Chapter 12
Distribution of Personal Protective Equipment, Derived from the Presence of the COVID-19 Virus in Mexico

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Abstract As a result of a wide variety of risks, diverse in scale, complexity, and consequences, countries must generate various strategies through which they can face them, protecting the population, the ecosystem, and the economy. The objective of the document to be presented is to help health organizations in decision-making in logistical aspects, specifically, in the location of facilities and distribution of supplies. This work proposes a logistic model that allows the location of a feasible municipality through the integration of the classic p-median problem and the Multiple Vehicle Routing Problem (MVRP). The goal is to determine a feasible location to establish a warehouse and the routes to supply Personal protection supplements for the health sector personnel to municipalities that host hospitals of different public institutions with COVID-19 patients. The model is evaluated in one of the states belonging to Mexico, making a typification of its municipalities. The results are obtained in four scenarios, showing both the host municipalities and the delivery routes. The results showed the municipalities of Cuitláhuac, Huiloapan de Cuauhtémoc, Huatusco, and Tlalixcoyan as feasible locations for the warehouse. From the information provided and through the *vehicle routing problem with time windows* (VRPTW), new delivery routes are established, showing a comparison of results. The total of established routes for delivery is seven. Due to the characteristics of the content, this research falls into the classification of case studies.

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F. Regis-Hernández et al. (eds.), *Humanitarian Logistics from the Disaster Risk Reduction Perspective*, https://doi.org/10.1007/978-3-030-90877-5_12

Keywords Location · Multiple vehicle routing · Time windows · Health · Personal protective equipment

12.1 Introduction

According to international organizations, all countries of the world face a wide range of emergencies resulting from different risks in terms of scale, complexity, and international consequences, including (a) outbreaks of infectious diseases, (b) chemical and radiation contamination, (c) armed conflicts, and d) consequences of climate change. These can have profound political, economic, social, and public health repercussions and long-term consequences that can sometimes persist for several years (WHO 2015; Veracruz, State Government 2019).

In the area of emergencies derived from outbreaks of infectious diseases, an outbreak is defined as the occurrence of two or more similar cases, which are epidemiologically related (Government of Mexico 2018). In this same field, infectious diseases can be defined as those caused by pathogenic microorganisms such as bacteria, viruses, parasites, or fungi. These diseases can be transmitted, directly or indirectly, from one person to another (WHO, 2020a; IAEA, 2020). In this way, the term endemic is reached, which refers to the constant presence of cases of a disease or infectious agent in human populations within a given geographic area (Government of Mexico 2018). Moreover, the term epidemic refers to an unexpected or too high number of cases in a community or region derived from a disease's appearance. When an epidemic is described, the time, the geographical region, and the population group particularities in which the cases occur must be specified (BRÈS 1986) in (Beaglehole et al. 2003). A pandemic is defined as an epidemic disease that have spread to many countries or have attacked almost all the individuals in a community or region (Veracruz, State Government 2019).

It is worth mentioning that epidemics of highly infectious diseases represent a challenge for health workers, who face a higher risk of infection than the general population due to exposure during the performance of their activities work. Hence, knowledge about the type and correct use of Personal Protective Equipment (PPE) is essential. The use of such equipment should be done as part of prevention and control strategies. *PPE* is defined as any equipment, apparatus, or device specially designed and manufactured to preserve the human body, in whole or in part, from specific risks of accidents at work or professional diseases (Government of Mexico 2020a).

Figure 12.1 shows the chronology of some of the most lethal pandemics throughout history, including the one currently known as COVID-19.

In the same way, over the years, Mexico has been affected by infectious diseases, causing the infection and death of thousands of people. Figure 12.2 shows some of them.

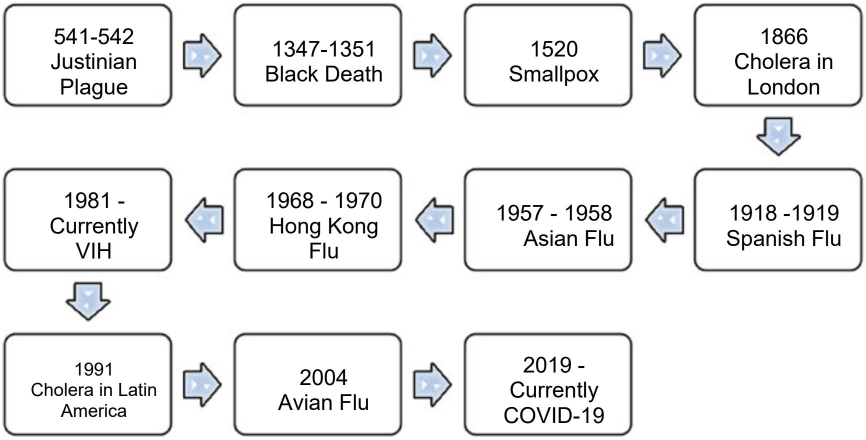


Fig. 12.1 Pandemic timeline. *Source* (Álvarez 2014; Barricarte 2006; WHO 2007; The Editors of Encyclopaedia Britannica 2020)

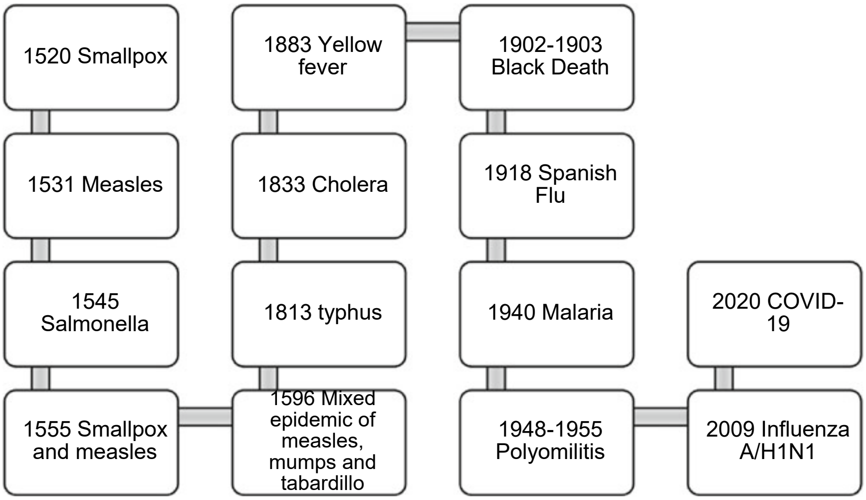


Fig. 12.2 Epidemics in Mexico. *Source* (SEGOB 2018)

