Revista Iberoamericana para la Investigación y el Desarrollo Educativo
ISSN 2007 - 7467

https://doi.org/10.23913/ride.v15i29.2110

Artículos científicos

Logistic Design of Humanitarian Help in the State of Veracruz, Mexico LDHH in Veracruz

Diseño Logístico de Ayuda Humanitaria en el Estado de Veracruz, México DLAH en Veracruz

Desenho Logístico da Ajuda Humanitária no Estado de Veracruz, México DLAH em Veracruz

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Revista Iberoamericana para la Investigación y el Desarrollo Educativo
ISSN 2007 - 7467

Abstract

Extreme natural phenomena have brought, among other things, loss of human life, materials, and ecology all over the world. This situation requires humanitarian logistics as a relevant process in planning the activities of various individuals focused on saving human life. Time is a key factor behind the impact of a natural event that becomes a disaster, the location of facilities and provisional routes, and supply can make the difference between life and death. This article presents a Logistic Design of Humanitarian Help (DLAH in Spanish) in the Altas Montañas region of Veracruz, Mexico. The *p*-median model is used as a base for the location of various humanitarian warehouses combined with the vehicle routing problem with function capability for the response time to determine the delivery routes of products to municipalities affected by a natural disaster. Satisfactory results were obtained due to the geographical characteristics of the area subject to study, obtaining a DLAH made up of six warehouses and a total of fourteen routes with an average travel distance of 67.7 kilometers, which could support a fast supply route.

Keywords: humanitarian warehouses, logistic design of humanitarian help, *p*-median, vehicle routing problem.

Resumen

Las fenómenos naturales extremos han traído consigo entre otras afectaciones pérdidas humanas, materiales y ecológicas en todo el mundo. Situación que coloca a la logística humanitaria como un proceso relevante en la planeación de las actividades de múltiples actores, enfocadas a salvaguardar la vida del ser humano. Siendo el tiempo, un factor clave tras el impacto de un evento natural que desencadeno un desastre, la ubicación de instalaciones y sus caminos de aprovisionamiento y suministro pueden hacer la diferencia entre contar vidas o contar víctimas mortales. El presente artículo, muestra un Diseño Logístico de Ayuda Humanitaria (DLAH) en la región de las Altas Montañas en Veracruz, México, tomando como base el modelo de la *p*-mediana para la ubicación de múltiples almacenes humanitarios en combinación con el problema de ruteo vehicular con capacidad en función al tiempo de respuesta, para determinar las rutas de entrega de productos a municipios afectados por una catástrofe natural. Se obtuvieron resultados satisfactorios, debido a las características geográficas de la zona sujeta de estudio, obteniendo un DLAH compuesto de seis almacenes y un total de catorce rutas con un promedio de distancia recorrida de 67.7 kilómetros, con lo cual se podría llevar a cabo un rápido abastecimiento.

Palabras clave: almacenes humanitarios, diseño logístico de ayuda humanitaria, *p*-mediana, problema de ruteo vehicular.

Resumo

Fenómenos naturais extremos trouxeram consigo, entre outros efeitos, perdas humanas, materiais e ecológicas em todo o mundo. Situação que coloca a logística humanitária como um processo relevante no planeamento de atividades de múltiplos atores, com foco na salvaguarda da vida humana. Dado que o tempo é um factor chave após o impacto de um evento natural que desencadeou uma catástrofe, a localização das instalações e o seu abastecimento e rotas de abastecimento podem fazer a diferença entre contar vidas ou contar vítimas mortais. Este artigo mostra um Projeto Logístico para Ajuda Humanitária (DLAH) na região das Altas Montanhas em Veracruz, México, baseado no modelo p-mediana para a localização de múltiplos armazéns humanitários em combinação com o problema de roteamento de veículos com capacidade baseada em. tempo de resposta, para determinar rotas de entrega de produtos aos municípios afetados por um desastre natural. Foram obtidos resultados satisfatórios, devido às características geográficas da área em estudo, obtendo-se um DLAH composto por seis armazéns e um total de catorze percursos com uma distância média percorrida de 67,7 quilómetros, com os quais se realiza um rápido catering.

Palavras-chave: armazéns humanitários, desenho logístico de ajuda humanitária, p-mediana, problema de roteamento de veículos.

