupies 3.8% of the national territory, making it the eighth largest state, with a population of 5,543,828. Chiapas ranks 8th at the national level for its number of inhabitants [25]. Figure 1 presents the geographic location of Chiapas within the national territory (a) and its municipal division, with 124 municipalities comprising it (b).

Chiapas is one of the six states of Mexico with the most significant number of affectations by hydrometeorological phenomena; 120 of 124 municipalities suffered one or more effects during 2015-2022. For example, in 2022, Hurricane Stan's passage affected more than 670 homes in the municipality of Escuintla [27]. It is worth mentioning that of its 124 municipalities, of which: 1 is classified with a lesser degree of marginalization; 7 municipalities have a low degree of marginalization; 29 municipalities have a medium degree of marginalization; 67 municipalities have a high degree of marginalization, and 20 municipalities with a very high degree of marginalization [28].

Therefore, the present case study aims to design a delivery network of essential products to areas affected by a natural phenomenon in Chiapas under the assumptions of *1.* The roads are not damaged; *2.* Considerable traffic; *3.* Pertinent climatic conditions; *4.* No social problems in terms of demonstrations and security, and *5.* Qualified driver. For which the methodology embodied in the continuous section is established.

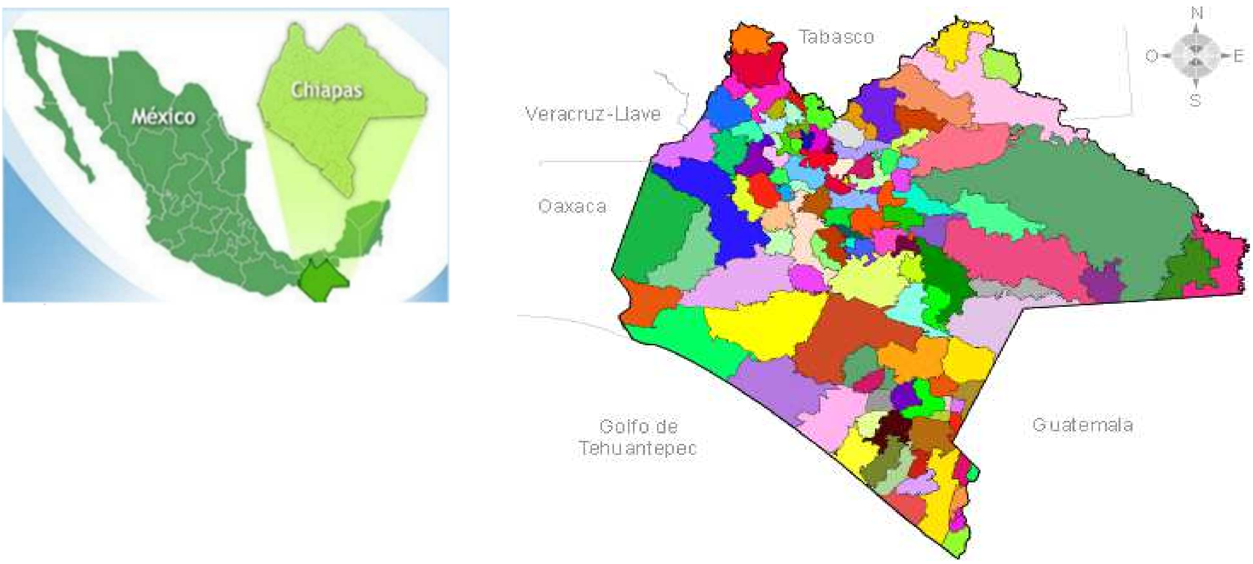


Figure 1 Location and municipal division of the state of Chiapas [25,26]

