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# Sustainable Urban Logistics Model Applied to Food Trucks. Case Study and Descriptive Analysis

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**Abstract**

The food truck service is growing due to the change in customers' fast food consumption habits. This research aims to test the logic of using urban logistics to improve the optimization of food truck supply. This research proposes a case study where route optimization methods, central location, and the estimation of the environmental impact through the emission of pollutant gases at the time of supplying food trucks are proposed; RStudio and COPERT V software was used to obtain quantitative results. Concerning the results, it was found that the food truck is viable due to the number of potential customers within the case study area. The central location (longitude, latitude) of the food truck within the area where its customers are located was found; in addition, thanks to the optimal supply route, it was possible to calculate the emissions of polluting gases: CO2, PM2.5, PM10, NOX, VOC.

**Keywords**

Urban Logistics; Food Truck; Environmental Impact; Route Optimization; Optimal Downtown Location

## 1. Introduction

Today, it is possible to appreciate different changes such as a continuous increase of population within urban areas, citizens' concern about environmental pollution or the same safety within their cities, co-management, and traffic problems, the emergence of new technological opportunities, and policymakers of urban transport [1].

The new challenges cities face due to large concentrations, different stakeholders are affected, and it becomes more challenging to meet the needs of citizens efficiently and effectively [2]. Companies must reevaluate their logistics practices when forced to work with their suppliers and customers in urbanized areas [3].

Urban logistics has been applied within the food supply process as it presents environmental, social, and economic challenges. Different local authorities consider the quality and safety of food and the impact on the environment generated by food supply and transportation systems [2]. Therefore, it is essential to find the best location of distribution centers within cities for interested companies. By achieving this, a change in the cities could be appreciated because transportation routes will be more efficient, bringing less congestion and a lower negative environmental impact. However, to implement urban logistics, transportation, food demand, and distribution must be considered variable.

Nowadays, not only fast-food restaurants have grown, but also the number of food trucks that can be found parked on busy streets that facilitate access to food consumption. A food truck is a truck or trailer equipped with the necessary tools (e.g., kitchen) to produce and sell fast food. However, the mode of distribution of

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these is in fixed points that must be located strategically to reduce transportation costs and have the optimal inventory of raw materials to avoid being out of stock in a day or, on the contrary, having an excess that generates food waste. The warehouses of urban distribution points involve many vehicles for which operational monitoring of the routes must be carried out to limit consumption and excessive emission of polluting gases [4].

This generates transportation costs and raw material waste and leads to environmental impact. Even though urban logistics is a minor part of the total transport time of goods, it comes to represent 28% of transport costs. On the other hand, polluting gases vary between 16- 50% of global pollution due to activities carried out within urban areas [5].

Despite technological advances that include the development of electric powered trucks, such as battery electric heavy-duty trucks cause less emission of Carbon Dioxide ($CO_2$) than Disel [6], it is rarely done at present due to the require investment and the slow introduction of it in the international market.

However, despite the advances in the different published sources described above, more is needed to know about how urban logistics affects different city services, specifically food trucks. Since few researchers have addressed urban logistics applications in food trucks, it is necessary to explore this modality of fast-food service to align it with the purpose of urban logistics, which is to be sustainable and efficient.

The research question is: Can the urban Logistics model be run to achieve an optimal and sustainable supply of inventory in food trucks in Metropolitan Lima through a simulation to reduce the environmental impact emitted by polluting gases? This work aims to simulate an urban logistics model to achieve an optimal and sustainable inventory supply in Metropolitan Lima food trucks.

This research is to check the logic of using urban logistics to improve the optimization of food truck supply. In this way, the emissions of Carbon Dioxide ($CO_2$), Nitrogen Oxides ($NO_x$), Volatile Organic Compounds (VOC) and Particulate Matter (PM) can be estimated for sustainable distribution, and with the knowledge of potential customers and suppliers, the food truck's optimal location and supply route can be found.