Fecha Recepción: Enero 2024 **Fecha Aceptación:** Septiembre 2024

Introduction

There is a *global risk* of the possibility of an event that negatively affects the gross national product, the population, and natural resources. Under this definition are 32 political, social, economic, technological, and environmental factors (Gobierno de España, 2024). With these parameters, the Global Risk Report (2023) divides its study into two periods of time, short-term (two years) and long-term (ten years). In both, the environmental risks that we can visualize are natural disasters and extreme weather events, the failure of mitigating and/or adapting to climate change, large-scale incidents that are harmful to the environment, a natural resource crisis, loss of biodiversity, and the collapse of ecosystems.

Flórez-Oviedo mentions that "worldwide natural disasters have been part of all of the generations of humanity, of existence and human development, leaving invaluable losses as a consequence" (2018, p. 319). In the same sphere, the General Law of Civil Protection (Ley General de Protección Civil [LGPC], in Spanish) defines a *disaster* as*:*

> The result of an occurrence of one or more severe or extreme events, linked together or not, whether natural, man-made, or space events, and occurring in a specific time and area, causing damage, and with its magnitude exceeding the affected community's ability to respond. It also defines as a *victim* a person affected by a disruptive element, whether they have suffered physical harm or damage to their assets in such a way that requires external assistance for survival, considering in the meantime that the emergency does not conclude until the situation returns to how it was before the disaster. (2023, p. 2)

The disasters can: 1. originate from nature: *a)* geological phenomena caused directly from actions and movements from the earth's crust; *b)* hydrometeorological phenomena, derived from the actions of atmospheric agents, and *c)* sanitary-ecological phenomena, a product of pathogenic action of biological agents that affect the population, animals, and harvests, causing death or affecting health. 2. originate from human activity: *a)* chemical-technological phenomena, arising from different substances derived from its molecular or nuclear interaction, and *b)* social-organizational phenomena, caused by human error or premeditated actions, in the framework of great concentrations or population movements (Secretaria de Salud, 2015).

Within disaster management are four main phases: 1. Mitigation. Its focus is prevention or reduction of the dangers of a disaster before they occur. 2. Preparation. This refers to a group of actions to empower society or the government in their efforts during a disaster. 3. Response. This includes the presence of emergency services after a disaster to protect life and property affected by the threat. 4. Recovery. Managing efforts to restore affected areas (Altai and Verde III, 2006).

In the last few years, there have been catastrophic disasters in diverse areas of the planet, among which we can mention the recent 7.5 magnitude earthquake in Japan on January 1st, 2024, the earthquake in Turkey and Syria (2023), the earthquake in Indonesia, the floods in Chad, Gambia, Pakistan, northeastern Bangladesh, heavy snowfall in Pakistan (2022), heavy rains in Germany, Belgium, Switzerland, and the Netherlands (2021), monsoon rains in South Asia (2020), droughts and fires in Australia (2020), the Idai cyclone that struck southeastern Africa (2019), earthquakes in Mexico (2017 and 2019), hurricane Maria in Puerto Rico and the Caribbean (2017), the earthquake in Quito, Ecuador (2016), landslides in the Serrana Region of the state of Rio de Janeiro in Brazil (2011), the earthquake and tsunami in Chile (2010), the earthquake in Haiti (2010) (Organización de las Naciones Unidas [ONU], 2023; Fondo de las Naciones Unidas para la Infancia [UNICEF], 2022; World Wildlife Fund, 2020; ONU HABITAD, Secretaria de Desarrollo Agrario, Territorial y Urbano [SEDATU] and Secretaria de Gestión Integral de Riesgo y Protección Civil de la Ciudad de México, 2019).

According to the report from the United Nations for Humanitarian Affairs (2020), the second region most prone to natural disasters in the world is Latin America and the Caribbean. From 2000 to 2020, 152 million Latin Americans and people in the Caribbean were affected by 1205 disasters such as floods, hurricanes, storms, earthquakes, landslides, droughts, fires, extreme temperatures, and volcanic events, Cuba, Mexico, and Haiti being the most affected countries.

