

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

Received: 12 Sep. 2025; Revised: 20 Jan. 2026; Accepted: 10 Feb. 2026
<https://doi.org/10.22306/al.v13i2.769>

Simplex linear programming for route optimization model in urban distribution**Raudel Flores-Moreno**

Polytechnic University of Texcoco, Carretera Federal los Reyes - Texcoco 14.200 San Miguel Coatlinchan, 56250
Texcoco de Mora, Edo. Mexico, Mexico, <https://orcid.org/0000-0002-3917-1355>,
raudel.flores@uptex.edu.mx

Pablo Iván Flores González

Polytechnic University of Texcoco, Carretera Federal los Reyes - Texcoco 14.200 San Miguel Coatlinchan, 56250
Texcoco de Mora, Edo. Mexico, Mexico, <https://orcid.org/0000-0003-1436-2371>,
pablo.flores@uptex.edu.mx

María Jesica Zavala Pineda

Polytechnic University of Texcoco, Carretera Federal los Reyes - Texcoco 14.200 San Miguel Coatlinchan, 56250
Texcoco de Mora, Edo. Mexico, Mexico, <https://orcid.org/0000-0002-5370-9983>,
maria.zavala@uptex.edu.mx

Ernest Yasser Núñez Betancourt

Polytechnic University of Texcoco, Carretera Federal los Reyes - Texcoco 14.200 San Miguel Coatlinchan, 56250
Texcoco de Mora, Edo. Mexico, Mexico, <https://orcid.org/0000-0002-5706-1854>,
ernest.nunezbe@uptex.edu.mx (corresponding author)

Keywords: planning, freight transportation, logistics, logistics costs.

Abstract: This study proposes a mathematical model for optimizing delivery routes in the urban distribution of Coca-Cola FEMSA to OXXO stores in Texcoco municipality, State of Mexico. Based on a theoretical framework grounded in linear programming using the Simplex method and graph theory, an algorithm was developed and implemented in LINDO software to minimize logistics costs, distance traveled, and fuel consumption. This approach, in turn, ensures a more sustainable route by achieving a reduction in polluting gas emissions. The results show a 12.3% reduction in distance, decreasing from 66.25 km to 58.1 km, and a 12.4% saving in fuel costs, from 686.28 to 600.96 Mexican pesos, for the route. The results demonstrated a significant contribution to the reduction of the carbon footprint, with a decrease of approximately 2.04 kg of CO₂, achieving a more sustainable urban distribution and greater operational efficiency.

1 Introduction

The optimization of distribution routes represents a critical challenge in contemporary logistics management, particularly in emerging economies, where transportation inefficiencies can account for up to 30% of total operational costs [1]. For this reason, route optimization in emerging economies presents unique challenges due to specific infrastructural and operational conditions that can increase logistics costs by up to 25-30% compared to developed economies [2]. In Mexico, freight trucking handles 56% of the overland distribution of goods, generating logistics expenses that directly impact business competitiveness. This scenario is exacerbated in urban contexts such as Texcoco municipality, State of Mexico, where the convergence of factors like an accelerated annual population growth of 4.2%, an insufficient road infrastructure and a high vehicle density of 2,500 vehicles/km² during peak hours, generates congestion losses estimated at \$92,000 million Mexican pesos (MDP) annually.

Fast-Moving Consumer Goods (FMCG) companies, such as Coca-Cola FEMSA a leader in bottling across Latin America with a presence in 10 countries [3] face complex logistical challenges, especially in distribution to convenience store chains like OXXO, which has over 22,000 stores in the region. This operational scale demands the implementation of robust mathematical solutions to optimize routes, reduce costs and guarantee delivery efficiency. In FMCG distribution, optimization implementations based on linear programming consistently validate savings of 10-15% in operational costs, with return on investment (ROI) periods of less than 6 months [4].