2 Methodology

The methodology to solve the problem of supplying necessities to areas affected by some natural phenomenon in the state of Chiapas is shown in Figure 2. It is divided into three stages (1) Collection of information from the municipalities that make up Chiapas: *a)* Municipalities that make up the state; *b)* road access, essential services, social interest stores, and degree of marginalization of each municipality; *c)* municipalities impacted by natural phenomena during the period 2015-2022 and a number of victims; *d)* necessities of the area, price and dimensions; *e)* product integration device for delivery, with content for families of four people, and *f)* means of transport for delivery and dimensions of their containers. (2) Development of databases for the supply of the CVRP programming *a)* database of the characterization and evaluation of each of the municipalities that make up the state of Chiapas in order to select the one with the highest weighting for locating a point of origin of routes; *b)* municipalities impacted by some natural phenomenon during the period 2015-2022, integrating the number of victims in each one; *c)* matrix of distances between the point of origin and impacted municipalities; *d)* Calculation of container capacity of the delivery vehicle; *e)* feeding the programming into Lingo 19®, and *f)* running the program. (3) Presentation of results *a)* generation of tables with the routes obtained, showing the municipalities to be supplied on each route, the distances traveled, and the groceries supplied; and *b)* comparison between venues.

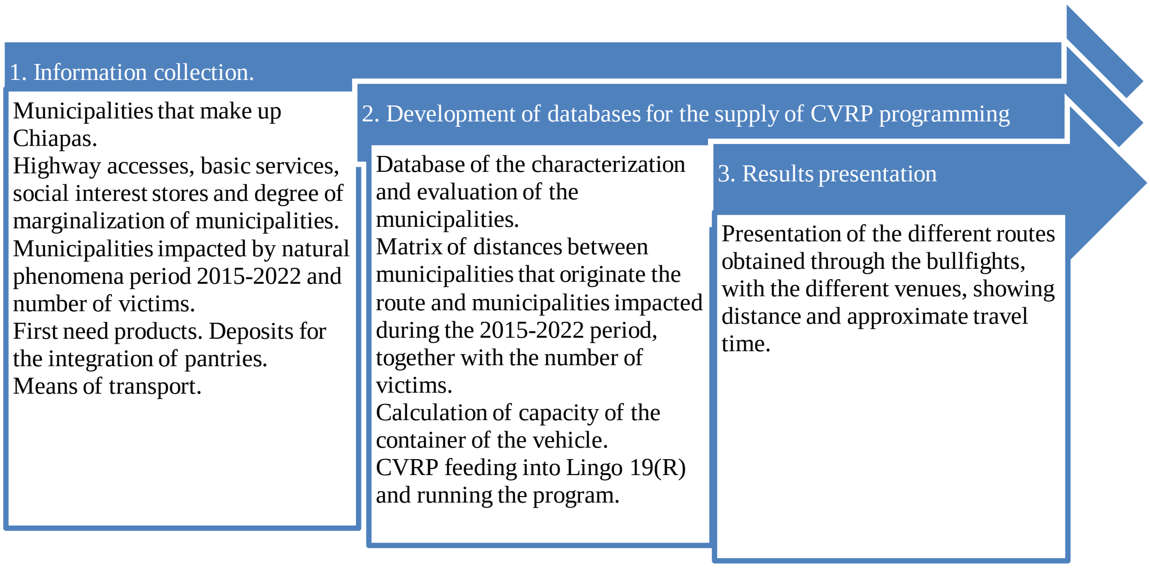


Figure 2 Problem-solving methodology

2.1 Information collection

This first step is based on seeking and collecting transparent information that allows the generation of tools to feed the CVRP programming.

2.1.1 Municipalities that make up the state of Chiapas

The state of Chiapas is made up of 15 regions; I. Metropolitan; II. Zoque Valleys; III. Mezcalapa; IV. From the Plains; V. Altos Tsotsil-Tseltal; SAW. Friary; VII. Of The Woods; VIII. North; IX. Isthmus-Coast; X. Soconusco; XI. Sierra Mariscal; XII. Lacandon jungle; XIII. Mayan; XIV. Tulijá Tseltal Chol, and XV. Comiteca Tojolabal Plateau. Which house a different number of municipalities, adding 124 in total. Such information limits the investigation's geographic scope [25,26].

2.1.2 Highway accesses, essential services, social interest stores, and the degree of marginalization of the municipalities

The information about types of road access, essential services, social interest stores, and the degree of marginalization of each of the municipalities will allow for establishing a geographical area. Where a pantry distribution center could be established, that is, a point of origin for people affected by the impact of a natural phenomenon, the information is obtained through databases of CONAPO (National Population Council) and the national report of INEGI (National Institute of Statistics and Geography) [26, 29].