Particularly, the exposure Mexico has to natural disasters has grown. The Managing Confederation of Mexico [COPARMEX] mentions that:

> According to experts, 40% of the country is exposed to a risk of earthquakes, droughts, floods, fires, or hurricanes. According to the World Bank, 68% of the Mexican population and 71% of the Gross National Product (GNP) are given to suffer the effects of natural disasters”. (2023, p. 1)

Mexico has 32 federal entities, and states such as Colima, Jalisco, Michoacan, Guerrero, Oaxaca, Veracruz, and Chiapas, among others, have greater exposure to seismic events due to their geological features. Meanwhile, states such as Baja California, Baja California Sur, Sinaloa, Tamaulipas, Guerrero, Oaxaca, Veracruz, Tabasco, Campeche, Yucatán, Quintana Roo, and Chiapas, among others, have an elevated level of exposure to tropical cyclones (Zepeda-Gil et al., 2018).

The engineering branch focuses on analyzing storage and distribution problems for products required for victims of a disaster and is denominated humanitarian logistics [HL] (Camacho-Vallejo et al., 2015). Humanitarian logistics is responsible for estimating, providing, storing, transporting, and distributing personnel, services, and materials required for the disaster area (Sharif and Salari, 2015). This is where location and routing models are essential for a fast and opportune response to victims of a natural disaster, either by transporting victims or support staff or provisioning and supplying products and services to victims.

Problem statement

The state of Veracruz is located in the central part of the slope of the Gulf of Mexico and borders seven Mexican states, Tamaulipas, San Luis Potosi, Hidalgo, Puebla, Oaxaca, Chiapas, and Tabasco. With a surface of 78 815 km^2, it represents 3.7% of the total surface area of Mexico (Secretaría de Desarrollo Económico y Portuario [SEDECOP], 2024). Likewise, Veracruz is divided into ten regions, Huasteca Alta, Huasteca Baja, Totonaca, Nautla, Capital, Altas Montañas, Sotavento, Papaloapan, Los Tuxtlas, and Olmeca. According to the Municipal Methodological Strategy Guide of Integral Management of Disaster Risks, Veracruz is among the eight states with a high concentration of municipalities that with a high to very high vulnerability to climate change (ONU HABITAD, Secretaria de Desarrollo Agrario, Territorial y Urbano [SEDATU] and Secretaria de Gestión Integral de Riesgo y Protección Civil de la Ciudad de México, 2019). Moreover, from 2000 to 2023, Veracruz was the site of 131 declared disasters according to the National Center for Disaster Prevention (Centro Nacional de Prevención de Desastres [CENAPRED], 2023).

Immersed in the state of Veracruz is a region denominated as Altas Montañas which has 57 municipalities, which has been the site of at least one declared disaster from 2000 to 2023. This is the reason that as a logistic strategy for HL, it hosts a Logistic Design for Humanitarian Help structure, based on the *p*-median and the vehicle routing problem for the location of humanitarian warehouses and delivery routes for products to the Altas Montañas region, Veracruz, which allows for the supply of essential products to victims of a natural disaster. Figure 1 shows Mexico and highlights the state of Veracruz, the Altas Montañas region is colored red.

Figure 1. Altas Montañas Region, Veracruz

Source: Secretaría de Finanzas y Planeación [SEFIPLAN] - COPLADER, 2005

The document is structured from here into the following sections, as part of the introduction, The Literature Review can be found, which reveals different investigations carried out concerning HL, specifically in aspects regarding location and routing. The document continues with Materials, Methods, and Techniques, in which the methodology that allows for the application of *p*-median and vehicle routing problems is presented. It continues with the Results Section, as well as the Discussion, Conclusions, and Future lines of research, and is finalized with a bibliography used to write this article, which can be characterized as a study case.

Literature Review

Humanitarian logistics has had a relevant role in the lives of human beings, elements such as pollution, climate change, and human activities have brought with it health problems, infrastructure damage, human loss of life and ecological imbalance worldwide. This is why various authors have carried out studies and applied methods in distinct disaster phases, either as a measure of prevention or as a response. Next, some of this research will be shown, focused on 1. The Facility Location Problem; 2. The Vehicle Routing Problem, and 3. A combination of these two problems.