Previous studies demonstrate that optimization models can reduce logistics costs in urban distribution by up to 20% [5]. The use of methods such as linear programming (LP) [6], Graph Theory (GT) [7] and Origin-Destination (O-D) Matrix [8] has shown high effectiveness in improving the efficiency of transport route design and resource allocation. However, significant gaps persist. In the literature, for instance, there is research such as that by [9], which focuses on theoretical models with scarce empirical validation, while industrial applications, such as those reported by [10], lack adaptability to Latin American contexts. In these contexts, factors such as informal road networks with 35% of access points not mapped, demand variability and vehicle limitations, complicate implementation. Furthermore, it is essential to

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

establish a direct link between modeling and real-world physical distribution. Optimization models adapted to the specific conditions of emerging economies have proven to be up to 25% more effective than generic approaches, particularly in contexts with limited road infrastructure [11].

Besides, most studies omit an integrated analysis of environmental sustainability, despite the fact that transport contributes to 24% of global CO₂ emissions. The correlation between distance reduction and decreased CO₂ emissions is well-established in the literature, where route optimizations of 10-15% typically generate proportional reductions in carbon footprint [12]. Work must be done on mobility systems that are human-centered and aim for transport sustainability. The integration of environmental criteria into logistics optimization models can generate CO₂ emission reductions of 1.5-2.5 tons annually per vehicle, contributing significantly to operational sustainability [13]. The failure to consider sustainability and environmental protection causes severe damage to human health.

The objective of this research was to develop a linear programming mathematical model solved using the Simplex method for the urban distribution of Coca-Cola FEMSA to 30 OXXO stores located in Texcoco municipality, Mexico. The model will be solved and implemented in LINDO Software, supported by extensive fieldwork and empirically validated. A combinatorial approach integrating the application of the Simplex method for multicriteria optimization will be adopted [14]. The application of the Simplex method to Vehicle Routing Problems (VRP) has demonstrated proven efficacy in reducing travel distances, with reported optimization levels of 10-15% in comparable industrial contexts [15]. The Simplex method, when applied to more complex urban distribution cases, has shown significant effectiveness, with reported cost reductions of 8-12% in route optimization for medium-duty freight vehicles [16].

The study employed a system of weighted directed graphs using arcs [17], as well as a statistical correlation analysis between distance and time. The model integrated a sustainability component through the quantification of carbon emissions, in alignment with the Sustainable Development Goals (SDGs) [9]. This research anticipates that the model will achieve a reduction of at least 10% compared to the current route in both distance and fuel consumption. In the Latin American context, the implementation of optimization models has proven to be particularly beneficial, with reported savings of 12-18% in logistics costs for manufacturing and distribution companies [18].

The relevance of this research transcends the case study, as it offers a replicable framework for supply chains in emerging economies, where logistics optimization can generate annual savings exceeding 15% across different sectors.

2 Literature review

Vehicle Routing Problems (VRP) seek to minimize operational costs, subject to constraints such as vehicle capacity, time windows and demand [17]. This research employs Graph Theory for the analysis of routes, legs and journeys. This theory belongs to the fields of mathematics and computer science, studying the properties of discrete structures composed of vertices (nodes) connected by edges, creating a highly analyzable representation of a transport route called "graphs". The theory formally emerged in 1736 with the work of Leonhard Euler, who solved the Königsberg bridge problem, laying the foundation for network analysis [19]. Its applications span from computer science to sociology, modeling relationships within complex systems.

A graph G is defined, according to Equation 1, as an ordered pair (1):

$$G = (V, E) \quad (1)$$

Where:

V is a non-empty set of vertices (e.g., $V = \{v_1, v_2, \dots, v_n\}$).

E is a set of edges connecting pairs of vertices.

The main theorems used in the research are described below:

Euler's Theorem (published in 1736) states that a connected graph contains an Eulerian cycle if and only if all vertices have even degree.

The Theorem by [20] establishes that a graph is planar if and only if it does not contain a subdivision of K_5 (the complete graph on five vertices) or of $K_{3,3}$ (the complete bipartite graph with two sets of three vertices).

The Four Color Theorem states that any planar map can be colored using only four colors, such that no two adjacent regions share the same color [21].

