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STUDY OF OPTIMIZATION STRATEGIES FOR LAST-MILE DELIVERY OF CPG PRODUCTS TO NANOSTORES IN THE CITY CENTER OF COCHABAMBA

ESTUDIO DE ESTRATEGIAS DE OPTIMIZACIÓN PARA LA DISTRIBUCIÓN DE ÚLTIMA MILLA DE PRODUCTOS DE CONSUMO (CPG) A NANOTIENDAS EN EL CENTRO DE LA CIUDAD DE COCHABAMBA.

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ABSTRACT

Last-mile logistics represents a major cost and environmental challenge in dense urban centers, particularly in emerging economies. In Bolivia, where over 92% of retail transactions occur through informal nanostores, urban freight operations to supply these channels are hindered by narrow streets, congestion, and a lack of logistics infrastructure. In this direction, this study explores an optimization strategy for last-mile delivery of consumer-packaged goods (CPGs) to nanostores in downtown Cochabamba. We used a mixed-methods approach, including surveys of 243 stores, interviews with logistics managers, and route modeling with VRP (Vehicle Routing Problem) Spreadsheet Solver. We considered a cluster-based logistics bay strategy, leveraging abandoned parking bays in the region for this purpose. Results show that the use of designated bays and the proposed route clustering can reduce delivery times by up to 11% and unit costs by 4,7%. These findings inform urban logistics planning and public policy for cities facing similar informal retail challenges.

Keywords: Last-mile distribution, traditional channel, public policies, routing model, bays

RESUMEN

La logística de última milla representa un importante reto económico y medioambiental en los centros urbanos densos, sobre todo en las economías emergentes. En Bolivia, donde más del 92% de las transacciones minoristas se realizan a través de nanotiendas informales, las operaciones de transporte urbano para abastecer estos canales se ven obstaculizadas por calles estrechas, congestión y falta de infraestructura logística. En esta dirección, este estudio explora una estrategia de optimización para la entrega de última milla de bienes de consumo envasados (CPGs) a las nanotiendas en el centro de Cochabamba. Usamos un enfoque de métodos mixtos, incluyendo encuestas a 243 tiendas, entrevistas con gerentes de logística y modelado de rutas con VRP (Vehicle Routing Problem) Spreadsheet Solver. Consideramos una estrategia de bahías logísticas basada en agrupaciones, aprovechando para ello las bahías de estacionamiento abandonadas de la región. Los resultados muestran que el uso de bahías designadas y la agrupación de rutas propuesta pueden reducir los plazos de entrega hasta en un 11% y los costes unitarios en un 4,7%. Estas conclusiones sirven de base para la planificación de la logística urbana y las políticas públicas de las ciudades que se enfrentan a retos similares en el comercio minorista informal.

Palabras Clave: Distribución de última milla, canal tradicional, políticas públicas, modelo de encaminamiento, bahías

1. INTRODUCTION

Urbanization in Latin America has reached unprecedented levels, with approximately 81% of its population living in urban areas [1]. This rapid growth has significantly strained transportation infrastructure, particularly in dense city centers. One of the most pressing challenges is the "last-mile delivery" process, the final leg in the supply chain, accounting for up to 28% of total logistics costs [2]. As cities grow and consumption patterns become more dynamic, last-mile operations face logistical and environmental pressures. Congested roads, limited parking, narrow streets, and restrictive urban policies all hinder efficient delivery systems, contributing to higher CO_2 emissions and longer lead times [3].

In Latin America, these challenges are compounded by the continued dominance of the traditional retail channel, which includes small neighborhood stores and kiosks, also called nanostores. These nanostores typically have low storage capacity and demand frequent, small-volume deliveries. As a result, manufacturers must design high-frequency, fragmented delivery routes, which add to operational complexity and cost [4] [5]. Despite the expansion of modern retail, countries like Bolivia still rely heavily on this informal and decentralized channel.

In this context, Cochabamba, Bolivia, presents a unique case. As the third-largest city in the country and the one with the highest population density (31,6 people per km²), Cochabamba combines rapid urban growth with aging infrastructure and minimal public investment in logistics planning [6]. The city center is characterized by narrow streets, heavy congestion, and limited designated areas for loading and unloading.