2.1.3 Municipalities impacted by natural phenomena period 2015-2022 and a number of victims

The municipalities impacted by a natural phenomenon of hydrometeorological type during the period 2015 - 2022 are extracted from databases of the Natural Fund for Disaster (FONDEN), the National Center for Disaster Prevention (CENAPRED), and the National Civil Protection System (SINAPROC) of the state of Chiapas Likewise, the calculation of victims is made from the average supply during the study period [30, 31].

2.1.4 Aid products

The content of the pantries is based on the AGREEMENT that establishes the Program's guidelines for the Attention of Emergencies due to Natural Hazards by the Secretary of the Interior (SEGOB), DOF 08/16/21, in the Transitory section. It establishes the Type B maintenance pantry for the southeast region [32]. These pantries are projected for four people (an average family).

2.1.5 Deposits for the integration of aid kits

For the deposits containing the set of products, a box of 40 cm long x 30 cm long and 30 cm wide is determined.

2.1.6 Means of transport for delivery and dimensions of the boxes

The means of delivery to consider is a 4-axle cargo truck, 8-ton tail type, with dimensions in the box of 943 cm long, 300 cm high, and 248 cm wide. It is used by social interest companies in territorial areas such as those present in the state under study [33].

2.2 Development of databases for the establishment of the CVRP programming

In this stage, the instruments that will allow the evaluation of the municipalities are generated.

2.2.1 Database of the characterization and evaluation of the municipalities

Table 2 shows an example of information organized according to the characterization of the municipalities and the region to which they belong (XIII. Mayan Region). Evaluating each region and its municipalities, the Tuxtla Gutiérrez city council has the highest compliance to be a point of origin in distributing food pantries to victims, followed by Tapachula.

Table 2 Mayan region characterization

Municipalities	Marginalization index	Degree of marginalization	Road access	Electric power	Sewer system	Telephony	Internet	Social interest stores
Catazajá	52.130	High	Federal & State	97.8	94.0%	14.7%	8.5%	0
La Libertad	52.693	Medium	Federal	98.3	96.2%	10.2%	9.4%	0
Palenque	52.674	Medium	Federal & State	98	92.9%	5.8%	16.6%	1
Benemérito de las Américas	51.419	High	Federal	97.3	91.3%	1.9%	6.5%	1
Marqués de Comillas	49.087	High	State	98.6	85.5%	1.9%	3.6%	0

2.2.2 Matrix of distances between municipalities classified as the origin and impacted municipalities during the period 2015-2022

Two matrices are developed, one belonging to the municipality of Tuxtla Gutiérrez, as the point of origin, the impacted municipalities, and the number of victims converted into families of four. Moreover, another is a sensitivity test with the municipality of Tapachula, the second municipality with the highest compliance in characteristics to be a point of origin.

2.2.3 Vehicle box

Based on the dimensions of the product container and the vehicle box, a maximum capacity of 1840 pantries to be transported is established.

2.2.4 Feeding CVRP into Lingo 19

With the matrices as a power source and a total capacity of 1,840 pantries, the programming run is carried out in Lingo 19®

3 Results

As a distribution point, the municipality of Tuxtla Gutiérrez contains 44 different routes with an average of 3 municipalities to be supplied on each route, without a municipality being supplied through two different routes and an average of 402 kilometers traveled per delivery. In the same area, if the result obtained when the supply point is the municipality of Tapachula, there are 44 different routes, with an average of 3 municipalities to be supplied within each of them and an average route of 769 kilometers per route.

Table 3 presents some examples of the routes obtained through the CVRP program, having the municipality of Tuxtla Gutiérrez as the point of origin; as can be seen, the first route delivers to two municipalities and returns to the origin, with a total of 1,810 pantries supplied and 413 km traveled. The second route delivers to a single municipality, covers 30 km, and delivers 1,622 groceries. The Figures are obtained through the Google Maps® software.

