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# Logistics Strategies for the Distribution of Humanitarian Aid

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**Abstract.** The purpose of this document is to track down feasible locations for the installation of pre-positioned warehouses and their inventory levels, in the different areas that make up the state of Veracruz, Mexico. To do this, support organizations and institutions that respond to the disaster to maintain a quality of life for people affected by a hydrometeorological phenomenon. An integer nonlinear programming model is developed, the inventory level equation (q,R) is considered, and the analysis of institutional databases for its feeding, evaluated through its application in 90% of the regions belonging to the State of Veracruz, Mexico. The minimization of logistics costs involved in locating municipalities, which due to their characteristics, maybe the headquarters of pre-positioning warehouses, in this case, are Naranjos de Amatlán, Cerro Azul, Tihuatlán, San Rafael, Manilo Fabio Altamirano, Fortín de las Flores, Cosamaloapan and Las Choapas. Together with the variables of their inventory levels based on the different stages of human life: economic order quantity, reorder point, safety inventory and non-supply, which allow the supply of both food kits, equipment such as water and medicines (vaccines), to victims of a natural hydrometeorological phenomenon.
**Keywords:** Hydrometeorological Phenomenon; Pre-positioned Warehouses; Inventory Levels.

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## 1 Introduction

The number and scale of humanitarian operations have increased significantly in recent decades due to the increasing number of humanitarian emergencies and natural disasters worldwide [1]. Every year millions of people worldwide suffer from disasters as a result of extreme natural events. Whether it is an earthquake, a cyclone, or a flood, the risk of a natural event turning into a disaster not only depends on the strength of the natural event itself but also the social conditions and mechanisms established to respond quickly and provide assistance. Extreme natural events cannot be directly prevented. However, countries can reduce the risk of disasters by fighting poverty and hunger, strengthening education, health, and taking preventive measures [2].

The WorldRiskReport belonging to the year 2019, mentions that the three countries with the highest risk of disasters worldwide are the island states of Vanuatu, Antigua, and Barbuda and Tonga. The Island States are above average for countries with high or very high disaster risk on all continents. The 2019 disaster risk hotspot regions are found in Oceania, Southeast Asia, Central America, and West and Central Africa [3]. Latin America and the Caribbean are not territories excluded from the impact of natural phenomena, which not only have a regular but also an energetic presence, bringing with them floods, droughts, frosts, earthquakes. Table I shows a series of disasters that occurred during the period between 2000 and 2011, published by the World Bank (2012). It is possible to see the places of impact, human losses, and the cost that it brought with it. The appearance of the phenomenon, it is worth noting the death of more than 2 million people due to these events.

**Table 1**. Disasters in 2000 and 2011. Own elaboration, with data from [4].

| Year | Disaster | Country | Human casualties | Cost in millions of dollars |
|---|---|---|---|---|
| 2000 | Floods | Mozambique | 800 | 400 |
| 2004 | Tsunami | Indonesia | 165.000 | 4.500 |
| 2005 | Hurricanes | United States | 1.833 | 125.000 |
| 2008 - 2010 | Drought | Horn of Africa | | 13.3 |
| 2010 | Earthquake | Haiti | 230.000 | 7.800 |
| 2010 | Earthquake and tsunami | Chile | 562 | 30.000 |
| 2010 | Forest fires | Russia | 53 | 1.800 |
| 2010 | Floods | Pakistan | 1.985 | 10.100 |
| 2011 | Floods | Thailand | 813 | 45.000 |
| 2011 | Earthquake and tsunami | Japan | 20.000 | 210.000 |

*Notes:* The table shows a series of disasters that occurred during the period between 2000 and 2011, published by the World Bank (2012). It is possible to see the places of impact, human losses, and the cost that it brought with it. The appearance of the phenomenon, it is worth noting the death of more than 2 million people due to these events.

In this same area, in Mexico, the presence of natural disasters has registered, on average, 443.2 deaths per year between 1980 and 1990 with the cost of 455.3 million dollars, while in the period from 2000 to 2018 there have been 190 deaths with the cost of 2357 million dollars, being in this last period, 86.8% of the damages and losses about phenomena of hydrometeorological origin. An example of this was presented in Tabasco. The state suffered the most expensive flood in the Republic of Mexico, for an amount of $ 2918.6 million. Figure 1 shows the percentage of impact repeatability of natural phenomena in Mexico, during the period from 1980 to 2017, of which the states of Veracruz and Chiapas have the highest indices [5].