Therefore, in this study, we will test the following hypotheses: It is possible to simulate an urban logistics model to achieve an optimal and sustainable supply of inventory in food trucks in Metropolitan Lima.

This paper is organized as follows: the formulation used to simulate the optimization process will be described in the Methods section. Then, in the Results section, the findings obtained from the simulation will be demonstrated. Finally, the Discussion section will analyze the results obtained to test the hypothesis formulated.

## 2. Literature review

### 2.1 Urban Logistics

Urban logistics is an inclusive term applied in different ways; for example, after using the Delphi methodology to 19 participants, it was obtained that the biggest perceived problem was congestion and traffic caused in cities [7]. Due to this, they defined the stakeholders' roles in the activities that fall under this heading. This is complemented in the research [8] where the context of urban logistics focuses on the optimal use of resources. Considering the above, simulations can be formulated to optimize distribution processes in urban areas concerning the importance given to stakeholders and resources used in urban logistics.

An essential term in logistics is the last mile, which refers to the delivery to the final customer within a logistics process. This is put into practice in the research [9], where they sought to determine the optimal number and location of product pick-up points in given periods using a Monte Carlo optimization simulation.

In conclusion, it was found that one of the essential points to consider for this last delivery and the efficient number of pickup/sale points is always to consider the uncertainty of the demand for decision-making.

As mentioned above, urban logistics generates an environmental impact as there is a negative impact on low-emission logistics if there is inadequate distribution. To achieve flue gas reduction within the urban logistics distribution process, the research [10] explores a closed-loop logistics distribution route optimization method that positively impacts low-carbon logistics, promoting a low-carbon agenda in logistics network practice. An alternative approach was developed [11]; these studies the emissions and the intensity of these related to trucks according to the purpose of the trip. The results of the work suggest that the design of emissions management measures should consider which factors (population densities, Euclidean distance, and empty weight of vehicles) impact GHG emissions for each trip purpose.

### 2.2 Logistic distribution simulation models

The formulation developed a mathematical model concerning the vehicle routing problem to test the reduction of total distribution costs and pollutant gas emissions [12]. The variables considered were distribution costs, carbon oxide emissions, total transportation time, number of routes, and distance. The SIMMAG 3D tool was used to implement the mathematical model formulated. The study showed an 8.1% reduction in total distribution costs.

On the other hand, a mathematical model applied to a context more like the problems of vehicular congestion in Bogota, Colombia [5]. In this, two scenarios were compared: collaborative and non-collaborative, where the purpose was the most efficient decision-making for urban distribution. The research also considered a term widely used within urban logistics: routing problems of capable vehicles. The variables used were distance, total number of delivery points, average vehicle transport speed, vehicle capacity, and demand. Finally, an approximate 25% cost reduction was achieved in a collaborative scenario.

Another model applied in Latin America was the research [13] in Santiago, Chile. In this model, an alternative approach was used, aiming at minimizing the environmental impact of air pollution to improve the efficiency of the distribution and commercial supply process. The optimization model was carried out, considering the vehicle routing problem. It was obtained that a reduction of 53 tons of carbon dioxide and a reduction of 1103 hours of annual interruptions in vehicle congestion in the sector can be achieved.

The Traffic and Land Use Simulator for Urban Logistics [14] was developed for Tokyo (metropolitan area). It seeks to evaluate the level of externalities linked to logistics facilities' spatial distribution patterns. It analyzes the different impacts of urban freight transportation through simulations of different scenarios of the locations of urban logistics facilities and chains and truck flow. The paper's results indicate that the scarcity of facilities in high-demand locations exacerbates negative externalities, while moderate concentration and deconcentration of facilities do not significantly affect them.

The research [15] presented a static deterministic mixed integer linear programming (MILP) model. This solves the two-box capacitated location-routing problem (2E-CLRP) with modal choice in the context of urban logistics services (ULS). It additionally provides an optimal routing cost estimation formula and optimization heuristics. The results demonstrate that the 2E-CLRP model generates high-quality, time-reasonable closed-form approximations for optimal routing costs.