12.1.1 COVID-19 Presence in the World

In late 2019, China reported a cluster of pneumonia cases in Wuhan, Hubei Province. Later it is determined that a new coronavirus causes them. Coronaviruses are a family of viruses that cause diseases ranging from the common cold to more serious respiratory diseases, circulating between humans and animals. Sometimes a new strain of coronavirus can emerge capable of causing disease in humans, such as (*a*) Severe Acute Respiratory Syndrome (SARS), in Asia in February 2003, and,

Table 12.1 Cases reported by region in the Americas. 2020 *Source* Authors with information on (PAO and WHO)

Sub-Region	Cases confirmed	Deaths confirmed	Recovered
North America	734,628	34,319	54,200
Central America	5,768	182	287
South America	73,553	3,362	20,768
The Caribbean and Atlantic Ocean Islands	7,911	395	1,038

(b) Middle East Respiratory Syndrome (MERS-CoV) in the Middle East in 2012. Moreover, since the end of 2019, COVID-19, a disease caused by the virus named SARS-CoV-2, is transmitted from an infected person to others when drops of saliva are expelled when speaking, coughing, or sneezing fall on the eyes, nose, or mouth of a healthy person. Since the virus survives on various surfaces, it is also transmitted by manipulating objects contaminated by the virus (hands, tables, cell phones, among others.) and then touching some part of the face such as eyes, nose, and mouth (WHO 2020b; Government of Mexico 2020b).

On April 18th, 2020, the Undersecretariat for Prevention and Promotion of Health in Mexico issued a New Coronavirus in the World Technical Report (COVID-19), which shows that 2,160,207 confirmed cases have been reported worldwide COVID-19 and 146,088 deaths with an overall case fatality rate of 6.8%. To date, 212 countries have reported cumulative cases in the six regions distributed by WHO: *(a)* America, 784,272 cumulative cases; *(b)* Europe, 1,086,889 accumulated cases; *(c)* Mediterraneo Oriental, 120,683 accumulated cases; *(d)* Southeast Asia, 25,291 accumulated cases; *(e)* Western Pacific, 129,968 accumulated cases, and *(f)* Africa, 13,104 accumulated cases (Secretary of Health 2020a).

The American continent has been considerably affected by the new coronavirus, and Table 12.1 shows the data belonging to the April 18th, 2020.

12.1.1.1 Mexico in the Face of the Pandemic

In Mexico, starting in 1997, the Action Program for Epidemiological Emergencies and Disasters was created, which has responded to the need of the Health Sector to have a response scheme for all kinds of health emergencies that may occur in said country, such as disasters caused by natural phenomena. The related risks for the occurrence of outbreaks due to communicable diseases, especially chickenpox, hepatitis A, dengue, or diarrhea, remain, the latter being the most frequent (Veracruz, State Government 2019).

At the end of February 2020, Mexico confirms the first case of infection with the new SARS-CoV-2 coronavirus. Derived from this, the Secretary of Health visualized three scenarios or phases for the new coronavirus spread, which emerged in China at the end of 2019.

- *Viral import*, where it is expected to detect the first cases from countries with the sustained local transmission;
- *Community dispersal,* once the virus is imported into Mexico, the presence of community outbreaks is expected, and;
- *Epidemic phase,* with the presence of the virus throughout the territory and the presence of outbreaks of COVID-19 in various regions of the country (Secretary of Health 2020b).

On May 31st, 2020, in Mexico, 90,664 confirmed cases and 9,930 deaths had been detected in 32 states. Indeed, Mexico City, Mexico, Baja California, Tabasco, Veracruz, and Sinaloa, are the states that have presented the highest number of positive deaths (Secretary of Health 2020b).

12.1.2 Importance of Logistics in Public Health

According to the International Health Regulations (IHR), an event is the manifestation of a disease or a potentially pathogenic event. In the same area, a public health emergency of international importance is called an extraordinary event that, by the IHR, has been determined to *(i)* constitute a risk to public health in other States due to the spread international management of disease, and *(ii)* could require a coordinated international response. While a public health risk refers to the probability of an event occurring that may adversely affect the health of human populations, considering, in particular, the possibility that it will spread internationally or could pose a severe and direct danger (Secretary of Health 2020c; WHO 2016).

Logistics for public health is an essential part of technical assistance delivered during a public health emergency. It covers a variety of functions, for example, inventory maintenance and distribution, handling and transportation management of infectious substances for laboratory tests, and the coordination of operations during epidemic outbreaks (WHO 2020d).

12.1.3 Problem Statement

Within the new social environment in which health organizations are immersed, they must adopt new strategies to manage their logistics activity more efficiently, thereby optimizing stock levels, delivery routes, and the required size by hospital warehouses (Ruiz 2005). Veracruz is one of the states that make up the Mexican Republic and is located on the Atlantic coast, in the Gulf of Mexico. To the north, it borders with Tamaulipas, to the south with Oaxaca and Chiapas, to the west with San Luís Potosí, Hidalgo, and Puebla the south-east with Tabasco. It has an area of 71,699 km^2 and around 8,112,505, according to the 2015 Intercensal Survey of the National Institute of Statistics and Geography (INEGI), making it one of the most populous states in the Mexican Republic (SECTUR 2020; SE 2019).

As a result of the increasing number of COVID-19 cases, in Veracruz, which is one of the six states with the highest number of deaths nationwide (until May 31st, 2020, having 3,717 confirmed cases, 1,524 suspected cases, and 538 deaths) (Veracruz, State Government 2020a). Parallel to this situation, health personnel assisting sick people is required, and these are those who have a higher degree of exposure to the SARS-CoV-2 virus. Motivated by the latter and to provide a support tool to health organizations in decision-making in logistical aspects, specifically in the location of warehouses and distribution of supplies, a logistics model is proposed that integrates the classic problem of the p-median and the multiple vehicle routing problems (MVRP). It allows proposing the location of a feasible municipality in which a warehouse is established that allows supplying personal protection implements for the health sector to the municipalities that host hospitals of different public institutions with people sick with COVID-19, in the state of Veracruz.