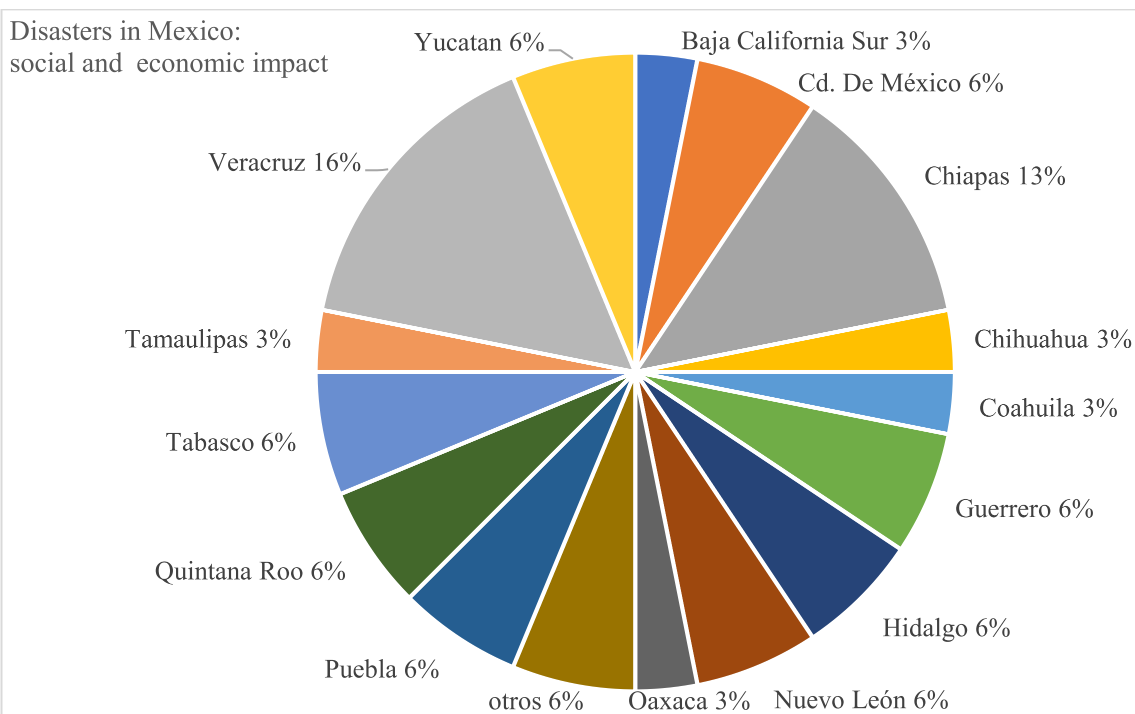


**Figure 1.** Disasters in Mexico: social and economic impact. Own elaboration, with data from [5].

*Notes:* The figure shows the percentage of impact repeatability of natural phenomena in Mexico, during the period from 1980 to 2017, of which the states of Veracruz and Chiapas have the highest indices.

### *1.1. Problematic*

The state of Veracruz is one of the wealthiest entities within the Mexican Republic, with an extension of 720 km of coastline, which represents 6.5% of the national total. Veracruz is a territory frequently impacted by hydrometeorological phenomena, which have damaged a large part of said entity, by 2015 more than 20 declarations of emergency was issued by the National Fund for Disaster (FONDEN, for its acronym in Spanish), while in 2016 were declared above 10 [6, 7, 8].

For this, it should be noted that the strategic proposition of emergency items, especially the decision on the location of emergency warehouses, have a significant impact on rapid disaster response to guarantee sufficient relief supplies. The decision to locate the emergency warehouse is a complex problem, where a wide variety of criteria must be considered, and the information of the decision-makers (DMs) may be imprecise or even absent [9].

For the before mentioned, and returning to the research [10], in which a mathematical model is developed based on *1.* The location of installation of pre-positioning for storing products, through which people affected by a hydrometeorological phenomenon can be supplied, and *2.* The extension of the inventory model (*q, R*) of continuous review with uncertain demand is established at the service level. Said document has two peculiarities: A. Products Division: *a)* food; *b)* equipment, personal hygiene, clothes, shoes; *c)* water, and *d)* medications, medical equipment and vaccines, and B. Division within the demand according to the human life cycle established by the World Health Organization (WHO): *a)* early childhood; *b)* childhood; *c)* adolescence; *d)* adulthood, and *e)* old age, leaving out particular stages such as the puerperium. Products *a)* and *b)* are calculated by the type of demand. These products are presented in the form of kits, while *c)* and *d)* are calculated from total demand. The model was evaluated in one of the ten regions of the state of Veracruz, Mexico called the Capital Region, leaving the field of application open to the remaining nine regions.

That is why, in this work, this model will be evaluated and validated, applied to 90% of the regions of the state of Veracruz, which have numerically higher and fewer instances, intending to establish a response network to the appearance of phenomena hydrometeorological that are the cause of a disaster.

The structure of the case study begins, first of all, with a literary review of the concepts used by institutions and organizations in Mexico that respond to disruptive agents, to describe later research that has been carried out in recent years in the field of emergency logistics, specifically in the aspects of the location of multiple facilities and inventory levels. Subsequently, the methodology used is proposed and developed, which includes the collection of information necessary for programming and feeding the logistics model, followed by the running of the said model through the Lingo 18.0 software, ending with the presentation of results. The corresponding conclusions and the bibliographic sources consulted and used for the investigation are shown below.

### *1.2. State of the art*

The phenomenon that occurs within the ecosystem is generically called a natural event and is generated by it on a large scale. Earthquakes, floods, and hurricanes are an example of this. When natural events are likely to occur, a natural event threat is said to exist [11].

According to the General Law of Civil Protection (2013), a disturbing phenomenon or agent/threat is a potentially damaging physical event, natural or derived from human activity, which can have different origins: 1. Natural: (a) Geological, earthquakes, volcanic eruptions, tsunamis, slope instability and subsidence, and (b) hydrometeorological, tropical cyclones, extreme rains, floods, snowstorms and hail, and 2. Anthropogenic: (a) chemical-technological; (b) sanitary-ecological, or (c) socio-organizational [12-13].

In order to respond to these events, and provide support to the people affected by it, the institutions and organizations dedicated to safeguarding and maintaining a quality of life for the victims, develop what is called disaster risk management.

Disaster risk management is a combination of activities that includes: 1. Risk identification, risk assessments, risk mapping, information campaigns, and public outreach, among others; 2. Risk reduction, structural and non-structural measures, land use planning, policy and regulations, infrastructure modernization; 3. Preparation, the prior establishment of emergency response teams, early warning systems, contingency planning, among others; 4. Financial protection, evaluation and reduction of contingent liabilities, budget allocation, and execution, ex-ante and ex-post financing instruments, and 5. Resilient reconstruction; resilient recovery and reconstruction policies, ex-ante design of institutional response mechanisms [4, 14].