The Origin-Destination (O-D) Matrix is a fundamental tool in route optimization, logistics and transportation studies. It quantifies flows between nodes to identify critical routes. O-D Matrix enables the identification of demand patterns by quantifying the demand between origin-destination pairs, thus allowing for the prioritization of critical flows [8]. The development of this Matrix facilitates the efficient allocation of vehicles, fuel and drivers by revealing travel volumes between zones [22]. It allows the reduction of operational costs and the consolidation of shipments or trips with similar destinations, minimizing empty kilometers and fuel costs. One aspect that is enhanced by the creation of the O-D Matrix is the simulation of scenarios to evaluate the impacts of changes in the network, such as new distribution centers or traffic and toll restrictions. It is also crucial for detecting inefficiencies by revealing imbalances like empty return trips or indirect

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

routes. The O-D Matrix is highly valuable for integration with optimization algorithms, serving as an essential input for Vehicle Routing Problem (VRP) or Traveling Salesman Problem (TSP) models.

Linear Programming (LP) is a mathematical optimization technique used to maximize or minimize a linear objective function, subject to a set of linear equality or inequality constraints. It is fundamental in logistics, economics, engineering, and resource management. An LP model (2) is mathematically expressed as:

Objective Function:

$$\text{Maximize (o Minimize) } Z = c_1x_1 + c_2x_2 + \dots + c_nx_n \quad (2)$$

Subject to the set of Equations (3):

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \leq b_1 \\ a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \leq b_2 \\ \cdot \\ \cdot \\ \cdot \\ x_j \geq 0 \text{ (non - negativity constraint)} \end{cases} \quad (3)$$

Where:

- x_j : Decision variables.
- c_j : Cost/benefit coefficients.
- a_{ij}, b_{ij} : Constraint parameters.

The first key element of an LP model is optimality—meaning it finds the optimal solution or best value of Z within a convex polytope, which is the feasible region defined by the constraints. Its *Fundamental Theorem* states that: if an optimal solution exists, it is located at a vertex of the polytope [23]. This algorithm pursues efficiency with low complexity; in practice, it is efficient, although in the worst case it is exponential [24]. The second element is the principle of duality, as every LP problem (*primal*) has an associated *dual* problem, which provides optimality bounds and enables sensitivity analysis.

The main limitations of Linear Programming (LP) lie in the fact that if the objective function or constraints are nonlinear, Nonlinear Programming (NLP) is required, which increases complexity. For integer variables involving discrete decisions, for example, the number of vehicles, Integer Programming (IP) is recommended.

LP is the scientific foundation for optimizing scarce resources in problems with linear relationships. In a routing study, it would enable the reduction of total fuel costs through a rigorous mathematical model, moving beyond a purely empirical approach.

The Simplex method, developed by George Dantzig in 1947, is a Linear Programming (LP) algorithm for optimizing functions subject to linear constraints. Its application in logistics allows for solving Vehicle Routing Problems (VRP) through mathematical formulation by transforming the real-world problem into linear equations; performing an iterative search moving between vertices of the polytope of feasible solutions; and ensuring convergence to guarantee finding the global optimum for convex problems [23].

Previous studies confirm that LP-based models reduce logistics costs by up to 20% [5]. Recent studies in Latin American contexts confirm the potential of these methods. [25] applied a route optimization model based on graphs and a simulated annealing algorithm for beverage distribution in Colombia, reporting a 14.7% reduction in distance traveled and a 15.3% saving in fuel consumption—results closely aligned with those obtained in this study.

3 Methodology

For the study, data was collected comprising the study area with 32 OXXO stores in Texcoco, supplied from the FEMSA CEDIS (Distribution Center) in Los Reyes (Geographic coordinates: 19°21'44.8"N 98°57'15.2"W).

Freightliner M2 (Figure 1) is a Class 6-7 commercial truck manufactured by Freightliner Trucks, a subsidiary of Daimler Truck North America. These vehicles are used by Coca-Cola FEMSA for distribution in the Mexico City metropolitan area. The aforementioned vehicles are equipped with either a Detroit Diesel DD5/DD8, Cummins B6.7, or L9 engine, depending on the configuration, and feature an automatic (Allison) or manual (Eaton) transmission with a payload capacity ranging from approximately 8,846 kg (Class 6) to 14,969 kg (Class 7).