Finally, a coding applied in RStudio software to calculate the optimal location through the center-of-mass approach so that the location is where the highest concentration of random points is. It was used as an assumption that the transport shipping volumes in the distribution truck and the potential customers have similar cost structures and that these depend on the distance traveled. The "x" and "y" coordinates were obtained from the weighting of sales demand in conjunction with the quantity supplied from the suppliers as the point of origin and the demand in costs of the point of arrival represented by the potential customers. Once the coding was run, the optimal location centroid was obtained, which can be visualized in ggplot2 or a ggmap [16].

## 3. Methodology

The present research has as variables: environmental impact and urban logistics [2] The first is caused due to the emission of gases at the time of making the supply route and subsequently to the point of sale. On the other hand, the dependent variable focuses on the urban logistics used to optimize the distances traveled and achieve a strategic location central for potential customers. The dimensions developed are environmental pollution and the type of delivery used to deliver food orders, in this case, food trucks.

To achieve an optimal location and supply route for food trucks, the following data must be considered: gas emissions, kilometers traveled, location of suppliers, number of potential customers, maximum temperature, minimum temperature, and relative humidity. In this way, it is shown that the research has a quantitative approach based on numerical databases, an experimental type, and pre-experimental scope where the formulas proposed and described in the research design to be carried out are put into practice.

It should be taken into consideration that the research consists of a case study in which a descriptive analysis is developed since a survey is conducted, which provides more accurate data regarding the number of potential customers.

Figure 1 shows the initial and practical phase of the research.

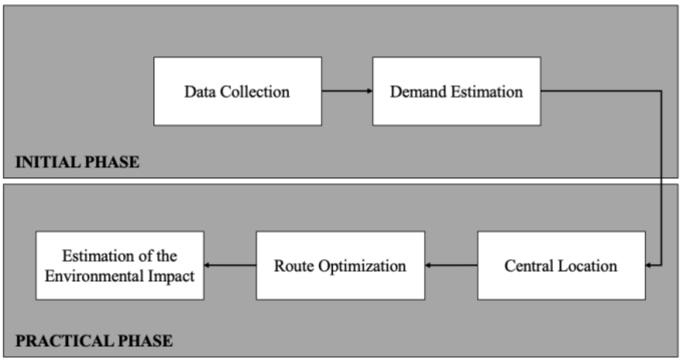


Figure 1: Research design

### 3.1 Initial phase

First, the initial phase of the research consisted of two stages: data collection and demand estimation. The first stage involved gathering the necessary information to build the following phases. The second stage consisted of estimating the demand of potential customers who will consume the food provided by the food truck.

#### 3.1.1 Data collection

The first stage of the initial phase was collecting data for the proposed models. To estimate the demand and thus obtain potential customers, information was collected through surveys conducted with different customers who consume food provided by food trucks in the area where the case study was conducted. The questionnaire had questions of intention and intensity to estimate the demand of potential customers. The sample was obtained thanks to the "finite population" formula because the size of the total population is known. The survey questions were validated by "Marketing Research" experts.

The sample to be studied was calculated by applying (1):

$$N = \frac{(N \times Z^2 \times p \times q)}{(d^2 \times (N-1) + Z^2 \times p \times q)} \quad (1)$$

Where:

- N: Total population of the case study area
- Z: Taking into consideration a 95% certainty, this value will be 1.96
- p: Expected proportion; this value will be 50%.
- q: Is the complement of p; in this case, it will be 50%.
- d: Accuracy of the investigation; in this case, it will be 5%.

Considering that a spatial approach must be taken to calculate travel distances, the addresses and stops involved in the food truck supply process were collected.

In addition, information on Lima's minimum temperature, maximum temperature, and relative humidity was extracted from the database of the National Meteorological and Hydrological Service of Peru (SENAMHI), an entity attached to the Ministry of Environment of Peru. These data were used for the experimental phase of the environmental impact estimation.