As part of the Facility Location Problem, Barojas-Payán et al. (2021) developed a hybrid model that uses the *p*-median algorithm, the nearest neighbor algorithm, the greedy randomized adaptive search procedure (GRASP), and the continuous review inventory model (q, R) with some uncertainty locating multiple feasible facilities for humanitarian help,

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evaluated in one of the federative entities of Mexico. In the same way, Rascón-Limón et al. (2022) found municipalities to establish regional humanitarian response distribution centers in the seven regions that make up the state of Puebla with the Weber Problem. De Oliveira-Silva et al. (2019) also presented a procedure to establish a disaster operation distribution network, using UAV technologies and geographical information systems, which was evaluated in the state of Rio de Janeiro, Brazil. It is worth mentioning Berger-Vidal et al. (2018) used a simulation, inventory, and location model for optimal warehouse management and the location of shelters at risk of flooding in the district of Chosica in the province of Lima.

The vehicle routing problem is addressed in the article of Bruni et al. (2018), yet the authors propose greedy heuristics iterated by the vehicle routing problem in the posterior disaster phase, with arrival time being the objective. The investigation of Barojas-Payán et al. (2023) its objective is to design a supply network of products to victims in Chiapas, Mexico, using two stores with social interest as a base to safeguard products and use the vehicle routing problem to establish delivery routes. Meanwhile Breitbarth et al. (2021) developed a vehicle routing problem together with a *k-means* clustering algorithm to deliver food to homes in urban areas during the pandemic (2020) in Germany. In this same field, researchers Viera et al. (2020) implemented the vehicle routing problem as a contextualized routing tool for practices and policies of distributing water pumps, commonly found in places with a lack of water. Likewise, a mathematical model for large-scale response operations to disasters is proposed by Rosa-Xavier et al. (2019), optimizing the use of helicopters and minimizing response time by considering elements such as multiple deposit centers, vehicles, and products.

The combination of location problems and routing also shines a light on Rivas-Pastor et al. (2022), who propose a mathematical model for locating centers for temporary transfer centers and resource distribution through secondary routes, derived from the aftermath of the earthquake in Ecuador in 2016. Likewise, Barojas-Payán et al. (2020) presented the evaluation of a logistic model in literature, which uses the *p*-median problem for the location of humanitarian shelters, an extension of the model (*q, R)* to calculate inventory, and the vehicle routing problem to deliver products to victims of a natural phenomenon.

In the same area, the researchers Rath and Gutjahr (2014), present a mathematical heuristic (of a restriction group) for the location and storage routing in disaster situations, involving strategic cost objectives, operative costs, and demand. Finally, Barojas-Payán et al. (2022) propose a logistics model that allows the location of a feasible municipality for the installation of a warehouse and delivery routes through the classic *p*-median problem and vehicle routing problem, through which personal protection equipment can be supplied to hospitals that have patients suffering from COVID-19.

Materials, Methods, and Techniques

With the purpose of carrying out the logical design of humanitarian help in the state of Veracruz, Mexico, the following steps were followed: Step 1. Information collection, which is essential to supply programming for the model, and Step 2. Application of mathematical models such as the *p*-median problem and the vehicle routing problem. It is worth mentioning that the DLAH obtained in these models can be found in the Results section.

Step 1. Information collection

1. *Distance matrix.* A matrix reflects the distance in kilometers of each one of the 57 municipalities that make up the Altas Montañas region.
2. *Declared disaster*, from the CENAPRED webpage. The number of declared disasters is obtained by municipality belonging to the region subject to study. The analysis allows for the observation of the 57 municipalities that have been the motive of the declared disaster, the largest of these municipalities being de La Perla y Tequila.
3. *Vehicle capacity.* Time is a relevant factor in humanitarian assistance, capacity is considered the maximum driving distance that a vehicle can travel beginning and ending at a humanitarian warehouse (performance). 100 km is considered a maximum.

Step 2. Application of models

1. *P*-median problem

In decisions regarding the location of facilities, they should be made choosing between different sites, normally the site is chosen based on cost, profitability, response time, and proximity (Carro-Paz and González-Gómez, 2024). In emergency situations, time plays a relevant role, so much so that it could be the difference between life and death. The mathematical model of the *p*-median was used to locate six municipalities to form the DLAH within the Altas Montañas region - the quantity calculated according to the research of Cornejo-Sánchez et al. (2013) which allows for the supply of basic products to victims that live in nearby municipalities and that have been impacted by a natural phenomenon. The entire mathematical model of programming for the *p*-median is in the next section, obtained by Drożdziel et al. (2017) and Daskin and Maas (2015):

Parameters:

$h_i \;\; = Demand$

$d_{ij} = Distance\ between\ each\ node\ i, j$

$p \;\; = Number\ of\ defined\ locations$

Sets

$W = Finite\ group\ of\ nodes\ not\ empty$

Variables

$x_i = Allocation\ for\ each\ node\ i, j$

$y_i = Allocation\ of\ a\ unique\ location$

$$Min = \sum_{i \in W} \sum_{j \in W} h_i d_{ij} x_{ij} \qquad (1)$$

Subject to:

$$\sum_{j \in W} y_j = p \qquad (2)$$

$$\sum_{j \in W} x_{ij} = 1\ ; \quad \forall\ i\ \epsilon\ W \qquad (3)$$

$$x_{ij} - y_j \leq 0;\ \forall\ i\ \epsilon\ W \quad \forall\ j\ \epsilon\ W \qquad (4)$$

$$y_j\ \epsilon\ \{0; 1\};\ \ \forall\ i\ \epsilon\ W \qquad (5)$$

Equation (1) minimizes the distances in the demand; *equation (2)* is responsible for which exact *p* vertices are assigned regarding the *p*-median. *Equation (3)* satisfies the demand in site *j*. *Equation (4)* assigns the demand nodes that belong to the *p*-median. *Equation (5)* establishes variables y_i as binary variables.

The result of the programming reflects the municipalities of Atoyac, Coscomatepec, Cuichapa, Orizaba, Texhuacán and Totutla as the sites for humanitarian warehouses that make up the DLAH.

2. Vehicle Routing Problem

In 1959, George Bernard Dantzig and J.H Ramser introduced the vehicle routing problem, presenting the "truck dispatch problem" that models and describes a real-life problem related to fuel distribution from an operation center to different service stations with the objective of creating routes for a homogenous fleet of vehicles to serve a group of clients and minimize travel distance, therefore having a direct effect on other factors (Koç and Laporte, 2018; Daza et al., 2009). The VRP is a type of problem that studies the distribution of goods or services between an establishment and its clients. The objective of the classic VRP is to allow various clients to create the minimum number of routes possible and the lowest cost, starting and ending with the distribution center. In general, to achieve this objective, it is necessary to respect the capacity limit of each vehicle (CVRP), and this is one of the limitations of this problem. A complete solution for the VRP is possible when visiting all parties involved with the problem (Belver et al., 2017).

The VRP with capacities (CVRP) is a more specific study case, a mathematical model for a CVRP has the objective of designing a distribution route at the lowest possible cost for a fleet of vehicles in a distribution center that visits a group of clients (nodes). The vehicles belong to a fleet, which belong to a distribution center, and have a capacity. Every route starts and ends from the same distribution center, and the vehicle capacity should not be overloaded (Cossio-Franco and Hernández-Aguilar, 2018; Kir et al., 2017). The mathematical CVRP formulation is in the next section, the same as obtained by Cossio-Franco and Hernández-Aguilar (2018).

$$\sum_{i\in V}\sum_{j\in V} c_{ij}x_{ij} \tag{6}$$

Subject to:

$$\sum_{i\in V} x_{ij} = 1 \qquad j \in V \setminus \{0\} \tag{7}$$

$$\sum_{j\in V} x_{ij} = 1 \qquad i \in V \setminus \{0\} \tag{8}$$

$$\sum_{i\in V} x_{i0} = K \tag{9}$$

$$x_{ij} \in \{0,1\} \quad i,j \in V \tag{10}$$

$$\sum_{i\notin S}\sum_{j\in S} x_{ij} \geq r(S), \quad \forall\, S \subset V \setminus \{0\}, \quad S \neq \phi \tag{11}$$