Otherwise, if there is no have successful risk management, the impact can bring disaster.

Disaster is called the result of the occurrence of one or more severe and/or extreme disruptive agents, concatenated or not, of natural origin or human activity, which, when they occur at a particular time and in a particular area, cause damage and which magnitude exceed the response capacity of the affected community. While the disaster area is the territorial space determined over time by the formal declaration of the competent authority, under the imbalance, it suffers in its social structure, preventing the common fulfillment of the activities of the community. It may involve the exercise of public resources through the Disaster Fund [15].

In Mexico, the Natural Disaster Fund (FONDEN) is a financial instrument through which, within the National Civil Protection System (SINAPROC, for its acronym in Spanish), through the Operating Rules of the Fund itself and the procedures derived from them, integrates a process respectful of the competences, responsibilities, and needs of the various levels of government, which aims, under the principles of co-responsibility, complementarity, opportunity, and transparency, to support the federal entities of the Mexican Republic, as well as the agencies and entities of the Federal Public Administration, in the care and recovery of the effects that produce a natural phenomenon, following the parameters and conditions provided in its Rules of Operation [16].

In the investigation of [17], it is mentioned that the inability to plan relief operations during disaster situations leads to enormous human suffering and wasted resources. Humanitarian relief efforts in response to natural and human-made disasters often involve complicated logistical coordination. In Mexico, the Government Secretary (SEGOB) in 2006, establishes that requests by federal entities for the supply of consumable supplies that are required to attend to the affected population are considered for a period of up to 4 days, with the possibility of making additional requests [18]. For this reason, it is necessary to establish strategic infrastructures that allow the safekeeping of goods that allow the needs of food, clothing, and health to be met promptly for people affected by a natural phenomenon.

Strategic infrastructure is one that is essential for the provision of public goods and services, and whose destruction or disqualification is a threat against national security and would affect the population, its assets or the environment [19].

Building on the preceding paragraphs and on strengthening [20], who mentions that "using the warehouse to guard emergency relief items has been shown to improve overall responsiveness, efficiency, and effectiveness of the chain of humanitarian supply while reducing the cost incurred in the process." This case study is based on the mathematical model of [10] in which it proposes the location of a single facility to a pre-positioned warehouse and its inventory levels in the event of a natural hydrometeorological disaster, said model is evaluated in the Capital Region of the state of Veracruz, Mexico.

Similar studies have been carried out in recent years; some of them are mentioned below:

In order for warehouses to work appropriately, it is sought that their location has specific attributes, which is why researchers [21], empirically identify critical factors for the selection of warehouse locations in logistics humanitarian using mixed methods. The results show that cooperation is the most important factor, followed by national stability, cost, logistics, and location. Subsequently, the research by [22], analyze the administrative implications in the previous positioning of warehouses, from a national to a local level. Using the fuzzy TOPSIS method to obtain final locations. Subsequently, in the year 2018, the researchers [23], structured a two-step methodology using the fuzzy AHP and fuzzy TOPSIS method to identify pre-positioning warehouse location factors, determine the applied weights to those factors and evaluate warehouse location alternatives for humanitarian aid organizations.

Different methods have been used for the establishment of warehouses in humanitarian logistics, one of them is the document by [9], which provides a flexible and systematic framework for selecting the location of a pre-positioned emergency warehouse. The authors attempt to propose a new stochastic multi-criteria classification method (MCDA) to solve the problem of imprecise weight information. The proposed method expands the conventional ELECTRE-II method by incorporating inaccurate information and extends its application to the emergency warehouse location field. An illustrative example shows that the method is effective and direct. In that same area, the researchers [24], provides a metaheuristic to determine the most suitable location for support centers. Such metaheuristics are based on the Means Clustering (KMC) algorithm extended to associated capabilities of support centers. A micro-genetic algorithm estimates the search interval and a decision model based on the chance to improve final assignments. Similarly, the document by [25], proposes a two-phase heuristic approach to locate the location of temporary warehouses and their supply points in humanitarian logistics. The benefits of the model are shown through a case study in Los Angeles County.

An addition in terms of elements to the logistics system is the inventory levels, in [26], the researchers present a model that combines the problem of locating facilities for the establishment of a pre-positioned warehouse, calculating its inventory levels and establishing delivery routes and one of the regions that make up the state of Veracruz. The results show the municipality of Fortín de las Flores as headquarters, its inventory levels, and 14 product delivery routes. For their part, [27], developed a two-stage stochastic programming model to minimize the total cost of installation location, inventory retention, transportation, and scarcity. The solution method shows the feasibility of up to 25 scenarios. Other elements have been added over time in the investigations, such as those by [28], who specify the optimal management of supply warehouses, the location of shelters and the risk of floods is analyzed through simulation models of different environments, inventories and location of the optimal number of centers to be installed, taking the Chosica district as a case study.

Likewise, researchers [29], present a routing location problem (LRP) model, which considers the location of warehouses and delivery routes to maximize rescue efficiency. The objective is to minimize the time and cost established by the LRP model considering different scenarios. A hybrid self-adaptive bat algorithm (HSABA) is improved to solve the NP model instead of the basic BA. The model is evaluated at 20 demand points, showing that the model can effectively select supply locations and plan rescue routes in the face of different disasters, and the HSABA exceeds the basic BA.