### 3.2 Demand estimation

The second stage consisted of obtaining the demand for daily orders through the survey, where the intention and intensity of these orders were obtained.

Once the sample was obtained, the survey was conducted among passers-by in the area where the food truck was parked to sell its dishes. The formula applied was (2)

$$Number\ of\ potential\ customers = N_{customers} \times I_1 \times I_2 \quad (2)$$

Where:

- *Number of potential customers:* The number of people surveyed who responded that they would be interested in consuming the dish offered by the food truck; therefore, it is the purchase intention multiplied by the intensity.
- $I1$: Intensity, percentage of people where the degree of interest in the purchase is demonstrated (Interval of 1-10).
- $I2$: Intention, percentage of people willing to consume in the food truck.

### 3.3 Practical phase

The experimental phase of the research demonstrated what was necessary for the central location of the food truck, route optimization, and estimation of environmental impacts.

First, the central location of the food truck obtained the point where the food truck should be located to stock and deliver the orders of dishes to its potential customers.

Secondly, by finding a central location, it was possible to obtain the optimal supply route for the food truck, covering all the points it needs to reach the warehouse, suppliers, and point of sale.

Thirdly, the environmental impact measured the number of gases emitted by the food truck concerning the distance traveled from the first point to the point of sale of the dishes to be offered.

### 3.3.1 Central location

Regarding the first stage of this phase, RStudio software was used to implement the coding performed [16]. The objective of the coding is to be able to find the centric location under the principles of the center of mass approach using the formulas of x (longitude) and y (latitude); these use a weight which is the "volume of expenditure per orders."

Having the weighted average coordinates of the center of mass, the location was visualized with a scatter plot with "ggplotz/ggmap". The heat map was plotted in RStudio with the Leaflet package, where the optimal center point can be visualized.

The central point was the food truck's location for the following route optimization calculations and estimation of pollutant gases emitted when traveling the food truck supply distances.

### 3.3.2 Route optimization

The second stage of the experimental phase of the research consisted of constructing an optimal route for food supply from the food trucks. The distance it takes to go to the different points to the endpoint was considered to spatialize the route. The points can vary between the raw material warehouse, the central location previously found, and that of the suppliers.

To create the optimal route, "Analytics in georeferenced systems" [17] was used, allowing route optimization and analysis of intelligent distribution models. In addition, the tool allowed to obtain the distance traveled in kilometers that the food truck travels to get from the initial point to the final point.

A+" and "Dijkstra" algorithms are used because the algorithm stops when it finds the shortest path leading from the initial point to the rest of the points.

### 3.3.3 Estimated environmental impact

To estimate the environmental impact, only the direct emissions of exhaust gases from the use of the vehicles were considered. The software estimated the emissions of CO2, NOx, VOC, and PM, as these are the ones involved in the process of supplying food trucks. These gases are a result from the use of Diesel which is a main resource to complete the route of truck supplying. The emission of this gases has consequences that not only contaminants the atmosphere of the cities, as well as the health of its citizens. The COPERT V software (Computer program for calculating emissions from transportation routes) is used (3) to estimate gas emissions:

$$Gas\ emission = f_{emission}(truck\ category\ , speed_{average}) \times\ distance \tag{3}$$

Where:

- $f_{emission}$: This function is extracted from the COPERT V emissions database.

Equation (3) consists of entering primary data on the minimum and maximum temperature and relative humidity of the area where the study was conducted, in this case, Lima, Peru. In addition, the category (model of the vehicle used to travel the route) and the distance traveled in kilometers were entered. The data entered will correspond to 2021 with the history SENAMHI (National Service of Meteorology and Hydrology) reported.