In order to obtain a municipality whose conditions allow proper warehouse management, a positional weight variable is established, which is made up of the level of compliance with a set of established characteristics *(1)* that does not have a presence or suspected coronavirus; *(2)* that it has the necessary services for the proper functioning of the warehouse (electricity, drainage, drinking water, telephone, and Internet); *(3)* that it has road access, and *(4)* that it has the necessary infrastructure—likewise, the establishment of delivery routes to municipalities with COVID-19 hospitals. Likewise, a comparison of routes is carried out between those obtained through the implemetation of the vehicle routing problem with time windows.

After the introduction, this document sets out the studies and research that have been done previously in health, humanitarian and environmental logistics, precise location, and vehicle routing. Subsequently, the methodology developed to meet the location and routing objectives in different scenarios are shown, ending with the authors' conclusions and the bibliographic sources used as the basis for the research.

12.2 State of the Art

Over time, many researchers have addressed logistics in various areas, including health, humanitarian, and environmental, to name a few. Either through a literary review, such as the research by Rahman and Smith (2000), in which they review the use of location and allocation models in health services. The purpose of the review is to examine the suitability of methods for designing health care systems and their relevance; or through applying of different methods, techniques, and tools that may include one or more logistical elements. As is the case, the article by (Castrellón-Tores et al., 2014) presents the results of the general modeling process for the logistics of drug distribution within the public health program in Colombia. The model is based on verifying the conditions on the actual information for the logistics distribution system for medicines in the six public health programs in Colombia.

The verification of the structure and robustness of the created model is carried out through an emulation system developed based on the actual information matrix, to be subsequently verified through discrete simulation using a program developed in visual. Net with input and output for Excel. The proposal is tested and validated through GAMS® (General Algebraic Modeling System), with the formulation of three operating scenarios that sequentially allow savings of up to 57.44% in the total cost of the logistics system for health drugs public.

Likewise, Talmor (2019) formulates a mathematical model to minimize the total logistical time required for medical prophylaxis for the urban population as a result of an anthrax attack in the air, balancing three cycles as follows: the cycle of loading, shipping cycle, and service cycle. Applying the model to two representative cases reveals the effect of various parameters in the process, such as the number of distribution centers and the number of servers in each center are critical parameters. In contrast, the number of central warehouses and the local shipping method are less critical. Similarly, Ceselli et al. (2016) develop an optimization model for the efficient distribution of vaccines or drugs through the simultaneous and coordinated use of distribution centers and vehicles. The authors present a Set Covering formulation with three types of columns and branching and price and cut algorithm to solve it. The model is tested on a set of 440 instances that demonstrate results that reach the optimal solution.

On the subject of routing, the authors Chowdhury et al. (2018) use a geographic information system (GIS) to design an emergency transport method for the rapid transfer of pregnant or postpartum women, newborns, and children under five years of age with suspected sepsis. The authors developed a travel time algorithm to incorporate the time taken by the different local transport modes to reach health complexes. The results yielded 15 pre-existing routes, and two new ones were identified as the shortest routes to the health complexes. Similarly, the article developed by Luan et al. (2019) presents a location routing problem model (LRP), which attempts to consider the relationship between the location of warehouses and delivery routes to maximize rescue efficiency. Researchers use the Hybrid Self-Adaptive Bat Algorithm (HSABA) to solve the deficiencies of the LRP; the model is evaluated in 20 coordinate data sets as demand points and four supply coordinate data sets due to the confidentiality of real data. Likewise, researchers Boyer et al. (2013) develop a mixed on-line programming model for the routing of waste, with two objectives: (*1)* to minimize the total cost, including transportation cost, operation cost, initial investment cost, and cost of waste sales. Furthermore, (*2)* minimize the risk of transportation. The authors use the GAMS software with CPLEX solver and apply it in the Markazi province in Iran.

The authors Landa et al. (2016), apply the classic p-median problem to identify a feasible municipality for providing support to low-income people in Mexico. Likewise, Caballero-Morales et al. (2018) provides a metaheuristic to determine the location of support centers in Mexico. The metaheuristic is based on an extension of the K-Means Cluster-ing (KMC) algorithm. This extension led to the GRASP-Capacitated-Means Clustering (GRASP-CKMC) algorithm. In the routing aspect, the researchers Barojas-Payán et al. (2018) address the problem of supplying necessities to people affected by a disaster. They use the heuristic technique of the nearest neighbor (NN) to establish delivery routes for these items in a municipality in Mexico.

Similarly, the research document by Barojas-Payán et al. (2019) shows a mathematical model that allows municipalities to be located for the installation of pre-positioned warehouses and the calculation of inventory levels of products. According to the WHO, it allows supplying people affected by a natural phenomenon, said population is divided according to the stage of life of the human being according to the WHO, avoiding special situations such as the puerperium.

12.3 Methodology

The methodology is described in Fig. 12.3. It begins with the compilation of the information necessary for feeding the programs; programming with Lingo 18.0 software continues, and vehicle routing programming with time windows in commercial software is carried out, ending with evaluating different scenarios discarding municipalities obtained in previous runs.

12.3.1 Collection of Information

To evaluate the logistics model, the information contained in the following points is searched in databases and transparency pages of various institutions:

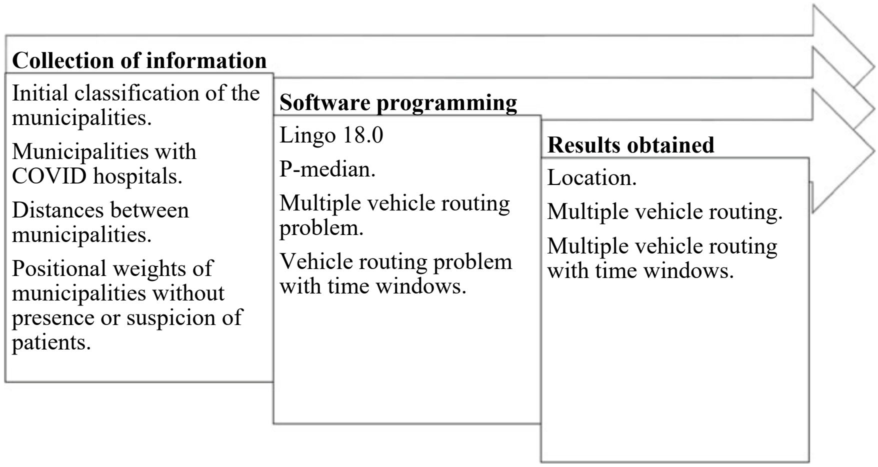


Fig. 12.3 Methodology to follow

12.3.1.1 Classification of Municipalities

With data published dated April 25th, 2020, a matrix is made, with the municipalities of the state of Veracruz that present suspected and/or confirmed cases of people sick with COVID-19 and the municipalities that have no presence or suspicion of cases (Veracruz, State Government 2020a).