## 2 Methodology

Figure 2 presents the methodology carried out for the investigation, which begins with the compilation of the necessary information to feed the programmed system from the logistics model, followed by the feeding of said system, then to gather and interpret the results.

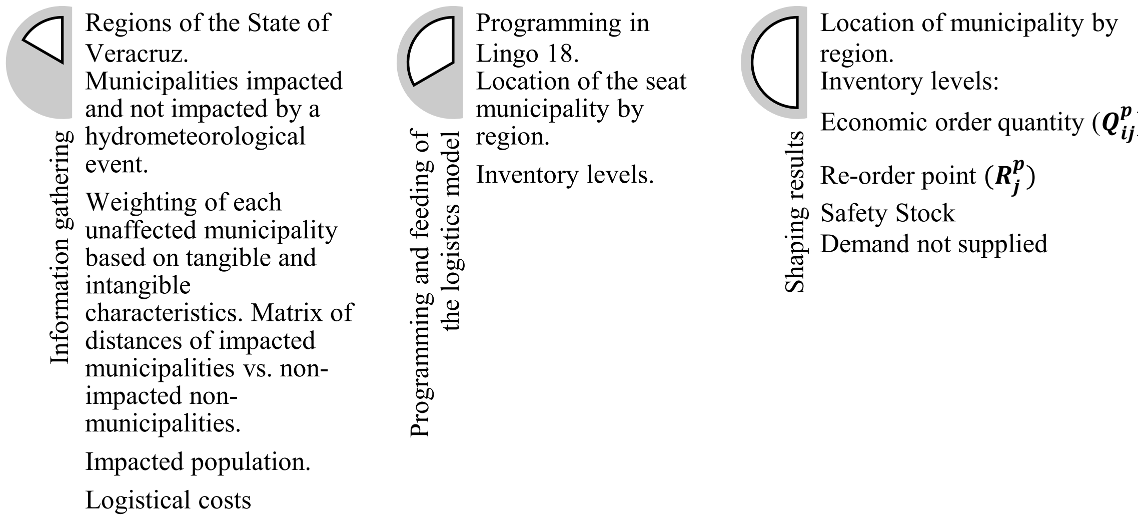


**Figure 2.** Research methodology.

*Notes:* The figure presents the methodology carried out for the investigation, which begins with the compilation of the necessary information to feed the programmed system from the logistics model, followed by the feeding of said system, then to gather and interpret the results.

### 2.1. *Information gathering.*

The database that feeds the system is created from government pages, with information from:

1. *Regions of the State of Veracruz*, the state of study, is home to 212 municipalities divided into ten regions. For the present case study and model evaluation, data from only nine regions will be used: (1) Huasteca Alta with 15 municipalities; (2) Huasteca Baja with 18 municipalities; (3) Totonaca with 15 municipalities; (4) Nautla with 11 municipalities; (5) Altas Montañas with 57 municipalities; (6) Sotavento with 12 municipalities; (7) Papaloapan with 22 municipalities; (8) Los Tuxtlas with four municipalities, and (9) Olmeca with 25 municipalities [30].
2. *Municipalities impacted and not impacted by a hydrometeorological event*, during 2016, 106 of the 179 municipalities studied, were the cause of an emergency declaration by FONDEN due to the impact of a hydrometeorological phenomenon: (1) Huasteca Alta, four affected municipalities; (2) Huasteca Baja, ten affected municipalities; (3) Totonaca, three affected municipalities; (4) Nautla, nine affected municipalities; (5) High Mountains 49 affected municipalities; (6) Sotavento, ten affected municipalities; (7) Papaloapan, seven affected municipalities; (8) Los Tuxtlas, four affected municipalities, and (9) Olmeca, ten affected municipalities [31]. It should be noted that analyzing the databases of institutional organizations to define the impacted municipalities of the non-impacted municipalities. It is observed that in the Region called Los Tuxtlas, all the municipalities have been the reason for an emergency declaration, for which reason, together with the Olmec Region for its application within the logistics model, having the zoning of 8 evaluation spaces.
3. *The weighting of each unaffected municipality based on tangible and intangible characteristics*, with a range from 0 to 100, refers to the compliance that a municipality has concerning the minimum characteristics to house a pre-positioned warehouse. (1) Proximity to suppliers refers to the number of social development stores immersed, with a maximum percentage of 30%; (2) access to the highway, with a percentage of 40%, and (3) marginalization rate, among other things, observe the population's infrastructure, services, and education levels; Maximum 30% [32, 33, 34, 35].
4. *Matrix of distances of impacted municipalities and non-impacted non-municipalities*, the distances between the municipalities are extracted from Google Earth® software.
5. *Impacted population, from the 2016 FONDEN declarations of emergency*, the demand to supply is obtained. Table 2 shows the demand, divided into each of the stages of human life established by the

World Health Organization (WHO) and taken by the model, as can be seen, the Capital Region is not found, because it was previously studied [31].

6. *Logistics costs, the costs associated with inventory levels*, such as *a)* ordering, includes administrative costs for order processing, transportation costs to the warehouse, and handling of product receipt costs; *b)* holding, includes space, service and risk costs; *c)* purchase, cost per product and *d)* stockout, associated with the unavailability of the product that requires movement between warehouses. All this is calculated with the support of [36, 37].