# 4. Results

## 4.1 Initial phase

### 4.1.1 Data collection

In order to collect the data needed to estimate demand and requirements, the inhabitants of the case study area, "Villa Militar Oeste Chorrillos", were surveyed. The total population was approximately 1708 local residents (N=1708); therefore, by applying the "Finite Population" formula, a sample size of 314 people was obtained. The 314 people were surveyed with an 8-question questionnaire with questions of intention "Would you buy food from this food truck? Yes or No" (I1=92.11%) and intensity "From 1 to 10, indicate how likely you are to buy fast food from the food truck" (I2=76.11%). Table 1 and Table 2 reflect the results of these types of questions.

Concerning the addresses and stops to supply the food truck in a day, four points were identified: the warehouse, supplier 01, supplier 02, and the point of sale (primary address).

Table 1: Results of the question "Intension".

| **Reply** | **Total** | **Porcentage** |
|---|---|---|
| Yes | 175 | 92.11% |
| No | 15 | 7.89% |
| **Total** | **190** | **100%** |

Table 2: Results of the question "Intensity".

| **Intensity** | **Total** | **Percentage** | **Weighted** |
|---|---|---|---|
| 1 | 2 | 1.14% | 0.01 |
| 2 | 2 | 1.14% | 0.02 |
| 3 | 1 | 0.57% | 0.02 |
| 4 | 5 | 2.86% | 0.11 |
| 5 | 14 | 8.00% | 0.40 |
| 6 | 16 | 9.14% | 0.55 |
| 7 | 25 | 14.29% | 1.00 |
| 8 | 53 | 30.29% | 2.42 |
| 9 | 32 | 18.29% | 1.65 |
| 10 | 25 | 14.29% | 1.43 |
| **Total** | **175** | **100.00%** | **7.611** |

Concerning the data obtained from the National Meteorological and Hydrological Service of Peru (SENAMHI), the history of temperature reports recorded in previous years was obtained. The data from the station closest to the district of Chorrillos (Lima, Peru) was used, in this case, the Campo de Marte station. These data will be used in the experimental phase to calculate the emission of polluting gases and apply the optimization based on the reduction of these gases for a route with sustainable impact.

Table 3 shows the data collected based on historical data for the year 2021.

Table 3: Minimum Temperature, Maximum Temperature, and Humidity in 2021

| **Month** | **Tmín** | **Tmáx** | **H %** |
|---|---|---|---|
| **Jan-21** | 18.80 | 28.00 | 80.06 |
| **Feb-21** | 18.20 | 28.60 | 76.74 |
| **Mar-21** | 18.60 | 29.10 | 76.66 |
| **Apr-21** | 16.30 | 27.80 | 82.46 |
| **May-21** | 15.00 | 24.40 | 86.91 |

| | | | |
|---|---|---|---|
| **Jun-21** | 14.90 | 21.50 | 86.17 |
| **Jul-21** | 14.50 | 19.90 | 86.52 |
| **Aug-21** | 13.40 | 19.60 | 87.68 |
| **Set-21** | 13.40 | 19.40 | 88.01 |
| **Oct-21** | 14.00 | 20.50 | 85.85 |
| **Nov-21** | 15.60 | 21.50 | 83.55 |
| **Dec-21** | 16.60 | 25.10 | 81.88 |

#### 4.1.2 Demand estimation

To calculate the demand, we used the data obtained from the survey on the intensity and intensity of the respondents.

$$Number\ of\ potential\ customers = 1708 \times 92.11\% \times 76.11\% \quad (4)$$

Using the formula described in the methodology chapter, we obtained the number of potential customers of 1198 people in the case study area.

### 4.2 Practical Phase

#### 4.2.1 Central Location

First, random data were used for potential customers, longitude and latitude, and volume of spending per order (PEN 50.00-PEN 100.00); to program the coding in the RStudio software and obtain the central location of the food truck. Figure 2 shows the result obtained. By randomly locating the distribution of potential customers, it is possible to visualize in the heat map the concentration of them within the case study area.