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt



Figure 1 Freightliner M2 Trucks for Coca-Cola FEMSA Distribution in Mexico
Source: Created by the author

The Freightliner M2 vehicle in its diesel version is equipped with either a Detroit DD13, DD15, or Cummins ISX engine and fuel tanks ranging from 380 to 570 liters; its estimated range is 965 to 1,930 km. Models with larger tanks can hold up to 757 liters, achieving a range of 2,414 km under optimal conditions. Key data include the location of OXXO stores in 2D geodetic coordinates, distances and travel times (Google Maps API), a fuel cost of \$25.86 MXN/L based on the average price for the year 2025, and a fuel consumption rate of 2.5 km/L for the Freightliner M2. Fuel consumption is assumed to be constant due to the lack of detailed data on traffic conditions and transported cargo. This assumption is common in logistics research, as in the study by [5], which adopts a uniform consumption rate for solving Vehicle Routing Problems (VRP).

Table 1 shows the 2D geodetic coordinates, or geographic coordinates, of the nodes of interest for the study. These coordinates are expressed only with latitude and longitude, excluding the ellipsoidal height. This defines the position of a point on the surface of a reference ellipsoid, assuming it lies precisely on its surface (height = 0).

Table 1 Nodes and their geographic position from 2D geodetic coordinates

No.	Location names	Latitude (N)	Longitude (W)	No.	Location names	Latitude (N)	Longitude (W)
1	CEDIS Femsas Los Reyes	19°21'44.8"	98°57'15.2"	17	Mapex	19°28'49.7"	98°53'39.2"
2	Atlipac	19°22'07.3"	98°56'53.9"	18	Boyeros	19°29'50.5"	98°53'47.7"
3	Rio Laja	19°22'20.5"	98°56'46.0"	19	Orion	19°30'21.0"	98°52'49.7"
4	Tlazala	19°22'39.5"	98°56'35.2"	20	Emiliano Zapata	19°30'26.7"	98°53'34.5"
5	Camino a Las Minas	19°25'54.0"	98°54'30.3"	21	Gante	19°30'29.5"	98°53'05.5"
6	Cantu	19°23'56.4"	98°55'52.5"	22	Ursula	19°30'34.4"	98°53'37.9"
7	Francisco Chicoloapan	19°24'17.9"	98°55'38.5"	23	Allende	19°30'44.6"	98°52'57.1"
8	Ciruelos	19°24'41.9"	98°55'38.3"	24	Arteaga	19°30'44.8"	98°53'10.0"
9	Prolongacion Lerdo	19°24'41.3"	98°55'18.9"	25	Montes de Oca II	19°28'12.5"	98°54'03.2"
10	Cedro Chicoloapan	19°24'49.6"	98°55'10.9"	26	Asunción	19°27'35.8"	98°54'17.6"
11	Tlatel	19°24'59.0"	98°54'41.1"	27	Colón	19°27'18.9"	98°54'25.4"
12	2 de marzo	19°25'15.8"	98°54'23.8"	28	Texcoco Centro	19°30'42.3"	98°52'45.7"
13	Rio Manzano	19°25'20.5"	98°54'09.9"	29	Leandro Valle	19°29'55.1"	98°53'12.8"
14	Olmillos	19°26'14.9"	98°54'21.1"	30	Plaza Morena	19°31'07.4"	98°52'33.9"
15	Centro Cultural	19°27'12.7"	98°53'59.0"	31	Americas Texcoco	19°31'22.6"	98°52'18.5"
16	Acolhuacan	19°27'52.5"	98°52'55.0"	32	Camino San Simón	19°32'05.3"	98°51'47.2"
				33	Tocuila	19°33'14.8"	98°50'55.6"

Table 2 details the fuel expenditure (in MXN) and distance (in km) for each segment of the current operational route. The data is segmented into two parts with corresponding subtotals and a consolidated total. Particular focus is placed on minimizing distance in extended route segments (Ñ-Q, W-Z), which significantly influence overall operational expenses.

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

Table 2 Data from the current route obtained through field measurements, including fuel consumption and kilometers traveled