**Table 2.** Demands by region and by stage of life of the human being. Own elaboration, with data [31].

| No. | Region | Demand_1 $D_j^p$ (early childhood) | Demand_2 $D_j^p$ (childhood) | Demand_3 $D_j^p$ (adolescence) | Demand_4 $D_j^p$ (adulthood) | Demand_5 $D_j^p$ (old age) | Demand_6 $D_j^p$ (general) |
|---|---|---|---|---|---|---|---|
| 1 | Huasteca Alta | 4917 | 11077 | 17210 | 17723 | 4559 | 55486 |
| 2 | Huasteca Baja | 5689 | 13723 | 18557 | 17398 | 5097 | 60464 |
| 3 | Totonaca | 3552 | 7897 | 13903 | 13993 | 3520 | 42865 |
| 4 | Nautla | 4248 | 10050 | 14922 | 14299 | 3984 | 47503 |
| 5 | Sotavento | 9710 | 20929 | 41432 | 43352 | 9764 | 125187 |
| 6 | Altas Montañas | 26144 | 55938 | 86991 | 70294 | 17151 | 256518 |
| 7 | Papaloapan | 4231 | 9713 | 16537 | 17000 | 4424 | 51905 |
| 8 | Los Tuxtlas | 3480 | 8391 | 13004 | 12068 | 2913 | 39856 |
| 9 | Olmeca | 13218 | 29110 | 53007 | 46370 | 9509 | 151214 |

*Notes:* The table shows the demand, divided into each of the stages of human life established by the World Health Organization (WHO) and taken by the model, as can be seen, the Capital Region is not found, because it was previously studied [31].

*2.2. Programming and feeding of the logistics model.*

A territorial extension is made to the mathematical model of [10], which presents the location of 1 pre-positioned warehouse and its inventory levels for each of the demands of a single Veracruzana region. This case study reflects the results of its application in 9 regions immersed in the State of study with different numbers of instances. Next, we will see the objective function and the restrictions of the mentioned mathematical model.

$$\text{Min} \ \left\{f(Y) = \sum_{j=1}^{J}\sum_{i=1}^{I} w_i d_{ij}(Y_{ij})\right\} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P}\left[ {Co_i^p\left(D_j^p\right)}/{Q_{ij}^p} + Cs_i\left({Q_{ij}^p}/{2} + z_{cls} * S'^p_j\right) + C_i^p\left(D_j^p\right) + \frac{D_j^p}{Q_{ij}^p}\left(Cf_i^p + S'^p_{D_j} * E_{z_i}^p\right)\right] \quad \ldots\ldots\ldots (1)$$

Subject to:

$$\sum_{j=1}^{J} Y_{ij} = 1 \qquad i = 1,2,\ldots,I \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$S'^p_{D_j} = S'^p_{D_j}\sqrt{L} \qquad i = 1,2,\ldots,I \quad j = 1,2,\ldots,J \quad \ldots\ldots\ldots\ldots\ldots (3)$$

$$R_{D_j}^p = D_j^p L + Z_{CSL}\, S'^p_{D_j} \quad i = 1,2,\ldots,I \ \ j = 1,2,\ldots,J \quad p = 1,2,\ldots,P \ \ldots\ldots\ldots (4)$$

$$Q_{ij}^p = \sqrt{2Co_i\left({\sum_{j=1}^{J} Y_{ij}^p D_j^p}/{Cs_i^p}\right)} \qquad i = 1,2,\ldots,I \quad j = 1,2,\ldots,J \quad p = 1,2,\ldots,P \ \ldots\ldots (5)$$

$$E_{z_i}^p = z\left[F_s^p(z) - 1\right] + f_s^p\,(z) \quad i = 1,2,\ldots,I \ \ p = 1,2,\ldots P \ \ldots\ldots (6)$$

$$FR_i^p = 1 - {S'^p_j \ E_{z_i}^p}/{Q_{ij}^p} \qquad i = 1,2,\ldots,I \qquad p = 1,2,\ldots,P \ \ldots\ldots (7)$$

$$Y_{ij} \in \{0,1\} \ \ldots\ldots (8)$$

$$Q_{ij}^p \in Z^+ \ \ldots\ldots (9)$$

$$Y_{ij}^p \in \{0,1\} \ \ldots\ldots (10)$$

*Equation (1)* represents the objective function of the mathematical model, which seeks to minimize costs from the minimum distance travelled and the logistics costs generated by the installation of a pre-positioned warehouse. It should be noted that the cost is \$ 1.00 per kilometer travelled. The first term represents the positional weight calculated from the characteristics of the municipalities that have not been affected by a hydrometeorological natural event multiplied by the distance travelled between the municipalities mentioned above and those affected by the natural phenomenon. In contrast, the second term presents the sum of the logistics costs of the pre-positioned warehouse located in the municipality $i$, which supplies municipalities $j$ with products $p$ necessary to maintain a quality of life for the victims of said municipalities.

*Equation (2)* indicates the allocation to municipality $i$ where the pre-positioning warehouse of the impacted municipalities $j$ is located; *equation (3),* calculation of the adjusted deviation of each of the demands of the affected municipalities $D_j$; *equation (4),* calculation of the reorder point of the products $p$ for each demand of the affected municipalities $D_j$; *equation (5)* calculates the number of products $p$ ordered by the pre-positioned warehouse located in the municipality $i$, to supply affected municipalities $j$; *equation (6),* loss function, that is, affected people who did not receive help; *equation (7),* calculation of the level of service in the delivery of products.

*Equation (8),* the variable $Y_{ij}$ that represents the assignment of affected municipalities to the municipality where the warehouse is located is of a binary type; *equation (9),* the variable $Q_{ij}^{p}$ that represents the quantity of products $p$ that must be requested by the pre-positioned warehouse located in the municipality $i$ to cover the demand of the impacted municipality $j$ is of integer type, and *equation (10),* the variable $Y_{ij}^{p}$ that represents the pre-positioned warehouse in the municipality $i$, which supplies the impacted municipalities $j$, with products $p$ is of a binary type.