Nanostores dominate the retail landscape, with over 92% of transactions still taking place through traditional outlets such as nanostores [7]. Authors estimate that there are around 50 million nanostores in emerging markets [8], which are a significant part of the informal economy [4]. These small businesses are inclined to employ a traditional distribution channel that encompasses the retail sale of a wide variety of products. In 2018, Castañon Choque [9] study found that improving the survival rate of nanostores can reduce transportation logistics costs by up to 31%. In this research, we study two formats of nanostores and kiosks.

This study considers the point of view of the manufacturers that execute the transportation operations in the last mile deliveries for nanostores. For this reason, we focus on companies that plan and manage consumer-packaged goods' (CPGs) distribution, and this research presents the following research question*: Is it possible to use a routing model to select the most appropriate bays to fulfill the demand of nanostores for a densely populated region, such as the city center of Cochabamba?*

The objective of the research is the proposal and evaluation of a cluster-based routing model using logistics bays to reduce congestion, optimize delivery routes, and improve service levels in informal retail contexts. The novelty lies in its application to a Latin American mid-sized city with high reliance on nanostores and limited infrastructure regulation.

The paper is structured as follows: Section 2 reviews related work and international experiences; Section 3 presents the methods and data collection process; Section 4 details the model and experimental setup; Section 5 discusses the results; and Sections 6 and 7 provide the discussion, conclusions, and future research directions.

2. BACKGROUND

Previous case studies can help when structuring proposals to facilitate the movement of cargo in urban contexts with difficult access. A review of different global case studies, with a focus on Latin America and similar characteristics to Cochabamba, was conducted to understand how different cities have addressed similar problems in urban commercial distribution issues. This research includes interventions through regulatory frameworks, improvements in supply chain timing and infrastructural adjustments. The main methodologies used, along with their operational scenarios and results, are compiled in Table 1. These proposals extend to the private sector and the strategies that can be addressed by government agents responsible for public policy in cities.

TABLE 1 - RECAPITULATION OF THE REVIEWED CASE STUDIES

CITY	CONTEXT	SOLUTION	CONCLUSIONS
Buenos Aires, Argentina	This project establishes a standard for distribution operations to prevent loading and unloading from being carried out on double lines or in restricted parking areas.	Assignment of blue boxes for the exclusive use of distribution vehicles at specific schedules.	This is an example of public policy development opportunities that collaborate with the distribution of merchandise in a high-density urban center.
Mexico City, Mexico	The objective is to develop distribution activities for manufactured consumer goods and generate information on the variables of the operation. This, to try to solve the Territory Design Problem.	The use of vehicles with smaller capacities (4 tons), and with different characteristics like a greater maneuverability capacity in urban infrastructure, establishing an optimal model	As a result, the importance of traffic conditions information is emphasized to establish a transportation profile.
Quito, Ecuador	The historic center of the city has a problem of high vehicular congestion in which companies must develop distribution operations to retail establishments.	The proposed solution is an optimization model installing loading and unloading docks in the area to improve distribution time and reduce the cost of the operation.	The methodology characterizes the operations of the traditional channel and commercial establishments that represent the highest frequency of visits in this area of Quito.
Santiago, Chile	A study of the loading and unloading docks in the central area of the city of Santiago de Chile was carried out, applying the diagnosis	Maximize the coverage of the demand of the sector's commercial establishments by using loading and	The proposed plans sought consensus between the regulations and the reality of the area, understanding that demand could

CITY	CONTEXT	SOLUTION	CONCLUSIONS
	and characterization methodology and the logistics profile.	unloading docks in the downtown area.	not be distributed homogeneously throughout the area.
São Pablo, Brazil	The primary focus of the study was on safety and noise issues, as well as productivity aspects such as travel time, vehicle speed, and delivery times.	Applying off-hour delivery operations in São Paulo involving all the stakeholders to identify the main requirements, restrictions, opportunities, and threats for the operation.	The impact must be mitigated with incentives and by establishing improvements in the service level with more reliable delivery schemes and less interference with the establishment's sales operations.

Sources [10-18]

Urban planning approaches provide a comprehensive view of the challenges in urban freight transportation and principally propose interconnected strategies for sustainable and efficient last-mile logistics. Many authors emphasize that solutions for last-mile inefficiencies are not only a problem for CPGs manufacturers, but also for the community and principally for policymakers. For example, Merchán et al. [17] highlight the importance of standardized urban logistics metrics for policymakers, and the need to enable data-driven planning across regions. Complementing this, Wisetjindawat [18] further reviews and presents best practices in city logistics, emphasizing the need for public-private coordination to implement effective and tailored solutions. Further, Taniguchi and Thompson [19] advance this discussion proposing a conceptual framework for city logistics, where stakeholders are integrated through iterative planning (using PDCA cycles), and advocating for the deployment of advanced information systems to align logistics operations with urban sustainability goals.