Route segments	Fuel cost (MXN)	Distance (km)	Route segments	Fuel cost (MXN)	Distance (km)
A-D	37.24	3.6	P-Q	75.51	7.3
D-C	6.72	0.65	Q-R	67.24	6.5
C-B	6.21	0.6	R-S	27.93	2.7
B-E	14.48	1.4	S-T	14.48	1.4
E-G	24.83	2.4	T-R	16.55	1.6
G-F	15.52	1.5	R-V	14.48	1.4
F-H	8.28	0.8	V-Y	20.68	2
H-I	15.52	1.5	Y-AA	9.82	0.95
I-J	7.24	0.7	AA-AC	11.38	1.1
J-K	16.55	1.6	AC-AE	7.78	0.75
K-L	11.38	1.1	AE-AB	11.38	1.1
L-M	32.07	3.1	AB-AD	10.34	1
M-N	21.72	2.1	AD-AF	4.65	0.45
N-Ñ	24.83	2.4	AF-X	9.82	0.95
Ñ-Q	44.48	4.3	X-W	6.2	0.6
Q-P	31.03	3	W-Z	59.96	5.7
Subtotal	318.1	30.75	Subtotal	368.2	35.5
			Total	686.28	66.25

Using the collected data, properly structured O-D matrices were developed based on distance, time, and cost. The analysis identified the most costly route segment as P→Q (\$75.51 MXN) and the longest route segment as P→Q (7.3 km), with global totals of \$686.30 MXN for fuel and a distance of 66.25 km.

During the model construction, the routing problem was formulated as a Linear Programming (LP) problem. Therefore, to optimize the distribution routes, the following elements are required:

Decision Variables:

x_{ij} : A binary variable (0 or 1) indicating whether the arc between nodes i and j is used.

In the the study carried out inTexcoco, 73 x variables represented segments between 33 nodes.

Objective Function equation (4):

$$\text{Min } Z = \sum_{i=1}^{73} (c_i * x_i) \quad (4)$$

Where:

c_i : cost of arc i (fuel cost in Mexican pesos, distance in km)

x_i : binary variable (1 if the arc is used, 0 otherwise)

Constraints equation (5):

$$\sum \text{distance} \leq 100 \text{ km (vehicle range)} \quad (5)$$

For the purposes of the model, the range was restricted to only 100 km. This was based on criteria of simplicity, practical applicability, and empirical evidence, without precluding the vehicle's ability to operate over longer ranges if necessary. Equation (6) shows the fuel constraint.

$$\sum \text{fuel cost} \leq 1000 \text{ MXN} \quad (6)$$

Coverage constraints are shown in equation (7):

$$\sum_{\text{arc } X_j \in S} X_j \geq 1 \quad (7)$$

(for each set S), where each inequality ensures that at least one arc exits from a critical node.

These constraints ensure the minimum connectivity of the network. The Simplex method utilizes an approach involving slack/artificial variables, and the analysis of reduced/dual costs will enable finding the optimal solution that minimizes costs while covering all critical nodes.

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

Connectivity constraint is shown in Equation 8:

$$\text{destination node} - \sum \text{origin node} \leq 0 \quad (8)$$

These constraints enable the modeling of connectivity between nodes in a network. Each variable X_i represents an arc between nodes, and inequalities ensure that the solution adheres to the hierarchy of connections. These constraints are essential for modeling hierarchical networks. The Simplex method guides the search toward solutions that respect actual connectivity, avoiding broken or infeasible routes.

Flow constraint equation (9) for intermediate nodes:

$$\sum x_{ij} - \sum x_{ji} = 0 \quad (9)$$

This constraint prevents infeasible solutions. Without this constraint, the model could propose "broken" routes. It also reduces costs by eliminating unbalanced flows that generate overcosts and, furthermore, achieves network integrity by ensuring that all intermediate nodes function as transshipment points, not storage points.

The model was implemented using LINDO software v18.0, utilizing the Simplex method. The problem dimension consisted of 73 decision variables and 45 linear constraints.

4 Results and discussion

The analysis of the geographical data and other metrics obtained for the optimization of the logistics transport network was conducted prior to implementing the improvement algorithms.

For the current route, the critical segments (high cost/km) were identified:

- **Q-P:** \$31.03 MXN for only 3 km (\$10.34 MXN/km).
 - **W-Z:** \$59.96 MXN for 5.7 km (\$10.52 MXN/km).
 - **Ñ-Q:** \$44.48 MXN for 4.3 km (\$10.34 MXN/km).
- (These segments are priority candidates for optimization).*

Efficient segments (low total cost):

- **D-C:** \$6.72 MXN for 0.65 km.
 - **C-B:** \$6.21 MXN for 0.60 km.
- (Although the total cost is low, these are short segments; they could potentially be improved with more direct routes).*

Average cost per km equation (10):

$$\text{Total: } \frac{686.3 \text{ MXN}}{66.25 \text{ km}} = \$10.36 \text{ MXN/km} \quad (10)$$

Critical nodes were identified by calculating centrality (sum of times/distances) from each node to all others, revealing that Node E had the lowest values on the route (E→F: 3.2 min/7 km, E→G: 2.4 min/4 km). Node F was detected as key for fast connections (F→G: 0.8 min/1 km). This analysis indicates that Node E or F could serve as primary hubs to minimize total travel times.