### *2.3. Programming software.*

LINGO 18.0 is a comprehensive tool designed to make the construction and resolution of linear, nonlinear (convex and non-convex / global), quadratic, constrained quadratic, second-order cone, semi-defined, stochastic, and integer optimization models faster, easier and more efficient [38].

## 3 Results

Before recording the results obtained from the different evaluations of the model, Table 3 shows the number of runs of the program, the regions of the state of Veracruz to which the model was applied, the number of municipalities that are concentrated, their municipalities impacted and its unaffected municipalities, to later give way to the concentration of results.

**Table 3.** Regions of application to the model.

| No. corrida | Region | Total Municipalities | Impacted municipalities | Municipalities not impacted |
|---|---|---|---|---|
| 1 | Huasteca Alta | 15 | 4 | 11 |
| 2 | Huasteca Baja | 18 | 10 | 8 |
| 3 | Totonaca | 15 | 3 | 12 |
| 4 | Nautla | 11 | 9 | 2 |
| 5 | Altas Montañas | 57 | 49 | 8 |
| 6 | Sotavento | 12 | 10 | 2 |
| 7 | Papaloapan | 22 | 7 | 15 |
| 8 | Los Tuxtlas + Olmeca | 4 + 25 = 29 | 4 + 10 | 15 |

*Notes:* The table shows the number of runs of the program, the regions of the state of Veracruz to which the model was applied, the number of municipalities that are concentrated, their municipalities impacted and its unaffected municipalities.

Figure 3 shows the nine regions subject to study and the location of the municipalities host to the pre-positioned warehouses on the left side, while the municipalities host to the pre-positioned warehouses and the impacted municipalities, (through the application from Google Maps®) due to some natural phenomenon of hydrometeorological type on the left side.

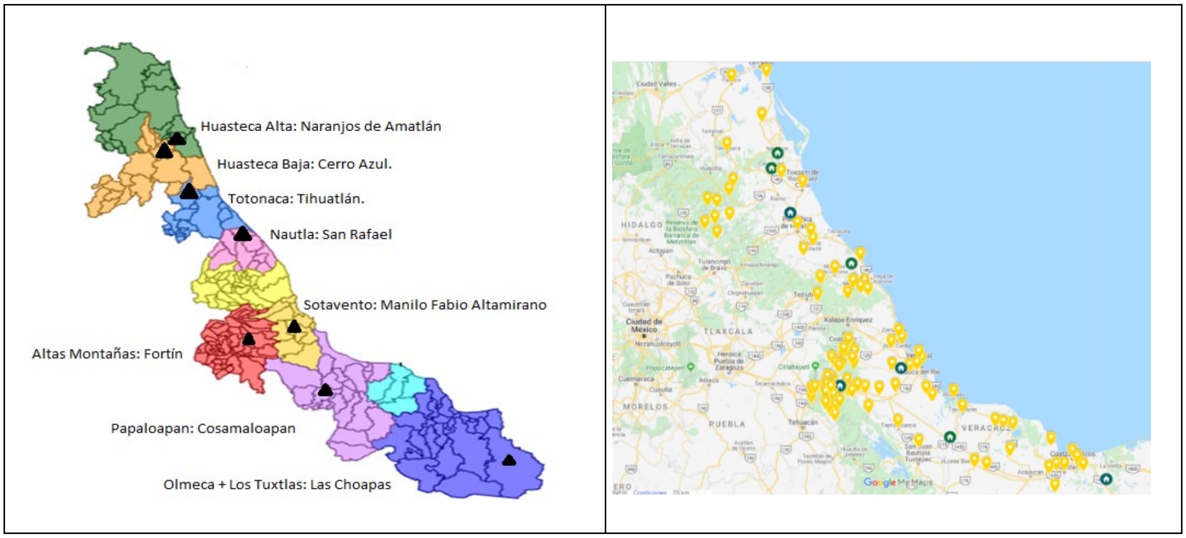


**Figure 3.** Location of pre-positioned warehouses by region [39].

*Notes: T*he figure shows the nine regions subject to study and the location of the municipalities host to the pre-positioned warehouses on the left side, while the municipalities host to the pre-positioned warehouses and the impacted municipalities, (through the application from Google Maps®) due to some natural phenomenon of hydrometeorological type on the left side.

While Table 4 shows the economic quantities of the order, re-order point, safety inventory and the non-supply of food and water; It is complemented by Table 5, where the same indicators are shown, but in equipment (clothing, cleaning equipment, boots) and medications for each demand, both in the form of kits.