Figure 12.4 shows a map of the state of Veracruz that shows the situation of each municipality it houses concerning the presence of confirmed cases (red color), suspicious cases (yellow color) without the presence or suspicion of cases (green color).

While in Table 12.2, it can be seen part of the matrix prepared (10 municipalities) from this selection. Said information would allow the municipalities that can reach the headquarters of the personal protection products warehouse to be identified and the first typification of the municipalities to be supplied.

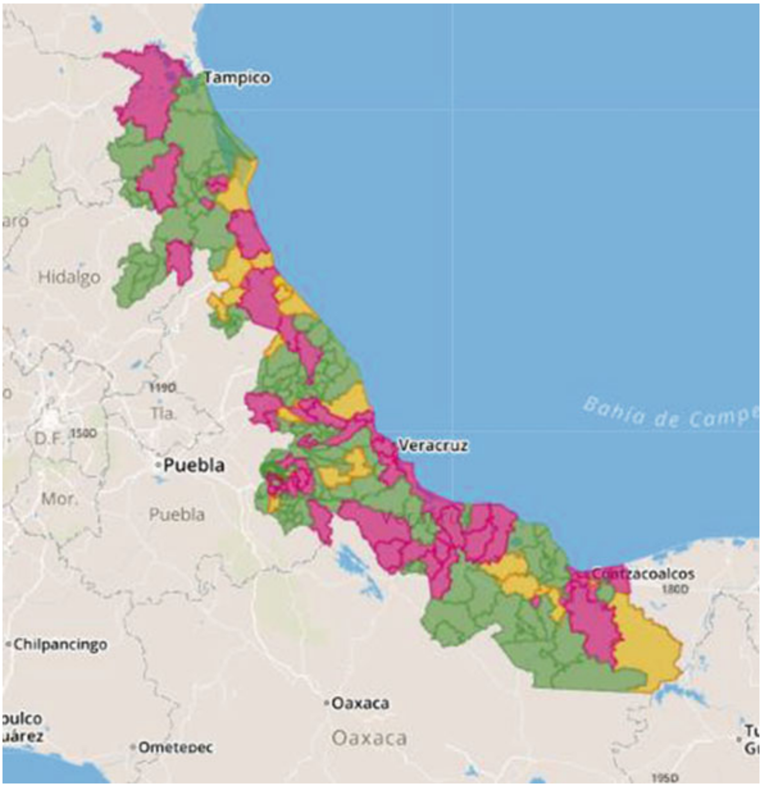


Fig. 12.4 Veracruz, municipalities with presence, with suspicion and without the presence and suspicion of people sick with COVID-19. *Source* (Veracruz, State Government 2020a)

Table 12.2 Municipalities with presence, with suspicion and without the presence and suspicion of people sick with COVID-19

Municipality	Presence	With suspicion	Without the presence and suspicion
Pánuco			
Jáltipan			
Banderilla			
Córdoba			
La Perla			
Orizaba			
Agua Dulce			
Misantla de Altamirano			
Tenampa			
Soledad Atzompa			

Source (Veracruz, State Government 2020a)

12.3.1.2 Municipalities with COVID-19 Sanitary Units

To provide care to Covid-19 sick people, institutions such as (*a*) SS (Secretary of Health); (*b*) IMSS (Mexican Social Security Institute); (*c*) ISSSTE (Institute of Security and Social Services of State Workers), and Pemex, to name a few, designated hospitals to carry out this activity efficiently (PR 2020; Veracruz, State Government 2020b).

And, in order to feed the logistics model, the municipalities that contain hospitals belonging to said institutions that could provide medical care to people with Covid-19 sicknesses and that present confirmed or suspected cases of sick people are identified, obtaining: (1) Boca del Rio; (2) Coatzacoalcos; (3) Córdoba; (4) Cosamaloapan; (5) Martínez de la Torre; (6) Minatitlán; (7) Orizaba; (8) Panuco; (9) Poza Rica; (10) Río Blanco; (11) San Andrés Tuxtla; (12) Tierra Blanca; (13) Tuxpán; (14) Veracruz, and (15) Xalapa (Veracruz, State Government 2020b; IMSS 2020; SCT 2020; PEMEX 2020).

12.3.1.3 Distances Between Municipalities

With the support of the Google Earth® application, a matrix of distances in km is made between municipalities with COVID hospitals and municipalities without

Table 12.3 Municipal attributes

Weight factor	Relative weight (%)	Description
Road access	50	State or federal terrestrial communication road
Services	30	Constructions with drainage service, piped water, energy, telephone, internet
Infrastructure	20	A number of classrooms built per school, this data is taken as a reference, since due to it being a new pre-positioned warehouse, there is no construction for it

Source (SCT 2016; INAFED 2010)

suspicion or confirmation of people infected by a said disease that allows the installation of a warehouse for safekeeping of personal protective equipment, said matrix has dimensions of 15×136.

12.3.1.4 Positional Weights

Once the municipalities were identified without the suspicion or presence of people sick with the COVID-19 coronavirus, a variable of the positional weight of each of them was determined, said weight is calculated from attributes, determined from the Authors' experience: (*1) services,* so that it can operate effectively in communication, cleaning, among others.; (*2) road accesses,* that allow a fast delivery in terms of distance traveled to the municipalities that are the headquarters of warehouses, and (*3) infrastructure,* that provides an adequate and safe space for the equipment to be supplied; this information is obtained from the transparency pages of government institutions. Table 12.3 shows a description of these characteristics.

12.3.2 Logistics Model

The model was implemented using Lingo 18.0, which is a comprehensive tool designed for the construction and resolution of optimization models, such as linear, nonlinear (convex and non-convex / global), quadratic, constrained quadratically, second-order cone, semi-defined, stochastic, and integer. The program allows the fast, easy, and more efficient implementation of an optimization model (Lindo Systems INC 2020).