In addition, the figure shows the center of mass, representing the food truck's optimal location. Thus, the sales coordinates are:

- Longitude: x = -77.02059
- Latitude: y = -12.15889

Once the central location is obtained, the routing tool "Analytics in georeferenced systems", [17] is used. In this way, the optimal supply route the food truck should follow for its supply and, finally, the point of sale is calculated.

The route shown in Figure 3 is obtained using the tool, where the optimal minimum distance between the food truck's supply and sales points is given.

Thanks to the optimal route, the distances from point to point were obtained, and the results can be seen in Table 4.

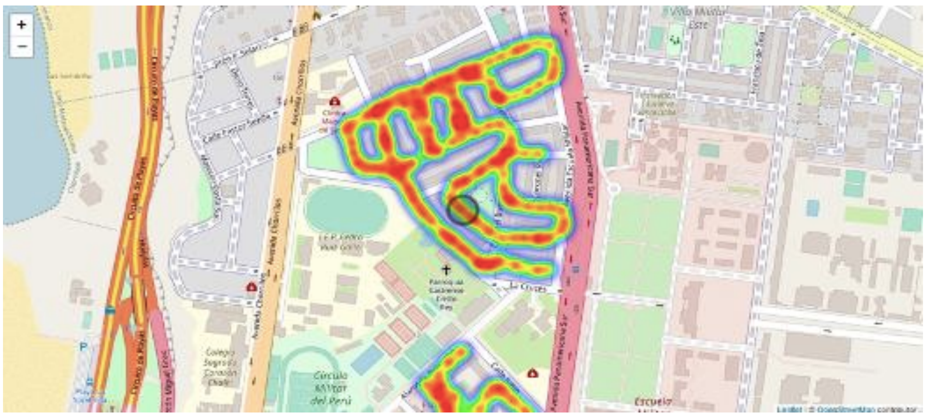

Figure 2: Load distribution and central location

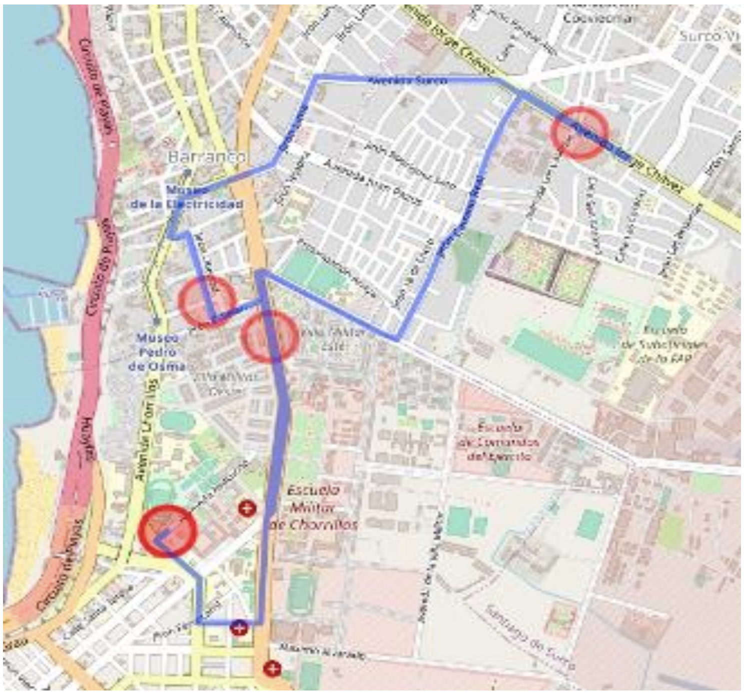


Figure 3: Load Distribution and Central Location

Table 4: Distances in Km

| Points | Distance (km) |
|---|---|
| Warehouse | 0.362487 |
| Supplier 01 | 0.554349 |
| Supplier 02 | 1.485415 |
| Point of Sale | 0.461031 |

### 4.2.2 Estimated environmental impact

Finally, once the optimal route was obtained, the total distance traveled by the food truck was calculated and entered into the pollutant gas emission simulation in the Copert V software with the data collected on minimum and maximum temperature and relative humidity in the study area.