**Table 4.** Results were obtained for the supply of food and water in the nine regions.

| Location of the warehouse/ Kits/type of demand | Demand_1 early childhood | Demand_2 childhood | Demand_3 adolescence | Demand_4 adulthood | Demand_5 old age | Demand_6 general |
|---|---|---|---|---|---|---|
| Huasteca Alta: Naranjos de Amatlán | | | | | | |
| Economic order quantity | 2020 | 3830 | 5827 | 5996 | 1674 | 27644 |
| Re-order point | 1544 | 3354 | 5532 | 5562 | 1318 | 17288 |
| Safety Stock | 897 | 1897 | 3268 | 3230 | 718 | 9988 |
| Not supplied | 2 | 3 | 5 | 5 | 2 | 15 |
| Huasteca Baja: Cerro Azul | | | | | | |
| Economic order quantity | 3539 | 8046 | 10828 | 10157 | 3051 | 53304 |
| Reorder point | 878 | 2109 | 3004 | 2955 | 865 | 9738 |
| Safety Stock | 130 | 304 | 563 | 666 | 194 | 1782 |
| Not supplied | 1 | 1 | 1 | 1. | 1 | 3 |
| Totonaca: Tihuatlán | | | | | | |
| Economic order quantity | 1518 | 2674 | 4544 | 4572 | 1285 | 20413 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Reorder point | 769 | 1621 | 3186 | 3389 | 822 | 9768 |
| Safety Stock | 301 | 582 | 1356 | 1548 | 359 | 4128 |
| Not supplied | 1 | 1 | 2 | 3 | 1 | 7 |
| Nautla: San Rafael | | | | | | |
| Economic order quantity | 2156 | 4494 | 6586 | 6316 | 1859 | 31114 |
| Reorder point | 777 | 1781 | 2745 | 2556 | 660 | 8486 |
| Safety Stock | 218 | 459 | 781 | 674 | 135 | 2236 |
| Not supplied | 1 | 1 | 2 | 1 | 1 | 4 |
| Sotavento: Manilo Fabio Altamirano | | | | | | |
| Economic order quantity | 3624 | 7087 | 13829 | 14463 | 3398 | 57637 |
| Reorder point | 2205 | 4697 | 9623 | 10015 | 2119 | 28647 |
| Safety Stock | 927 | 1943 | 4172 | 4311 | 835 | 12175 |
| Not supplied | 2 | 3 | 7 | 67 | 2 | 18 |
| Altas Montañas: Fortín de las Flores | | | | | | |
| Economic order quantity | 8753 | 17948 | 27779 | 22477 | 5629 | 117672 |
| Reorder point | 3711 | 7920 | 12421 | 10193 | 2488 | 36,640 |
| Safety Stock | 271 | 560 | 975 | 944 | 231 | 2,888 |
| Not supplied | 1 | 1 | 2 | 2 | 1 | 5 |
| Papaloapan: Cosamaloapan | | | | | | |
| Economic order quantity | 1806 | 3431 | 5698 | 5850 | 1651 | 25869 |
| Reorder point | 711 | 1571 | 2725 | 2666 | 654 | 8277 |
| Safety Stock | 155 | 293 | 549 | 429 | 72 | 1448 |
| Not supplied | 1 | 1 | 1 | 1 | 1 | 3 |
| Los Tuxtlas + Olmeca = Las Choapas | | | | | | |
| Economic order quantity | 5882 | 12416 | 21691 | 19219 | 4230 | 93797 |
| Reorder point | 3214 | 7071 | 12609 | 11033 | 2359 | 36255 |
| Safety Stock | 1017 | 2137 | 3923 | 3344 | 724 | 11114 |
| Not supplied | 2 | 4 | 6 | 5 | 2 | 17 |

*Notes:* The table shows the economic quantities of the order, re-order point, safety inventory and the non-supply of food in form of kits and water for the all regions; It is complemented by table V.

**Table 5.** Results were obtained for the supply of equipment and medicines in the nine regions.

| Location of the warehouse/ Kits/type of demand | Demand_1 early childhood | Demand_2 childhood | Demand_3 adolescence | Demand_4 adulthood | Demand_5 old age | Demand_6 general |
|---|---|---|---|---|---|---|
| Huasteca Alta = Naranjos. | | | | | | |
| Economic order quantity | 1832 | 3830 | 5827 | 5996 | 1674 | 27583 |
| Reorder point | 1544 | 3354 | 5532 | 5562 | 1318 | 17288 |
| Safety Stock | 897 | 1,897 | 3268 | 3230 | 718 | 9,988 |
| Not supplied | 2 | 3 | 5 | 5 | 2 | 15 |
| Huasteca Baja = Cerro Azul. | | | | | | |
| Economic order quantity | 3419 | 8046 | 10828 | 10157 | 3035 | 27467 |
| Reorder point | 878 | 2109 | 3004 | 2955 | 865 | 9738 |
| Safety Stock | 130 | 304 | 563 | 666 | 194 | 1782 |
| Not supplied | 1 | 1 | 1 | 1 | 1 | 3 |
| Totonaca = Tihuatlán | | | | | | |
| Economic order quantity | 1335 | 2674 | 4544 | 4572 | 1258 | 20246 |
| Reorder point | 769 | 1621 | 3186 | 3389 | 822 | 9768 |
| Safety Stock | 301 | 582 | 1356 | 1548 | 359 | 4128 |
| Not supplied | 1 | 1 | 2 | 3 | 1 | 7 |
| Nautla = San Rafael. | | | | | | |
| Economic order quantity | 2006 | 4494 | 6586 | 6316 | 1838 | 22473 |
| Reorder point | 777 | 1781 | 2745 | 2556 | 660 | 8486 |
| Safety Stock | 218 | 459 | 781 | 674 | 135 | 2236 |
| Not supplied | 1 | 1 | 2 | 1 | 1 | 4 |
| Sotavento = Manilo Fabio Altamirano. | | | | | | |
| Economic order quantity | 3422 | 7087 | 13829 | 14463 | 3370 | 35049 |
| Reorder point | 2205 | 4697 | 9623 | 10015 | 2119 | 28647 |
| Safety Stock | 927 | 1943 | 4172 | 4311 | 835 | 12175 |
| Not supplied | 2 | 3 | 7 | 67 | 2 | 18 |
| Altas Montañas = Fortín de las Flores. | | | | | | |
| Economic order quantity | 8531 | 17948 | 27779 | 22477 | 5599 | 36640 |
| Reorder point | 3711 | 7920 | 12421 | 10193 | 2488 | 22668 |
| Safety Stock | 271 | 560 | 975 | 944 | 231 | 2,888 |
| Not supplied | 1 | 1 | 2 | 2 | 1 | 5 |
| Papaloapan = Cosamaloapan de Carpio. | | | | | | |
| Economic order quantity | 1625 | 3431 | 5695 | 5850 | 1625 | 25562 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Reorder point | 711 | 1571 | 2725 | 2666 | 654 | 8277 |
| Safety Stock | 155 | 293 | 549 | 429 | 72 | 1448 |
| Not supplied | 1 | 1 | 1 | 1 | 1 | 3 |
| Los Tuxtlas + Olmeca = Las Choapas. | | | | | | |
| Economic order quantity | 5670 | 12416 | 21691 | 19219 | 4201 | 37478 |
| Reorder point | 3214 | 7071 | 12609 | 11033 | 2359 | 36255 |
| Safety Stock | 1017 | 2137 | 3923 | 3344 | 724 | 11114 |
| Not supplied | 2 | 4 | 6 | 5 | 2 | 17 |