12.3.2.1 Locating a Single Facility

To carry out the location of a feasible municipality to place a warehouse that allows the supply of personal protection items to municipalities with hospitals that care for people sick with the coronavirus COVID-19 in Veracruz. The following are established:

Municipalities with the presence or suspicion of COVID-19 are considered for their supply, as long as they have a health care unit belonging to any of the national health institutions immersed and cares for sick people with said coronavirus. While the municipalities are located, in addition to complying with the minimum distance traveled for the supply, they are evaluated according to their positional weight, which consists of *(1)* that it has the necessary services for the proper functioning of the warehouse (electricity), drainage, drinking water, telephone, and Internet); *(2)* that it has road access, and *(3)* infrastructure.

The mathematical formulation of the problem above is as follows:

$$\boldsymbol{Min} \sum_{i=1}^{n} \sum_{j=1}^{m} w_i d_{ij} x_{ij} \tag{12.1}$$

$$s.t.$$

$$\sum_{j=1}^{m} x_{ij} = 1, \forall_i, \tag{12.2}$$

$$x_{ij} \leq y_j, \forall_{ij}, \tag{12.3}$$

$$\sum_{j=1}^{m} y_j = p, \tag{12.4}$$

$$x_{ij}, y_j \in \{0, 1\} \tag{12.5}$$

Where Eq. (12.1) represents the minimization of the product of the positional weight w of the municipalities that can become the headquarters of the supply warehouse due to the distances traveled between said municipalities and those with presence or suspicion of coronavirus; Eq. (12.2) ensures that municipalities with presence or suspicion of coronavirus are assigned to a facility located in a municipality without presence or suspicion of contagion if assigned; Eq. (12.3) makes sure that each client is attended by exactly one server; Eq. (12.4), sets the number of facilities to be located; Eq. (12.5) indicates that the variables are binary (Landa et al. 2016).

12.3.2.2 Vehicle Routing Problem

The vehicle routing problem (VRP) raises the search for the optimal solution with different restrictions such as the number of vehicles, their capacity, destinations (clients), and client demand, among others. The first VRP-type problem proposed was that of the traveling agent (TSP). It receives this name because it can be described in terms of a selling agent who must visit a certain number of cities in a single trip, in such a way that it begins and ends its journey in the “origin” city.

A variation of this is the multiple TSP (m-TSP), in which you have a warehouse and m vehicles, that is, m traveling agents. The stated objective is to build precisely m routes, one for each vehicle, so that each customer is visited once by one of the vehicles. Each route must start and end at the depot and can contain at most p customers. In the m-TSP problem, each customer is associated with demand and each vehicle has a specific capacity, which is why it is concluded that the travel agent problem gives rise to the routing problem.

Another variation of VRP appears in 1967, called the Vehicular Routing with Time Windows Problem (VRPTW), which is a VRP problem with the additional restriction of a time window associated to each consumer that defines an interval of time within a consumer must be served. The interval in the warehouse is called the programming horizon (DAAVEDRA. 2013; Rocha-Medina et al. 2011; Toth and Vigo 2002).

In this document, multiple vehicle routing and multiple vehicle routing with time windows are applied to distribute personal protection equipment to medical units in municipalities with hospitals belonging to public institutions that provide care to people sick with COVID-19. The mathematical model of the multiple vehicle routing problem is presented below.

$$Min \sum_{i=1}^{n} \sum_{j=i}^{n} c_{ij} x_{ij} \tag{12.6}$$

s.t.

$$\sum_{j=2}^{n} x_{1j} = m \tag{12.7}$$

$$\sum_{j=2}^{n} x_{j1} = m \tag{12.8}$$

$$\sum_{i=1}^{n} x_{ij} = 1, \ j = 2, \ldots, n \tag{12.9}$$

$$\sum_{j=1}^{n} x_{ij} = 1, \ i = 2, \ldots, n \tag{12.10}$$

$$+ \text{ sub tour removal constraints.} \tag{12.11}$$

$$x_{ij} \in \{0, 1\}, \ \forall (i, j) \in A \tag{12.12}$$

Where Eqs. (12.7) and (12.8) ensure that exactly m sellers exit and return to node 1 (deposit). Equations (12.9), (12.10), and (12.12) are customary assignment constraints (DAVENDRA 2013). Equation (12.11) is used to avoid sub-tours, i.e., it degenerates tours that form between intermediate nodes and are not connected to the origin. These are:

$$\sum_{i \in S} \sum_{j \in S} x_{ij} \leq |S| - 1, \forall S \subseteq V \setminus \{1\}, S \neq \oslash \tag{12.13}$$

$$\sum_{i \in S} \sum_{j \in S} x_{ij} \geq 1, \forall S \subseteq V \setminus \{1\}, S \neq \oslash \tag{12.14}$$

$$u_i - u_j + p x_{ij} \leq p - 1 for 2 \leq i \neq j \leq n \tag{12.15}$$

Equations (12.13) and (12.14) avoid the formation of S cardinality sub tours without including the deposit (Dantzing et al. 1954 in DAVEDRA 2013). Unfortunately, both families of these constraints increase exponentially with an increasing number of nodes; therefore, they are not practical to solve the problem or its linear relaxation of programming directly. Miller et al. (1960) (DAVEDRA 2013) surpasses this. Hence the Eq. (12.15), the variable p denotes the maximum number of nodes that any vendor can visit.

Similarly, the mathematical model of vehicle routing with time windows is presented below:

$$\boldsymbol{Min} \sum_{k \in K} \sum_{(i,j) \in A} c_{ij} X_{ijk} \tag{12.16}$$

$$s.t.$$

$$\sum_{k \in K} \sum_{j \in \Delta^+(i)} x_{ijk} = 1 \forall i \in N \tag{12.17}$$

$$\sum_{j \in \Delta^+(0)} x_{0jk=1} \forall k \in N \tag{12.18}$$

$$\sum_{i \in \Delta^-(j)} x_{ijk} - \sum_{i \in \Delta^+(j)} x_{ijk} = 0 \forall k \in K, i \in N \tag{12.19}$$

$$\sum_{i \in \Delta^-(n+1)} x_{in+1k} = 1 \forall k \in N \tag{12.20}$$

$$W_{ik} + S_i + t_{ij} - W_{jk} \leq \left(1 - x_{ijk}\right) M_{ij} \forall k \in K, (i, j) \in N \tag{12.21}$$