The analysis identified strategic corridors, which are the most efficient segments of the route (low time/distance): F↔G: 0.8 min / 1 km; G↔H: 0.75 min / 4 km; and H↔I: 0.7 min / 3 km.

High-cost critical routes (to avoid or optimize): A↔AF: 25.15 min / 55 km and C↔AF: 27.35 min / 62 km.

Route Optimization through Clustering (Natural Clusters) is a technique that combines clustering algorithms with route optimization methods to improve efficiency in problems such as logistics distribution, goods delivery or transport services. The present research does not address this topic directly but mentions feasible zones for the application of clustering algorithms.

For this purpose, three distinct Zones are clearly shown in Table 3.

Table 3 Feasible zones for natural Clusters application

Clusters	Nodes	Internal time (min)	Distance (km)
Zone 1	E, F, G, H, I	< 4 min	< 11 km
Zone 2	J, K, L, M	< 5 min	< 15 km
Zone 3	Q, R, S, T	< 3 min	< 7 km

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

The recommended strategy is the consolidation of cargo within each cluster prior to inter-zone shipments.

Route segments were hierarchically classified for potential redesign, defined as:

High-Frequency Trunk Routes: $E \leftrightarrow F \leftrightarrow G \leftrightarrow H \leftrightarrow I$ and $Q \leftrightarrow R \leftrightarrow S \leftrightarrow T$.

Secondary Routes: Serving as connections between clusters ($E \leftrightarrow J, I \leftrightarrow Q$).

Tertiary/Low-Priority Routes: Peripheral routes ($A \leftrightarrow AF, C \leftrightarrow AF$).

Through the application of the optimization model implemented in the LINDO v18.0 Software, using the Simplex method for multicriteria optimization, the route shown in Table 4 was obtained. This table shows that the route segment with the highest cost was P-Q, reaching \$75.51 MXN; the longest route segment was P-Q with 7.3 km, resulting in a total fuel consumption for the route of \$601.51 MXN and a total travel distance of 58.10 km.

Table 4 Route obtained through the Simplex method-based model for multicriteria optimization

Routes	Fuel cost (MXN)	Distance (km)	Routes	Fuel cost (MXN)	Distance (km)
A-D	37.24	3.6	P-Q	75.51	7.3
D-C	6.72	0.65	Q-S	44.48	4.3
C-B	6.21	0.6	S-U	10.34	1
B-E	14.48	1.4	U-T	8.79	0.85
E-G	24.83	2.4	T-R	16.55	1.6
G-F	15.52	1.5	R-AC	14.48	1.4
F-H	8.28	0.8	AC-AE	7.76	0.75
H-I	15.52	1.5	AE-AB	11.93	1.1
I-J	7.24	0.7	AB-AD	10.34	1
J-K	16.55	1.6	AD-AF	4.65	0.45
K-L	11.38	1.1	AF-X	9.82	0.95
L-M	32.07	3.1	X-W	6.2	0.6
M-N	21.72	2.1	W-V	19.65	1.9
N-Ñ	24.83	2.4	V-Y	20.68	2
Ñ-O	44.48	4.3	Y-AA	9.82	0.95
O-P	31.03	3	AA-Z	12.41	1.2
Subtotal	318.1	30.75	Subtotal	283.41	27.35
			Total	601.51	58.1

Table 5 shows a precise comparison of the most important metrics between the current route and the optimized route. A relatively considerable decrease in distance, consumption and time of 12.3%, 12.4% and 12.2%, respectively, is observed. These figures align approximately with those reported by [26], which states that in the beverage sector, route optimization via linear programming has enabled average reductions of 14.2% in distance traveled and 13.8% in fuel consumption.