*Notes:* The table shows the economic quantities of the order, re-order point, safety inventory and the non-supply of equipment (clothing, cleaning equipment, boots) and medications for each demand, both in the form of kits.

Continuing with the presentation of the results obtained, Table 6 shows the distances to be travelled and the costs of the inventories incurred.

**Table 6.** Distances and total supply costs per the pre-positioned warehouse.

| No. | Region | Location | Impacted Municipalities | Distance (km) | Inventory cost ($ in MX) |
|---|---|---|---|---|---|
| 1 | Huasteca Alta | Naranjos de Amatlán | 4 | 415.11 | 86,483,149.00 |
| 2 | Huasteca Baja | Cerro Azul | 10 | 1,277.03 | 94,199,986.58 |
| 3 | Totonaca | Tiahuatlán | 3 | 176.46 | 47,575,344.00 |
| 4 | Nautla | San Rafael | 9 | 525.90 | 74,202,592.25 |
| 5 | Sotavento | Manilo Fabio Altamirano | 10 | 885.10 | 196,722,909.80 |
| 6 | Altas Montañas | Fortín de las Flores | 49 | 1,855.05 | 397,229,513.27 |
| 7 | Papaloapan | Cosamaloapan | 7 | 447.99 | 81,485,299.62 |
| 8 | Los Tuxtlas + Olmeca | Las Choapas | 14 | 1,479.66 | 364,360,158.24 |
| TOTAL | | | 106 | 7,062.29 | 1,342,258,952.76 |

*Notes.* The table shows the region, locations for the installation of pre-positioned warehouses, number of impacted municipalities, distances (km) to be travelled and the costs of the inventories incurred.

In order to evaluate the results obtained from the programming of the aforementioned mathematical model, Table 7 shows some municipalities, where temporary shelters established by the Government of the State of Veracruz are located, together with the Secretary of Civil protection. With this, it can be concluded that there is adequate infrastructure in the municipalities shown by the programming of the model for the installation of a pre-positioning warehouse.

**Table 7.** Temporary shelters [40].

| Location | No. Temporary shelters |
|---|---|
| Naranjos | 10 |
| Cerro Azul | 3 |
| Tihuatlán | 18 |
| San Rafael | 7 |
| Naolinco | 23 |
| Manilo Fabio Altamirano | 11 |
| Fortín de las Flores | 3 |
| Cosamaloapan de Carpio | 13 |
| Las Choapas | 2 |

*Notes:* The table shows some municipalities, where temporary shelters established by the Government of the State of Veracruz are located, together with the Secretary of Civil protection. With this, it can be concluded that there is adequate infrastructure in the municipalities shown by the programming of the model for the installation of a pre-positioning warehouse.

## 4 Conclusions

The inability to plan relief operations during disaster situations leads to increased human suffering and wasted resources. Humanitarian relief efforts in response to natural and human-made disasters often involve complicated logistical coordination. For this reason, the purpose of this document is the location of pre-positioned warehouses and their inventory levels, in the different areas that make up the state of Veracruz, Mexico. That can support the organizations and institutions and respond to the disaster to maintain a quality of life for people affected by a phenomenon of a hydrometeorological nature. The analysis of various databases allows the feeding of a program based on a mathematical model, which is applied to 90% of the regions belonging to the State of Veracruz, Mexico. The minimization of logistics costs is calculated based on a) the location of municipalities that due to their characteristics may be the headquarters of pre-positioning warehouses and which are mentioned below: Naranjos de Amatlán, Cerro Azul, Tihuatlán, San Rafael, Manilo Fabio Altamirano, Fortín de las Flores, Cosamaloapan and Las Choapas, and b) the variables of their inventory levels based on the different stages of human life (early childhood, childhood, adolescence, adulthood and old age); obtaining results in the variables of the economic order quantity ($Q_{ij}^{p}$) reorder point ($R_{j}^{p}$), safety inventory, and non-supply, which allow the supply of both food and equipment kits as well as water and medicines (vaccines), to victims of a natural hydrometeorological phenomenon. According to a literary review, it is concluded that even though there is more and more research on the subject, there are no cases solved with real data in Mexico. Likewise, it is worth mentioning that the municipalities obtained have the infrastructure to be able to host a pre-positioned warehouse. It is determined by the fact that these municipalities have assigned temporary shelters authorized by the country's government.

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