$$a_i \sum_{j \in \Delta^+(i)} x_{ijk} \leq W_{ik} \leq b_i \sum_{j \in \Delta^+(i)} x_{ijk} \forall k \in K, i \in N \tag{12.22}$$

$$E \leq W_{ik} \leq L \forall k \in K, i \in (0, n+1) \tag{12.23}$$

$$\sum_{i \in N} d_i \sum_{j \in \Delta^+(i)} x_{ijk} \leq C \forall k \in N \tag{12.24}$$

$$x_{ijk} \geq 0 \forall k \in K, (i, j) \in A \tag{12.25}$$

$$x_{ijk} \in (0, 1) \forall k \in K, (i, j) \in A \tag{12.26}$$

Equation (12.16) represents the total cost, which can be interpreted as travel time or total distance traveled. Finding the minimum total travel distance using the fewest vehicles is required. Equation (12.17) restricts the assignment of each client to a single-vehicle route. Equations (12.18), (12.19), and (12.20) provide the characteristics of the route to be followed by each vehicle k. Equations (12.21), (12.22), (12.23), and (12.24) guarantee the feasibility of the sequence concerning time conditions and aspects of retrospective capacity. Equation (12.25) represent the non-negativity of variable x, and Eqs. (12.26) define the model as linear, integer, binary (Cruz 2018).

12.3.3 Results Obtained

The feasibility of the model is validated by running it on five occasions, discarding the municipalities obtained from a previous run, in order to provide possible additional locations for the installation of the personal protective equipment warehouse. The model results are presented in Fig. 12.5 and in Tables 12.4, 12.5, 12.6 and 12.7.

Figure 12.5 shows the host municipalities of the personal protective equipment warehouse, obtained in the following order: *(1)* Cuitláhuac; *(2)* Huiloapan de Cuauhtémoc; *(3)* Huatusco, and *(4)* Tlalixcoyan. Tables 12.4, 12.5, 12.6 and 12.7 show the delivery routes and some of the traveled circuits (i.e., the point of departure and return, the municipality where the warehouse is located, the municipalities where the hospitals to be supplied in order are located).

In the following paragraphs, more information is provided on the discarding of venues and the routes obtained to deliver the equipment to the Hospitals that could care for people sick with COVID-19.

12.3.3.1 Location One

Table 12.4 shows each route, the municipalities immersed in it, and the image obtained through Google Maps® of the supply circuits belonging to the first municipality derived from the programming of the model, which is called Cuitláhuac, with

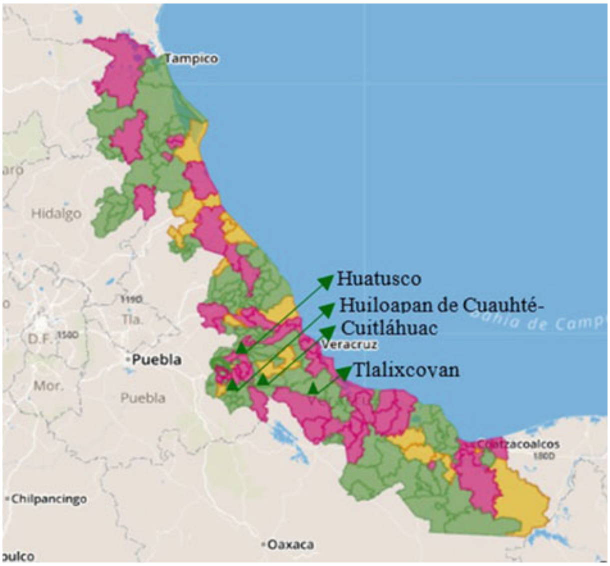


Fig. 12.5 Headquarters of the personal protective equipment warehouse. *Source* (Authors; Veracruz, State Government 2020a)

a total of 7 delivery routes to municipalities that host Hospitals that care for people sick with COVID-19.

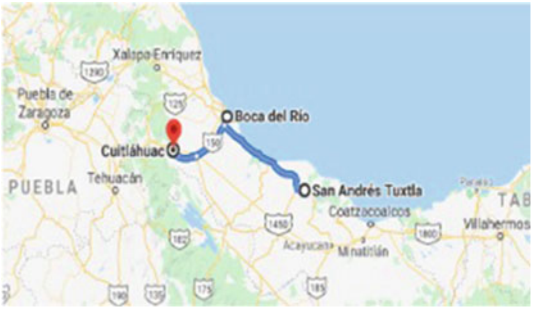
12.3.3.2 Location Two

When discarding the first headquarters, the results of Table 12.5 are obtained, which shows the delivery routes belonging to the second municipality shown by the programming of the model, which is called Huiloapan, with a total of 6 routes. Likewise, the table shows a delivery circuit that involves a different delivery sequence (regardless of the location shown in Table 12.4) to municipalities that host Hospitals that care for people sick with COVID-19.

12.3.3.3 Location Three

By discarding the first and second headquarters, the results of Table 12.6 are obtained, which shows the delivery routes belonging to the third municipality thrown by the programming of the model, which is called Huatusco, with a total of six routes. Likewise, the table shows a delivery circuit that involves a different sequence (regardless of the locations than those shown in Tables 12.4 and 12.5) to municipalities that host Hospitals that care for people sick with COVID- 19.

Table 12.4 Routes are belonging to location one

<table>
<tr><th>NO.</th><th>MUNICIPALITY _1</th><th>MUNICIPALITY _2</th><th>MUNICIPALITY _3</th><th>MUNICIPALITY _4</th></tr>
<tr><td rowspan="2">ROUTE_1</td><td>Martínez de la Torre</td><td>Poza Rica</td><td>Tuxpan</td><td>Pánuco</td></tr>
<tr><td colspan="4">
</td></tr>
<tr><td rowspan="2">ROUTE_2</td><td>Boca del Río</td><td>San Andrés Tuxtla</td><td></td><td></td></tr>
<tr><td colspan="4">
</td></tr>
<tr><td rowspan="2">ROUTE_3</td><td>Veracruz</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">
</td></tr>
<tr><td>ROUTE_4</td><td>Cosamaloapan</td><td>Minatitlán</td><td>Coatzacoalcos</td><td></td></tr>
</table>

(continued)

Table 12.4 (continued)