Building on the operational dimension, Gevaers et al. [20] offer a cost modeling approach that simulates last-mile delivery scenarios. The authors identify how factors such order size, delivery density, and urban typology impact cost structures. Thus, this study integrates such variables into the final model, based on this previous finding. Additionally, Crainic and Laporte [21] foundational review of freight transportation models, categorizing them into strategic, tactical, and operational levels, highlighted the role of network optimization, location planning, and heuristic methods. Among the techniques used are location-allocation models, vehicle planning routing models (VRPM), multimodel networks, and integrated planning.

As a result of reviewing the case studies and previous approaches, it was noticed that the effectiveness of urban transport solutions is variable depending on regional factors such as stakeholder involvement, regulatory maturity and traffic congestion. By striking a balance between factors such as well-defined legislative frameworks and stakeholder cooperation, the solutions presented have beneficial effects. On the other hand, lack of incentives, environmental behavior and even aspects of informal retail structures result in implementation problems. The restricted use of route optimization models to support infrastructure-based solutions is reflected in a weakness in all cases.

We based this study on the previous studies, applying the existing theory to models and validating how VRPM can help to improve the efficiency of last mile deliveries in a real environment. This study deepens into existing literature while respecting specific physical space constraints. Based on this, a route optimization model adapted to the informal retail environment of Cochabamba is proposed. Aspects such as local commercial density, nanostore variations and delivery constraints are considered. This is a more flexible, data-driven alternative that considers the reality on the ground. In this way, the gap between policy creation and efficiency of operations in cities with a poor urban logistics process is reduced.

3. METHODOLOGY

This research followed a structured methodological process that begins with a literature review and ends with the development and evaluation of a logistics strategy tailored to nanostores in Cochabamba's city center. The study was developed through four sequential phases: (1) literature review and design, (2) data collection, (3) data analysis and diagnosis, and (4) modeling and evaluation of proposed strategies. These phases are summarized in Figure 1, which presents the methodology framework applied throughout the research.

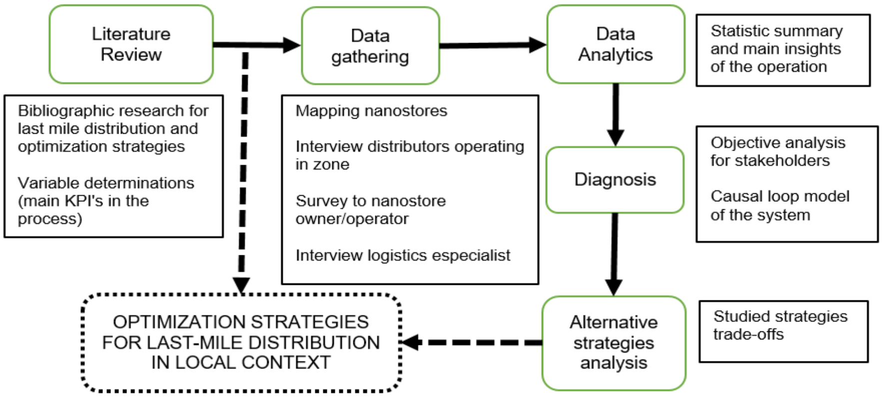


Figure 1: Methodology framework applied for the study.

To achieve the objectives proposed, it is important to ensure systematic and rigorous procedures. By applying the methodology presented in Figure 1, optimal results will be achieved.

3.1. Literature Review and Design

The first stage involved a comprehensive review of existing literature related to urban freight transport, last-mile logistics, nanostore operations, public policy, and successful strategies implemented in similar contexts across Latin America. Based on the literature, key variables were defined for data collection, including delivery frequency, service levels, operational constraints, and perceptions of the various stakeholders involved in distribution processes.

3.2. Data collection

The data collection process in this research endeavor is meticulously designed to gather comprehensive insights. Through a combination of collaborative fieldwork, advanced geo-referencing technology, and structured stakeholder surveys.