Table 5 Optimized route vs. current route

Metrics	Current route	Optimized route	Reduction (%)
Distance (km)	66.25	58.10	12.3%
Fuel consumption (MXN)	686.28	601.51	12.4%
Time (min)	180	158	12.2%

This study demonstrates practical implications of significant interest, as the estimated annual savings amount to \$62,243 MXN/year. This is derived from a route cost of \$85.32 MXN/route, considering 2 routes/day over 365 days in a year. This represents a considerably high emissions reduction, as the distribution distance is reduced by 8.15 km compared to the current route. The vehicles analyzed in this research emit 0.25 kg of CO₂/km. Consequently, the optimized route achieved a decrease in emissions, with a reduction of approximately 2.04 kg of CO₂ per day, leading to an annual reduction of 1.49 metric tons of CO₂/year, thereby contributing to environmental protection. The model presents advantages through its replicability and it is applicable to other FEMSA routes or similar companies. It is scalable, as it can be easily adapted to dynamic constraints by incorporating parameters such as traffic and demand.

The main limitations of this model are that it does not account for real-time traffic variability and assumes a constant demand, thereby avoiding a seasonality analysis.

Figure 2 shows the operational logistics network based on consumption and distances, featuring 33 nodes and 32 route segments, where the route segments with their trajectories, fuel consumption and travel distances are visualized.