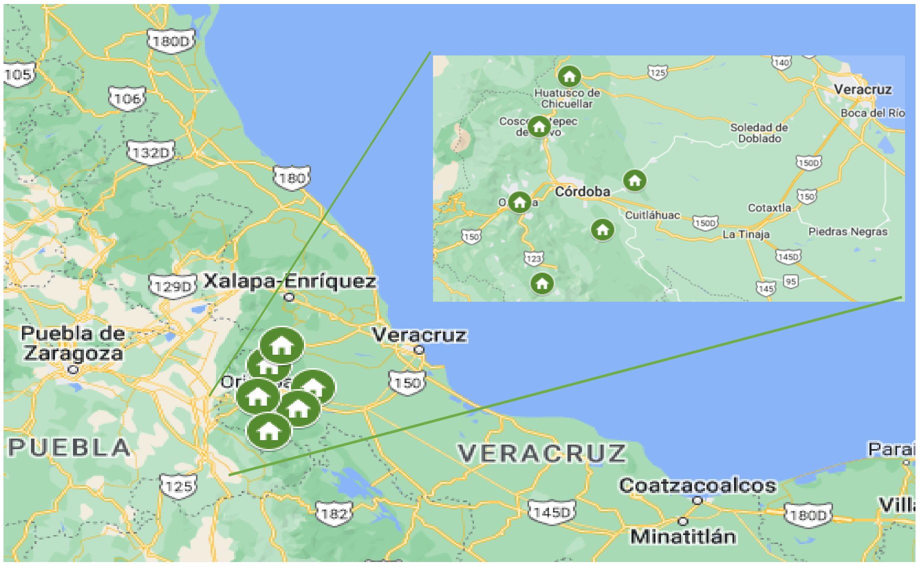
Equations (7), *(8)* and *(9)* correspond to the routing restrictions, *equation (10)* is for the model of two indexes that consider the decision variables, and *equation (11)* impedes the existence of sub-tour, controlling capacity and outage restrictions. $r(S)$ is where the minimum number of vehicles necessary to satisfy the demand on S is.

The vehicle routing problem was demarcated, not because of the load capacity of the trucks, but because of an average performance of 100 km for 40 L of gasoline. This was derived from the observation of the mountainous area, and as previously mentioned, in emergency situations time plays a relevant role. The results indicated two routes for the Atoyac site, one route for the Coscomatepec site, two routes for the Cuichapa site, four routes for the Orizaba site, two routes for the Texhuacán site, and three routes for the Totutla site.

Results

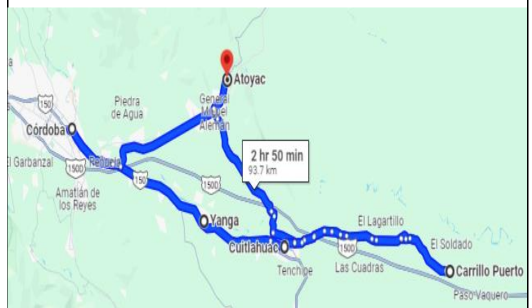
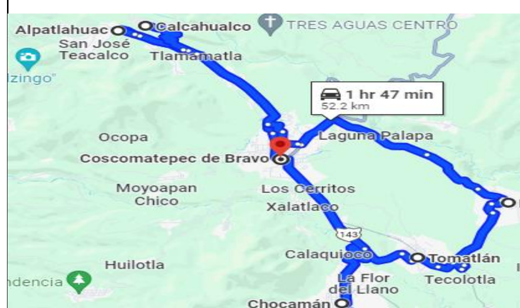
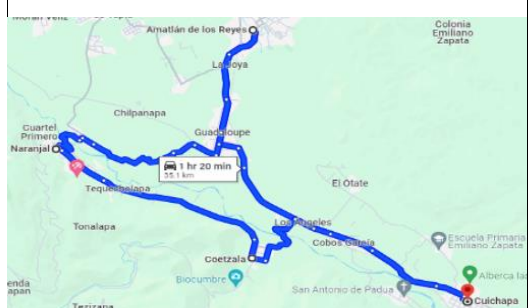
In figure 2, the six municipalities that make up the DLH can be seen, while in table 1, *a)* municipalities that form part of the DLAH; *b)* the number of routes per site; *c)* route description (municipality to supply) belonging to each site; *d)* distance in kilometers per route, and finally *e)* the graph obtained through Google Maps® to provide visual information of the results is presented. The following facts can be observed: 1. The site with the largest number of municipalities to supply is Orizaba with 18, and the lowest number is Cuichapa with five; 2. Every humanitarian warehouse supplies an average of 8.50 municipalities; 3. The average distance traveled from the site to the municipality affected is 156.73 km, and 4. A total of fourteen routes with an average distance of 67.17 km, the maximum distance being 93.9 km and the minimum 35.1 km.