TABLE 2 - STAGES OF DATA COLLECTION OF METHODOLOGY

STAGE	TARGET ACTOR	INFORMATION APPROACH	TOOL
First	Neighborhood store owner/salesperson	Frequency of visits Level of service	Survey
Second	Transporter	Perception of operating difficulties in the area Number of people in operation Number of stops on route. Territory of operation	Interview
Third	Logistics management	Distribution planning process Operation cost parameters	Interview

Table 2 presents the stages of data collection. These phases will allow us to have an overview of the steps to follow for the research.

3.2.1. Surveys to nanostores

To estimate the number of stores in the universe of nan stores in the city center, geo-referencing mapping was employed using Google Maps' Street View platform. The georeferencing and mapping of the nanostores is provided in the map in Figure 2, which details the location of the kiosks (marked in red) and the nanostores (marked in blue). The population was estimated to be 224 establishments in the study area. Given that Google information was last updated in 2015, the 2,5% annual growth calculated by Ciesmori [7] was considered, obtaining that, currently, there is an approximate total of 243 establishments in the nanostore category within the study area. Considering the surface area of the zone, approximately one square kilometer (km^2), we conclude that the density of this retail format in the city center is approximately 250 nanostores/km^2.

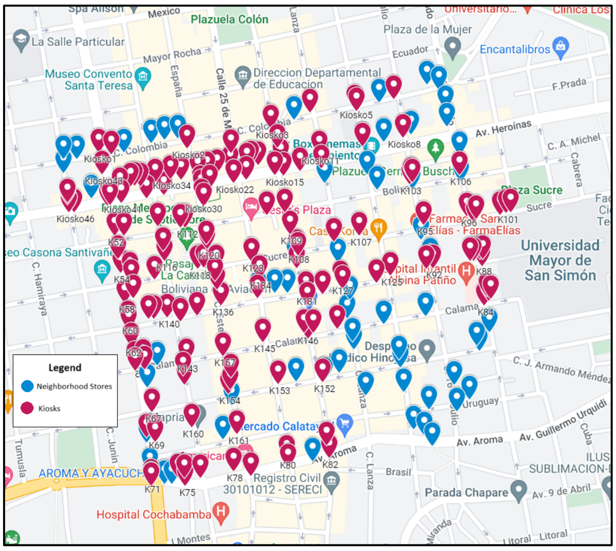


Figure 2: Mapping of nanostores and kiosks at the study site in Google Maps.

Using the calculation of a probabilistic sample considering the estimated population of 243 business outlets in the central area of the city of Cochabamba, a 90% confidence level and an equal proportion of success and failure, a representative sample size of 53 outlets was determined. In the surveys for the points of sale, a total of 98 commercial establishments were reached, including neighborhood stores and kiosks, approximately 43% of the total mapped population.

3.2.2. Interviews with logistics decision-makers from leading nano-store companies

The study selected companies with a high frequency of visits to nanostores based on their presence and perceived service level. They were asked about their logistics operations, objectives, and performance in the city center. The consultation also aimed to gather data on customers of nanostores and compare information from kiosks and nanostore owners. Finally, we used the results of the surveys and interviews to construct the first urban freight transport profile of Cochabamba's city center and to identify the system's key operational problems. Each stakeholder's role and perspective were mapped and analyzed to develop an integrated diagnosis based on their respective objectives.

3.3. VRP Model

The study proposed alternative logistics strategies and evaluated them through modeling, comparing them with urban distribution challenges in Latin American cities. The VRP Spreadsheet Solver was chosen for its suitability, replicability, and transparent route optimization capabilities. The model incorporated inputs such as customer locations, product volumes, service times, vehicle capacity, and delivery time windows. Although advanced sensitivity or stochastic analysis was not feasible due to limited data, model validation was conducted by comparing simulation outputs with actual delivery routes and stakeholder feedback.

4. EXPERIMENTAL/NUMERICAL SETTING

Urban freight distribution problems mean developing a model is too extensive and complex. A descriptive research approach is adopted. Table 3 presents the main variables in the distribution process for the traditional channel and identifies as determinants to collect information from the main actors through surveys.