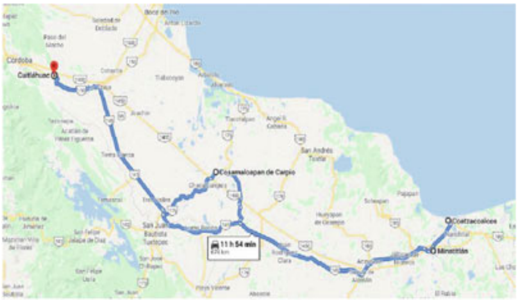
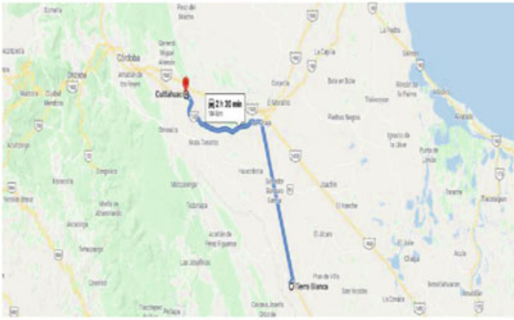
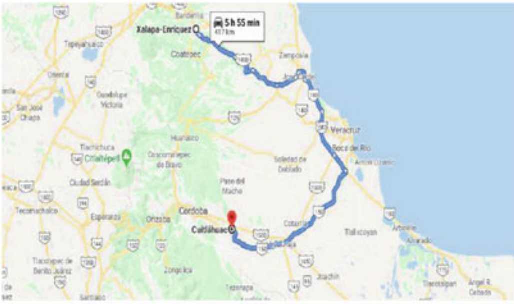
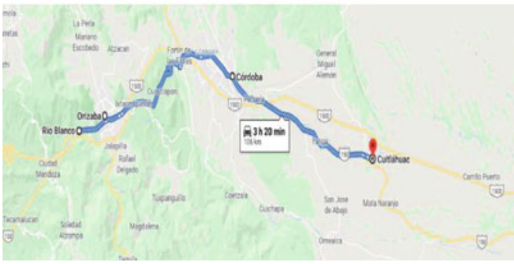
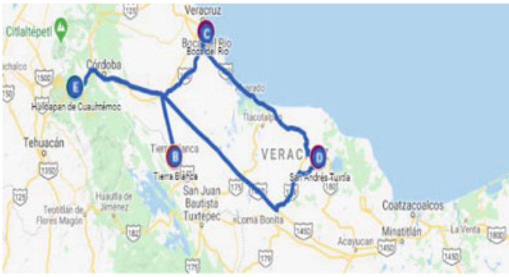
<table>
<tr><td></td><td colspan="4">
</td></tr>
<tr><td rowspan="2">ROUTE_5</td><td>Tierra Blanca</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">
</td></tr>
<tr><td rowspan="2">ROUTE_6</td><td>Xalapa</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">
</td></tr>
<tr><td>ROUTE_7</td><td>Córdoba</td><td>Orizaba</td><td>Río Blanco</td><td></td></tr>
<tr><td></td><td colspan="4">
</td></tr>
</table>

Table 12.5 Routes are belonging to location two

NO.	MUNICIPALITY _1	MUNICIPALITY _2	MUNICIPALITY _3	MUNICIPALITY _4
ROUTE_1	Martínez de la Torre	Poza Rica	Tuxpan	Pánuco
ROUTE_2	Veracruz			
ROUTE_3	Cosamaloapan	Minatitlán	Coatzacoalcos	
ROUTE_4	Tierra Blanca	Boca del Río	San Andrés Tuxtla	
ROUTE_5	Xalapa			
ROUTE_6	Rio Blanco	Orizaba	Córdoba	



12.3.3.4 Location Four

A third evaluation is carried out without weighing the municipalities, that is, removing the positional weight of the municipalities. Based on this, the results of Table 12.7 are obtained, which shows the delivery routes belonging to the municipality shown by the programming of the model, called Tlalixcoyan, with seven delivery routes. In the same way, they show three delivery circuits to the municipalities to municipalities that host Hospitals that provide care to people sick with COVID-19.

Table 12.8 shows the comparison of the distances traveled in each delivery circuit with departure and arrival at the warehouse headquarters. As can be seen, the first location contains a more significant number of kilometers traveled for the supply; however, derived from the positional weight of the municipality of Cuitláhuac, compared to Huiloapan and Huatusco, allowed it to be the main campus. Unlike the municipality of Tlalixcoyan, which is the host municipality that would allow the least number of kilometers traveled if the characterization made for the municipalities will not be taken as a variable.

Table 12.6 Routes are belonging to location three

NO.	MUNICIPALITY_1	MUNICIPALITY_2	MUNICIPALITY_3	MUNICIPALITY_4
ROUTE_1	Martínez de la Torre	Poza Rica	Tuxpan	Pánuco
ROUTE_2	Boca del Río	San Andrés Tuxtla		
ROUTE_3	Veracruz			
ROUTE_4	Cosamaloapan	Minatitlán	Coatzacoalcos	
ROUTE_5	Xalapa			
ROUTE_6	Rio Blanco	Orizaba	Córdoba	Tierra Blanca

12.3.3.5 Vehicle Routing Problem with Time Windows

With the headquarters of the personal protective equipment warehouse in the municipality of Cuitláhuac, there are six delivery routes (see Table 12.9) with their respective traveled distances and their traveled time using normal-type traffic. At the same time, Fig. 12.6 shows the delivery routes from headquarters and their return to it.

Table 12.10 shows a comparison of travel distances between two types of VRP used. As can be seen, the distance between both options is only 19 km.

12.4 Conclusions and Future Work

Logistics is a critical aspect of assistance to different sectors, including health. It is because it facilitates critical processes for the material distribution, the deployment of qualified personnel, and the location of relief facilities and infrastructure.