Table 4 presents some examples of the routes obtained through the CVRP program, having the municipality of Tapachula as the point of origin; as can be seen, the first route delivers to a municipality and returns to the origin, with a total of 1,753 pantries supplied and 492 km traveled. The second route delivers to two municipalities, covers 93 km, and delivers 1,597 groceries. Figures are obtained through the Google Maps® software.

Table 3 Route with origin Tuxtla Gutierrez

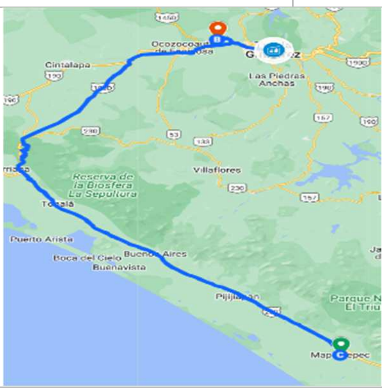
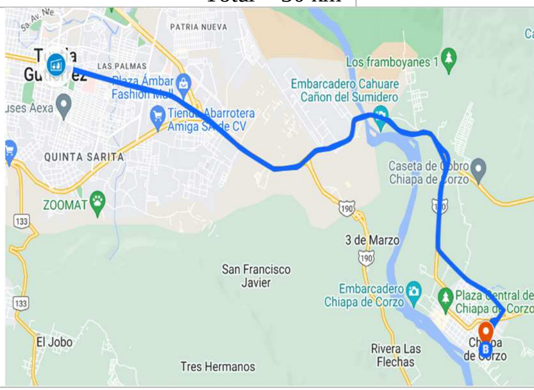
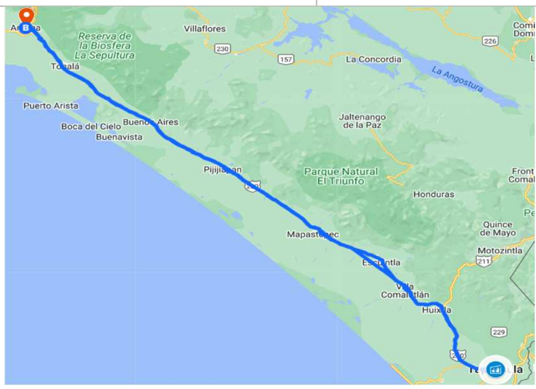
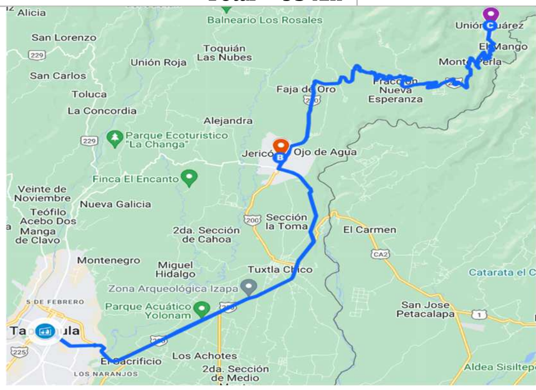
ROUTE 1.		**ROUTE 2.**	
Tuxtla Gutiérrez, Berriozábal, Mapastepec y Tuxtla Gutiérrez		Tuxtla Gutiérrez, Chiapa de corzo y Tuxtla Gutiérrez	
Traveled distance	Families of victims	Traveled distance	Families of victims
Tuxtla Gutiérrez – Berriozábal = 26 km Berriozábal – Mapastepec = 137 km Mapastepec - Tuxtla Gutiérrez = 413 km Total = 413 km	Berriozábal=904 Mapastepec=906 Total = 1,810	Tuxtla Gutiérrez - Chiapa de Corzo = 15 km Chiapa de Corzo - Tuxtla Gutiérrez = 30 km Total = 30 km	Chiapa de Corzo =1,622 Total = 1,622
			

Table 4 Route originating in the municipality of Tapachula

ROUTE 17		ROUTE 21	
Tapachula – Arriaga – Tapachula		Tapachula – Cacahoatán – Unión Juárez – Tapachula	
Traveled distance	Families of victims	Traveled distance	Families of victims
Tapachula – Arriaga = 246 km Arriaga – Tapachula = 492 km Total = 492 km	Arriaga = 1,753 Total = 1,753	Tapachula – Cacahoatán = 22 km Cacahoatán - Unión Juárez = 47 km Unión Juárez – Tapachula = 93 km Total = 93 km	Cacahoatán = 761 Unión Juárez = 836 Total = 1,597