TABLE 3 - DEFINITION OF VARIABLES

VARIABLE	MEASURING UNIT	INFLUENCE ON THE PROCESS
Capacity utilization	% of capacity in weight (kg) or volume (L) of the vehicle	Indicator of the efficiency and costs of operating a vehicle with the minimum percentage of its capacity to make the operation profitable.
Average drop size	kg or liter/point of sale	Relates the total number of kg carried by a vehicle and the number of customers it delivers to. Quantity delivered per customer
Total operating time	Hours	Time from the time the vehicle leaves the factory or distribution center until it returns to the same point after making the corresponding deliveries.
Downtime	Minutes	Time the vehicle is stopped for loading and unloading operations, and for transferring products to the stores.
Service time	Minutes	Time it takes to prepare the product order on site, move it from the truck to the point of sale, perform the necessary tasks on site and return to the truck.
Service level	Satisfaction index	The quality perceived by the nanostores of the level of service provided by the company's policies and executed by the carriers.

Based on the data collected during the research and the type of operation to be emulated, it is concluded that the VRP Spreadsheet Solver tool is adequate to offer the optimal solutions in terms of routes and sequence of customers to be visited to maximize revenue from delivery routes. The following table presents the input data list for the template.

TABLE 4 - INPUT DATA LIST FOR TEMPLATE

DATA	UNITS/DATA TYPE	SPREADSHEET
Number of customers	Number	Console VRP Solver
Distance calculation method	Console selection	
Average vehicle speed	km/h	
Number of vehicle types	Number	
Name of locations	Number	Locations
Location coordinates	Latitude and Longitude	
Opening hours	Hours, minutes, seconds	
Closing time	Hours, minutes, seconds	
Visiting condition: mandatory/optional	Console selection	
Service time per location	Minutes	
Quantity to be delivered	Kg	
Revenue per delivery to location	Bs	
Vehicle types	Number	Vehicles
Vehicle capacity	Kg	
Fixed cost per trip	Bs	
Unit cost per distance	Bs	
Duration multiplier	Number	
Distance limit	km, meters	
Start time	Hours, minutes, seconds	
End time of day	Hours, minutes, seconds	

Table 4 offers valuable data for optimizing distribution processes. It enables efficient route planning and resource allocation by considering deposits, customers, location details, and vehicle specifications. Factors like distance calculation methods, service times, and revenue per delivery also contribute to informed decision-making. The dataset also includes opening hours, closing times, and visiting conditions.

The model assumes a fixed vehicle speed, constant human walking speed, a maximum cart capacity of 150 kg, and uniform service times, reflecting realistic operational constraints. Limitations and uncertainties are addressed through contextual interpretation and iterative adjustments. The final modeling outputs influenced the creation of cluster-based routing models and the optimal location of logistics bays to enhance efficiency, reduce congestion, and improve service levels in nanostore distribution.

The results encapsulate various key metrics essential for evaluating the efficiency and effectiveness of the distribution process. From customer assignment lists by vehicle to the visualization of optimal routes, each aspect offers valuable insights into the performance and outcomes of the implemented model. By delving into these processing results, stakeholders gain a comprehensive understanding of the distribution dynamics and can make informed decisions to enhance operational performance and customer satisfaction. The results were obtained considering the number of customers and deposits, the characteristics of the vehicles and the locations, an optimal route is reached with the objective of seeking to maximize revenues.

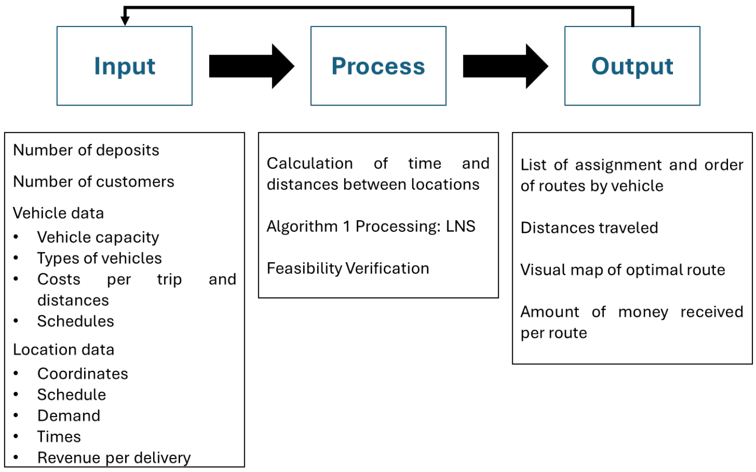


Figure 3: Input and output data processing.

The entire flow of data used in the modeling process, including input variables and resulting outputs, is summarized in Figure 3. This diagram visually outlines the structured integration of customer and vehicle data into the VRP Solver, leading to optimized routing sequences and revenue estimations.