This document aims to help health organizations in decision-making in logistical aspects, specifically in the location of warehouses and distribution of supplies. By integrating the classic p-median problem and the multiple vehicle routing problem (MVRP), programmed in Lingo, a logistics model is proposed that allows the location of a feasible municipality. With that, a warehouse is established that allows supplying

Table 12.7 Routes are belonging to location four, municipalities without positional weight

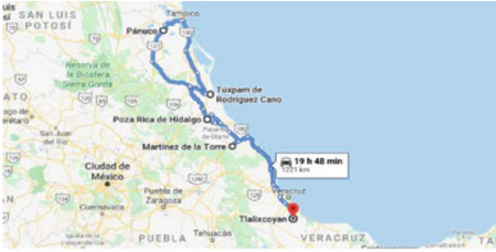
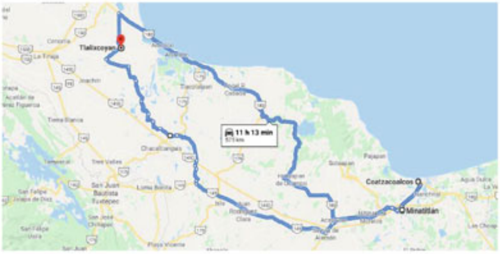
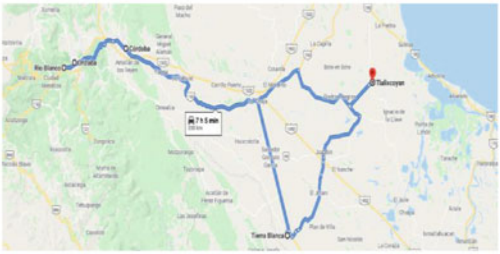
NO.	MUNICIPALITY_1	MUNICIPALITY_2	MUNICIPALITY_3	MUNICIPALITY_4
ROUTE_1	Martínez de la Torre	Poza Rica	Tuxpan	Pánuco
	 			
ROUTE_2	Cosamaloapan	Minatitlán	Coatzacoalcos	
	 			
ROUTE_3	Boca del Río			
ROUTE_4	Veracruz			
ROUTE_5	Tierra Blanca	Córdoba	Orizaba	Río Blanco
	 			
ROUTE_6	San Andrés Tuxtla			
ROUTE_7	Xalapa			

Table 12.8 Distances traveled from different headquarters to the municipalities

Routes	Cuitláhuac	Huiloapan	Huatusco	Tlalixcoyan
1	1331	1241	1229	1221
2	459	283	525	79.6
3	207	787	248	98.5
4	674	647	818	575
5	144	311	177	330
6	417	69.2	334	290
7	106			307
Total	3338	3338.2	3331	2901.1

Table 12.9 Vehicle routing with time windows, based in Cuitláhuac

No. Route	Municipality_1	Municipality_2	Municipality_3	Distance (km)	Time (Hr, Min)
1	Córdoba	Río Blanco	Orizaba	118	3,28
2	Veracruz	San Andrés Tuxtla		467	8,49
3	Boca del Río	Tierra Blanca		277	5,09
4	Cosamaloapan	Coatzacoalcos	Minatitlán	659	14.15
5	Poza Rica	Tuxpan	Pánuco	1230	21.49
6	Xalapa	Martínez de la Torre		606	22.21

personal protection implements for the health sector personnel to the municipalities that house hospitals of different public institutions with people sick with COVID-19 and the delivery routes of the same. For this, characterization of municipalities is carried out, the first based on whether or not these municipalities have confirmed or suspected cases of people sick with COVID-19, and later, with negative municipalities, weigh their attributes of *(1)* service; *(2)* highway accesses, and *(3)* infrastructure, to establish the warehouse headquarters in them.

For the evaluation of the model, four different scenarios are carried out, in the first, the headquarters obtained is the municipality of Cuitláhuac, with a distance traveled of 3338 km. In the second, the first location is discarded, and the municipality of Huiloapan is determined as the warehouse, with a traveled distance of 3338 km. The third scenario discards the first two, and the municipality of Huatusco is obtained, with a distance of 3331 km. The last scenario eliminates the positional weight, and as the headquarters of the warehouse, the municipality of Tlalixcoyan is obtained, with a distance traveled of 2901.1 km.

It is well seen that the first headquarters of the first three scenarios contain a more significant number of kilometers traveled for supply; however, due to its positional weight, it allows it to be the main headquarters. Unlike the municipality of Tlalixcoyan, the host municipality that would allow the fewest kilometers traveled, the characterization made for the municipalities will not be taken as a variable. A second

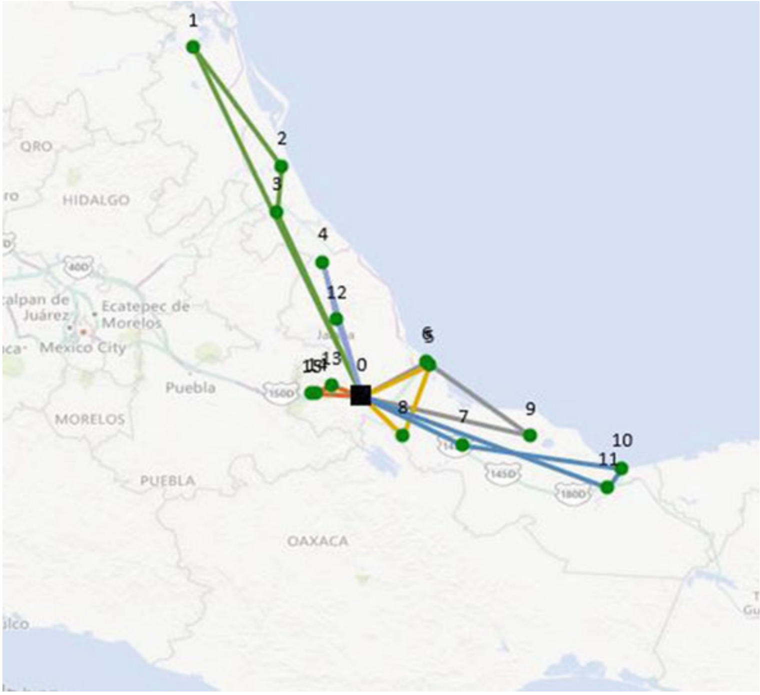


Fig. 12.6 Locations of the personal protective equipment warehouse

Table 12.10 Comparison of distances between routes based in Cuitláhuac

No. Route	VRP multiple Distance (km)	VRP Time window Distance (km)
1	1331	118
2	459	467
3	207	277
4	674	659
5	144	1230
6	417	606
7	106	
	3338	3357

comparison is made by applying the vehicle routing problem with time windows, six routes are obtained with a total of 3357 km and location of the warehouse in the municipality of Cuitláhuac, thus obtaining a difference of 19 km, with respect to scenario 1.

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