Figure 2. Sites for humanitarian warehouses within the (DLAH)



Source: Own elaboration with Google Maps®

Table 1. Municipalities that make up the DLAH and delivery routes

Warehouse site	Route	Route Description (municipalities to supply)	km	Map
Atoyac	1	Atoyac – Carrillo Puerto – Cuitláhuac – Yanga – Córdoba – Atoyac	93.7	
	2	Atoyac – Tepatlaxco – Camarón de Tejeda – Paso del Macho – Atoyac	93.9	
Coscomatepec de Bravo	1	Coscomatepec de Bravo - Alpatláhuac – Calcahualco – Ixhuatlán del Café – Tomatlán – Chocamán – Coscomatepec de Bravo	52.2	
Cuichapa	1	Cuichapa – Amatlán de los Reyes – Naranjal – Coetzala – Cuichapa	35.1	

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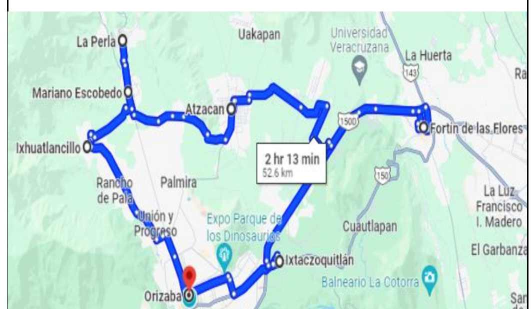
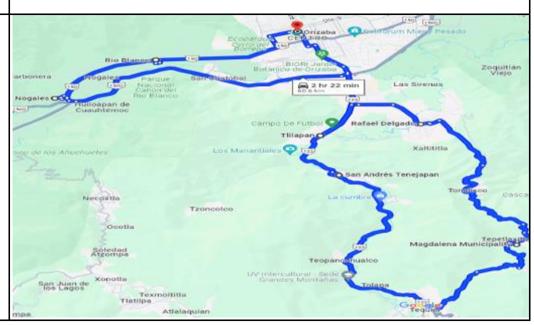
ISSN 2007 - 7467

	2	Cuichapa – Tezonapa – Omealca - Cuichapa	71	
Orizaba	1	Orizaba – Huiloapan de Cuauhtémoc – Soledad Atzompa – Acultzingo – Camerino Z. Mendoza - Orizaba	88.7	
	2	Orizaba – Ixtaczoquitlán – Fortín – Atzacan – La Perla – Mariano Escobedo – Ixhuatlancillo - Orizaba	52.6	
	3	Orizaba – Maltrata – Aquila - Orizaba	60.5	
	4	Orizaba – San Andrés Tenejapan – Magdalena – Rafael Delgado – Tlilapan – Nogales – Río Blanco - Orizaba	60.6	

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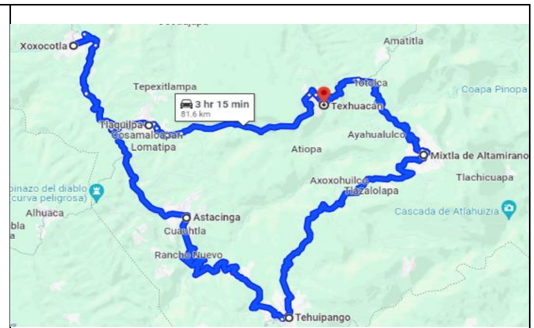
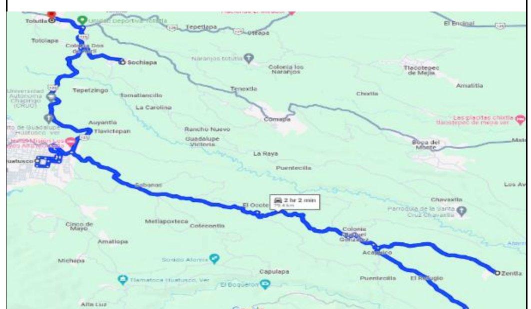
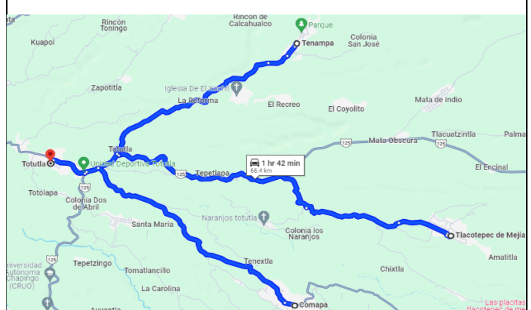
ISSN 2007 - 7467