5. RESULTS

In this study, once the fieldwork had been completed, including surveys and interviews, data analysis and process mapping began with the aim of generating strategies according to the requirements of customers and suppliers, as presented in the following sections.

5.1 Survey results

For the evaluation of the frequency of visits by the manufacturing companies, a percentage weighting of the responses of the nanostores was established for the frequency categories consulted. With a weighting of 0,45, the daily frequency is found to be the highest. According to the results visualized in Figure 4, the main companies with distribution operations in the central zone are Pil Andina S.A. and Embol S.A. in the CPGs product categories of dairy and beverages and beverages respectively.

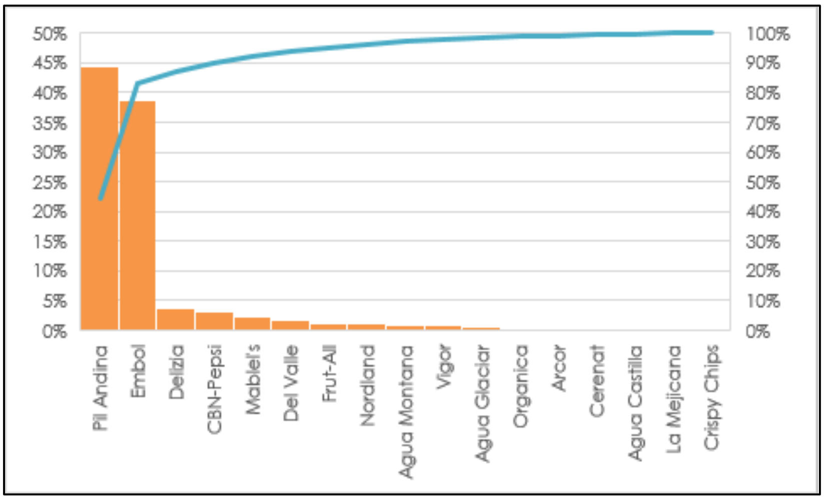


Figure 4: Frequency of visits by manufacturing companies.

Process mapping was conducted for each of the key stakeholders: manufacturing companies, nanostores, and local authorities. This analysis revealed that manufacturers face challenges related to outdated infrastructure, narrow streets, and traffic restrictions that force delivery vehicles to park in unauthorized areas. As a result, drivers often incur infractions or fines, increasing operational risk and cost. nanostores, on the other hand, were found to operate with minimal technological support, limited financial capacity for inventory, and highly fragmented demand. Store owners reported that they value frequent visits and direct delivery from distribution hubs such as "La Pampa" market, located approximately 1 km from the study area. Meanwhile, local authorities demonstrated a lack of coordination between freight logistics needs and public transportation policy, focusing solely on passenger mobility. The absence of municipal regulation for urban freight exacerbates traffic congestion and inefficiencies. This qualitative insight allowed the research to identify systemic misalignments and design a proposal that integrates logistical, commercial, and regulatory dimensions.

The quantitative evaluation of visit frequencies, the research integrated complementary variables such as average drop size, total operation time, and service time per delivery. These indicators were essential to understand the operational performance of last-mile logistics in the city center. For example, the average drop size varied significantly depending on the nanostore format (kiosks and neighborhood stores), reflecting differences in storage capacity and replenishment behavior.

5.2 Interview results

Currently, 3,5 tons and 5 tons capacity trucks are used in the operation, however, the actual occupancy, according to drivers and managers, is only an average of almost 60% of the truck's capacity. It takes an average of 14,41 minutes to serve a nanostore with an average deviation of 10,64. This is because the time to serve a kiosk is significantly less than the time to serve a grocery store, according to distributors. Table 5 presents the average operating times of distributors.

TABLE 5 - AVERAGE OPERATING TIMES OF DISTRIBUTION

	TOTAL SERVICE TIME (H)	TIME IN ROUTE ONE WAY (MIN)	TIME IN ROUTE RETURN (MIN)	AVERAGE TIME OF ATTENTION TO A NANOSTORE (MIN)
Average	10	54	41	14,41
Standard Deviation	1,29	7,35	11,14	10,64

The average drop size varies depending on the format of the nanostore. Kiosks regularly receive small products for personal consumption and small grocery stores have a wider range of products including large SKU presentations. One truck serves an average of 70 nanostores; however, it varies with truck capacity. The average delivery size for kiosks is 20 kg (SD=4,1) and for nanostores it is 53 kg (SD=16,91). To gauge the service level of nanostores, we assessed satisfaction across four distinct levels, revealing an overall positive response. The findings indicate that the current service level is effective, with 58,2% expressing satisfaction and 26,5% being very satisfied, 8,2% rated it as regular, and 7,1% were not satisfied.