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

References

- [1] CRAINIC, T.G., LAPORTE, G.: Planning Models for Freight Transportation, *European Journal of Operational Research*, Vol. 97, No. 3, pp. 409-438, 1997. [https://doi.org/10.1016/S0377-2217\(96\)00298-6](https://doi.org/10.1016/S0377-2217(96)00298-6)
- [2] KOK A.L., HANS E.W., SCHUTTEN J.M.J.: Vehicle routing under time-dependent travel times: The impact of congestion avoidance, *Computers & Operations Research*, Vol. 39, No. 5, pp. 910-918, 2012. <https://doi.org/10.1016/j.cor.2011.05.027>
- [3] FEMSA, Fomento Económico Mexicano, Informe Anual Integrado, [Online], Available: <https://www.femsa.com/wp-content/uploads/2024/05/FEMSA-Informe-Anual-Integrado-2023.pdf>, [05 Sep 2025], 2023.
- [4] WU, Y., LAM, J.S.L.: Strategic investment in supply chain resilience: A study of fast-moving consumer goods under demand uncertainty, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 205, 104495, pp. 1-23, 2026. <https://doi.org/10.1016/j.tre.2025.104495>
- [5] RAMÍREZ-VILLAMIL, A., MONTOYA-TORRES, J.R., JAEGLER, A.: Trends and Advances in Urban Logistics Research: A Systematic Literature Review, *Journal of Advanced Transportation*, Vol. 2025, pp. 1-30, 8859606, 2025. <https://doi.org/10.1155/atr/8859606>
- [6] DANTZIG, G.B., RAMSER, J.H.: The Truck Dispatching Problem, *Management Science*, Vol. 6, No. 1, pp. 80-91, 1959.
- [7] AHUJA, R.K., MAGNANTI, T.L., ORLIN, J.B.: *Network flows: Theory, algorithms, and applications*, Prentice Hall, NJ, United States, 1993.
- [8] DE DIOS ORTÚZAR, J., WILLUMSEN, L.G.: *Modelling Transport*, 4th ed., Wiley, 2011.
- [9] LAPORTE, G., GENDREAU, M., POTVIN, J.-Y., SEMET, F.: Classical and modern heuristics for the vehicle routing problem, *International Transactions in Operational Research*, Vol. 7, No. 4-5, pp. 285-300, 2000. <https://doi.org/10.1111/j.1475-3995.2000.tb00200.x>
- [10] POOT, A., KANT, G., WAGELMANS, A.P.M.: A savings based method for real-life vehicle routing problems, *The Journal of the Operational Research Society*, Vol. 53, No. 1, pp. 57-68, 2002. <https://www.jstor.org/stable/822879>
- [11] HESSE, M.: City Logistics: Network Modelling and Intelligent Transport Systems, Eiichi Taniguchi, Russell G. Thompson, Tadashi Yamada, Ron van Duin; Pergamon, Oxford, 2001, ISBN 0 08 043903 9, 260 pp, \$91/83.95 euros (hbk), *Journal of Transport Geography*, Vol. 10, No. 2, pp. 158-159, 2002. [https://doi.org/10.1016/S0966-6923\(01\)00041-2](https://doi.org/10.1016/S0966-6923(01)00041-2)
- [12] SUN, G., LI, T.: Optimizing Logistics in Forestry Supply Chains: A Vehicle Routing Problem Based on Carbon Emission Reduction, *Forests*, Vol. 16, No. 1, 62, pp. 1-21, 2025. <https://doi.org/10.3390/f16010062>
- [13] CHENG, F., JIA, S., GAO, W.: Low-Carbon Logistics Distribution Vehicle Routing Optimization Based on INNCGA, *Applied Sciences*, Vol. 14, No. 7, 3061, pp. 1-16, 2024. <https://doi.org/10.3390/app14073061>
- [14] HILLIER, F.S., LIEBERMAN, G.J.: *Introduction to Operations Research*, 9th ed., McGraw-Hill, 2010.
- [15] XIAO, Y., ZHAO, Q., KAKU, I., XU, Y.: Development of a fuel consumption optimization model for the capacitated vehicle routing problem, *Computers & Operations Research*, Vol. 39, No. 7, pp. 1419-1431, 2012. <https://doi.org/10.1016/j.cor.2011.08.013>
- [16] PEDRAM, A., SOROOSHIAN, S., MULUBRHAN, F., & ABBASPOUR, A.: Incorporating vehicle-routing problems into a closed-loop supply chain network using a mixed-integer linear-programming model. *Sustainability*, Vol. 15, No. 4, 2967, pp. 1-24, 2023. <https://doi.org/10.3390/su15042967>
- [17] TOTH, P., VIGO, D.: *Vehicle routing: problems, methods, and applications*, Society for industrial and applied mathematics, 2014.
- [18] ATTA-ADJEI, B., SEBIL C., OTOO, D., ACKORA-PRAH, J.: A quadratically constrained mixed-integer non-linear programming model for multiple sink distributions, *Heliyon*, Vol. 10, No. 19, pp. 1-19, 2024. <https://doi.org/10.1016/j.heliyon.2024.e38528>
- [19] BIGGS, N., LLOYD, E., WILSON, R.: *Graph Theory: 1736-1936*, Oxford University Press, NY, United States, 1986.
- [20] KURATOWSKI, K.: Sur le problème des courbes gauches en topologie, On the problem of skew curves in topology, *Fundamenta Mathematicae*, Vol. 15, No. 1, pp. 271-283, 1930. (Original in French)
- [21] APPEL, K., HAKEN, W.: Every planar map is four colorable. *Bulletin of the American Mathematical Society*, Vol. 82, No. 5, pp. 711-712, 1976. <https://doi.org/10.1090/S0002-9904-1976-14122-5>
- [22] GHIANI, G., LAPORTE, G., MUSMANNO, R.: *Introduction to logistics systems management*, John Wiley & Sons, 2013.
- [23] DANTZIG, G.B.: *Linear Programming and Extensions*, Princeton University Press, United States, 1963.
- [24] KLEE, V., MINTY, G.J.: *How good is the Simplex algorithm?*, Inequalities, Academic Press, New York, 1972.
- [25] GHAREHYAKHEH, A., KREJCI, C.C., CANTU, J., ROGERS, K.J.: A Multi-Objective Model for Sustainable Perishable Food Distribution Considering the Impact of Temperature on Vehicle Emissions and Product Shelf Life, *Sustainability*, Vol. 12, No. 16, 6668, pp. 1-21, 2020. <https://doi.org/10.3390/su12166668>

Simplex linear programming for route optimization model in urban distribution

Raudel Flores-Moreno, Pablo Iván Flores González, María Jesica Zavala Pineda, Ernest Yasser Núñez Betancourt

- [26] QIN, G., TAO, F., LI, L.: A Vehicle Routing Optimization Problem for Cold Chain Logistics Considering Customer Satisfaction and Carbon Emissions, *International Journal of Environmental Research and Public Health*, Vol. 16, No. 4, 576, pp. 1-17, 2019. <https://doi.org/10.3390/ijerph16040576>

Review process

Single-blind peer review process.