Texhuacán	1	Texhuacán – Mixtla de Altamirano – Tehuipango – Astacinga – Xoxocotla – Tlaquilpa - Texhuacán	81.6	
	2	Texhuacán – Zongolica – Los Reyes – Tlahuilco - Texhuacán	56.9	
Totutla	1	Totutla – Sochiapa – Huatusco – Zentla - Totutla	79.4	
	2	Totutla –Tlacotepec de Mejía – Tenampa - Comapa - Totutla	66.4	
	3	Totutla – Tlaltetela – Totutla	47.8	

Source: Own elaboration with information obtained from the model and Google Maps®

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Discussion

Natural disasters, whatever their origin may be, have become more and more frequent and have had a higher impact worldwide, and have left irreparable damage on many occasions, which entails taking measures to mitigate this damage. Within humanitarian logistics, strategies are designed that allow for the safeguarding of human life, among which location sources for the supply of products to disaster victims and delivery routes can be found, considering time as a variable of vital importance that could mean the difference between life and death.

The DLAH we have presented considers the time factor to be a primordial element in making decisions regarding location and routing humanitarian facilities, which considers a shorter distance to be a shorter travel time. The Altas Montañas region is made up of 57 municipalities, all affected by natural phenomena, for which it is imperative to establish an opportune response method for their residents. The obtained DLAH shows strength in the number of municipalities affected that are assigned by site, Orizaba having the largest number with 18, and Cuichapa having the fewest with five, as well as the distance traveled from the humanitarian warehouse site to the assigned municipalities to supply. Orizaba is an urban center with a mild and humid climate and an average temperature of 22°C, (state and federal) highway and railroad access, and is designated as having a low degree of marginalization, which makes Orizaba a feasible location for a humanitarian warehouse (Secretaría de Finanzas y Planeación [SEFIPLAN] (2021); Secretaría de Desarrollo Social, 2018). The researchers Barojas-Payán et al. (2022) presented the location of multiple facilities within the state of Veracruz, Fortín de las Flores within the Altas Montañas region being the site of one warehouse designated for hydrometeorological natural disasters and considered a feasible location. Once again evaluating the formation of the DLAH, the results obtained were: 1 *p*, the Fortín site, which would be responsible for supplying the remaining 56 municipalities, and 2 *p*, Orizaba and Huatusco, which would supply 40 municipalities first and 15 municipalities second, which is considered unacceptable, as the delivery time would be longer.

One of the limitations of the DLAH is that the characteristics of the municipalities are not taken into consideration (services, access, telephone service, etc.), in other words, whether they can shelter humanitarian aid.

Small routes with an average distance of 67.17 kilometers can be observed, the maximum distance being 93.9 km and the minimum distance being 35.1 km, which could support a fast supply route. However, there is the disadvantage of this route being in a mountainous area, which implies difficult access to municipalities in the region that could also be time-consuming. This limitation is not considered in the design but could be considered feasible due to the number of municipalities necessary to supply.

Conclusions

The facility location and vehicle routing problem have been used for organizations to increase utility and/or decrease cost. However, various researchers and other individuals have used them to design strategies that allow for safeguarding the lives of victims in disasters. This document shows a Logistic Design of Humanitarian Help (DLAH in Spanish) in the Altas Montañas region of Veracruz, Mexico, using the *p*-median model as a base to locate multiple humanitarian centers combined with the vehicle routing problem to determine the delivery routes to municipalities affected by natural catastrophes. A DLAH was obtained that is made up of six (6) warehouses and fourteen (14) routes with an average travel distance of 67.7 kilometers, which could support a fast supply route. With these two additional evaluations, the municipality of Orizaba appeared as a site for a humanitarian warehouse.

Future lines of research

The present case study gives relevance to more frequent exposure to natural phenomena, not only in the state of Veracruz but also in the 32 entities that constitute Mexico. The study is a base for research and future designs regarding HL above all in Veracruz. As previously mentioned, it is one of the states in Mexico that is most exposed to natural phenomena, especially that of a hydrometeorological nature. The emergency network design has greater and greater importance worldwide, not only in natural disasters but in those caused by humanity.

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Revista Iberoamericana para la Investigación y el Desarrollo Educativo
ISSN 2007 - 7467

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