4 Discussion

Although the results show that the number of trips traveled for the delivery of products is the same for both host municipalities, 44 routes, the average distance traveled for these varies considerably by approximately 47.72%. The municipality of Tuxtla Gutiérrez has a better geographical location, which allows a shorter mileage for the delivery of products with an average of 402 km, which would help reduce delivery and maintenance costs, and the municipality of Tapachula, with an average distance traveled of 769 km which implies a longer transfer time affecting the victims in a non-timely supply, both with an average supply of 3 municipalities per trip.

Likewise, within the characterization of the municipalities, Tuxtla Gutiérrez, being the capital of the state, occupies the best percentage within factors such as degree of marginalization, electric power, drainage, telephony, internet, hosted social interest stores, and road access, which facilitates the management of a warehouse. These two municipalities can be visualized in Figure 3; in green is the municipality of Tuxtla Gutiérrez, and in blue is the municipality of Tapachula, located in the south of the State bordering Guatemala.

Through a literary investigation, a case study of [34] is found where the problem of the location of facilities in the state of Chiapas is reflected, using the p-median, the researchers present as headquarters municipalities: Altamirano, El Parral, La Independencia, and Larráinzar under different scenarios, with an average of 609 kilometers traveled per route,

Although the results of this case study are satisfactory, some elements were not considered, such as breakdowns or road closures, weather conditions, demonstrations, support personnel, and others that may arise from the impact of a phenomenon natural.

Figure 3 Municipalities of origin in routing

As mentioned, few studies are related to vehicle routing in Chiapas State, one with the highest frequency of impact from natural phenomena. In addition, it is one of the three states with the highest percentage of population poverty [35]; it is imperative to carry out studies that provide tools to the actors in the face of the disaster in the various phases that converge to it, to provide a solution or maintain a quality of life for the victims. Humanitarian logistics is becoming increasingly relevant to climate problems, and political and social problems have alerted numerous researchers who, through different methodologies, techniques, and methods, provide a solution to the consequences caused. In this case, the CVRP was used to propose a timely supply.

5 Conclusions and future studies

It is known that logistics processes present a high cost to organizations, whatever they are. In the case of the actors before the disaster, the time factor is of predominant interest since it can be the difference between a person's life and death. Within emergency operations, items are distributed to victims, which is relevant to maintaining a quality of life. Chiapas is one of the states of Mexico which has suffered the impact of natural phenomena over time. Precisely, hydrometeorological type. The work aims to develop a delivery network for essential products to victims of a natural phenomenon. It is achieved through the characterization of municipalities to establish a geographical point which is the origin of the network. Then we look for the determination of the number of pantries to transport derived from the vehicle's capacity. Finally, the feeding of capacity and distance to the programming of the problem of vehicular routing with capacity. Obtaining as results: number of routes, municipalities that make up the routes, kilometers traveled on each route, and groceries to be transported.

Through the evaluation of the different municipalities that are home to the state under study through various infrastructure and service factors, the municipality of Tuxtla Gutiérrez is determined as the origin of the network, with a total of 44 routes and an average of 2.7 municipalities at supply for each one, through an average of 402 km traveled. A second municipality, Tapachula, is located, providing a longer route than in the case of Tuxtla Gutiérrez.

This study is essential for the actors who support society in a disaster context and for the community and researchers. Remember that a disaster can bring disastrous consequences not only at the time of the disaster but can trigger a series of effects for society, such as unemployment and economic instability beyond the affected area. This work provides a strategy for providing humanitarian aid as soon as possible. In addition, a real case study is used, facilitating the understanding of mathematical methods and stimulating critical thinking and creativity.

The CVRP provides an adequate solution to the product delivery area; as a suggestion in future works, the division of the network in more than one point of origin is planned, taking into consideration and weighting factor the frequency of impact to the municipalities to discard these as a network source.

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Review process

Single-blind peer review process.