Table 5 shows the amount of pollutant gas emissions during the route.

Table 5: Pollutant Gases Emissions

| Emission | kg/km |
|---|---|
| Carbon dioxide ($CO_2$) | 100.0847 |
| Particulate Matter $PM_{2.5}$ | 0.00049 |
| Particulate Matter $PM_{10}$ | 0.00902 |
| Nitrogen Dioxide (NOX) | 0.03367 |
| Volatile organic compounds (VOC) | 0.13582 |

Table 5 shows the amount of pollutant gas emissions during the route.

## 5. Discussion

It was possible to prove that using the center of mass theory and, subsequently, the calculation of the routing optimization based on Dijkstra's algorithm were fundamental tools to achieve an optimal route model. Thus, because of the shorter distance traveled, it was possible to reduce the environmental impact emitted by polluting gases when the food truck had to travel through the streets of Metropolitan Lima to supply raw materials and reach the final point of sale.

The data collection method was obtained as needed for each of the stages. Intensity and intensity data, the addresses of the points involved in the food truck supply, and temperature and humidity data were collected.

Thanks to the survey, we collected the intensity (I1 =92.11%) and intensity (I2 =76.11%), which helped to find the number of potential customers. The number of potential customers for the food truck within the case study area is 1198, which indicates that there is a demand to be met within the case study area and is profitable.

To obtain the optimal location, through the simulation performed in RStudio, longitude and latitude ( -77.02059; -12.15889) were obtained for the location of the food truck according to the estimated volume of spending by potential customers. The purpose of obtaining these coordinates was that the food truck is not only placed by default in a location but also has a relationship with the estimated income from the location of its potential customers.

For this stage, the four points involved in the food truck supply process were identified: the warehouse, supplier 01, supplier 02, and the point of sale (main address obtained in the previous point).

Once the food truck was located at the coordinates obtained, the optimal routing was made, considering the suppliers' locations of inputs for preparing the dishes to be offered at the point of sale. With the optimal route, we obtained the total mileage that the food truck travels daily to stock up and then position itself to prepare and sell dishes. The total distance traveled by the food truck is 1030.03 kilometers/year. With this distance, the environmental impact was calculated in the gas emission simulation based on the distance the vehicle travels in the Copert V software.

To complete the last stage of the research, information was collected on the maximum temperature, minimum temperature, and relative humidity of the nearest station in the case study area. In addition, the type of vehicle used by the food truck for fueling was also considered. Having the necessary data for COPERT V, the annual gas emissions of the food truck supply route were obtained. These were as follows: $CO_2$ 100.0847 kg/km, PM2.5 0.00049 kg/km, PM10 0.00902 kg/km, NOX 0.03367 kg/km, VOC 0.13582 kg/km.

As could be seen, the findings presented are consistent with the results reported [16]; thanks to its coding in RStudio software, it was possible to obtain the optimal location of the food truck, taking into account the volume of sales that the food truck would have and the random location of potential customers, thanks to the center of mass principle. Additionally, as shown in the research, the coordinates of the optimal location were displayed and could be visualized in a heat map using a leaflet.

Unlike the research [2], it can be noted that the distribution center of the case study is an established point. However, the two research find the optimal routes for minor pollutant gas emissions during the supply process. COPERT V software was used to estimate these annual emissions for the proposed scenarios. Thus, finding the amount of $CO_2$, PM2.5, PM10, NOX, and VOC emissions.

## 6. Conclusion

The results show the feasibility of applying the quantitative approach using simulation software used in RStudio and Copert V, where the optimal location and routes were obtained to reach the environmental impact caused by the emission of gases from the food truck at the time of supply. Based on these numerical results, the minimization of gas emissions can be sought for sustainable routing.

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