Notably, nanostores receive deliveries exclusively during their public opening hours primarily in the morning. Despite small nanostores maintaining an average customer service duration of 14 hours, kiosks operate for approximately 8 hours daily.

5.3 Stakeholder process mapping

Based on the analysis of the process mapping, it was identified that manufacturing companies face challenges due to aging infrastructure and narrow streets, limiting mobility and efficient coverage. Drivers violate regulations to avoid tickets, and vehicles with 3-person teams lose 1/3 of resource capacity for distribution due to one person remaining.

The output indicates that nanostores often lack access to technology and face financial constraints in acquiring products. Distributors frequently visit these stores to handle deliveries and collections, especially valuing direct distribution from the "La Pampa" market. In addition, sales representatives interact directly with the nanostore owners, emphasizing the importance of quality service. Finally, even though local authorities recognize the high traffic congestion in the city center; current policies focus mainly on public passenger transport, without addressing the role of urban goods vehicles. The absence of specific regulations allows private trucks to operate without respecting municipal regulations, which negatively affects the urban population.

This analysis reveals multiple supply chain challenges for manufacturing companies in the area, from outdated infrastructure to the financial constraints of neighborhood stores and kiosks. Lack of technology in nanostores and parking issues compound distribution problems. Despite efforts by local authorities to address congestion, a comprehensive solution that considers all these variables is required to improve transportation and distribution efficiency in the region.

5.4 Study of alternatives

Two key strategies designed to address the identified obstacles will be presented, along with a detailed analysis of an innovative model of clustered bays. These solutions aim to optimize mobility, reduce costs and improve customer satisfaction in the supply chain.

Strategy 1

Loading and unloading bays strategically located in territories designed in the region. With a balanced workload given by service time and demand. According to data one truck delivers approximately 70 nanostores, which means that the optimal number of bays for 250 outlets is almost four. This strategy would require a new public policy to establish bays in specific streets of the road network in the city center.

Strategy 2

Make after-hours deliveries for grocery stores and use certain stores to be a small distribution center for the next day. In this way, cargo would be delivered during off-peak hours (according to municipal restrictions, after 19:00) to small nanostores throughout the region and a certain number of nanostores could keep the cargo that belongs to the kiosks, until the next day. In the morning, the distributors deliver the products to the kiosks only in light-duty vehicles and the truck does not visit the region until the evening.

Table 6 presents a prioritization matrix of strategies to address logistical challenges in the distribution system, including morning delivery to kiosks and limited efficiency until evening truck arrivals. Strategies are categorized based on impact on infrastructure, transportation stakeholders, and operational risks.

TABLE 6 - PRIORITIZATION MATRIX

CRITERIA	PROPOSED STRATEGIES
A. New infrastructure requirement B. Negative impact on transportation stakeholder system	1. Distribution model with after-hours deliveries. Working with allied neighborhood stores that function as night warehouses.
C. Operation Risks D. Increase in costs of current operation	2. Territory design model, with routes for light-duty vehicles operating from logistics bays in existing infrastructure.

Table 6 outlines two strategies for optimizing the distribution process: implementing after-hours deliveries and using neighborhood stores as night warehouses and adopting a territory design model with dedicated routes for light-duty vehicles. These strategies can reduce the daytime logistics burden and minimize operational risks, ensuring timely delivery and operational efficiency.

5.5 Cluster Design

The design of clusters for product loading and unloading bays in neighborhood stores and kiosks aims to optimize distribution efficiency. These clusters are based on proximity to delivery points and product demand, facilitating consolidation of shipments, reducing logistics costs and delivery times, and promoting a more sustainable operation. Coordination between suppliers and logistics operators is crucial for the effectiveness of this approach, promoting collaboration and synergies benefiting the entire supply chain.

TABLE 7 - CLUSTER AND BAYS PROPOSED

BAY	ADDRESS	CLUSTER
West Calama Bay	Calama between Nataniel Aguirre and Esteban Arce	West Cluster
North Lanza Bay	Lanza between Sucre and Jordán	East Cluster, North Cluster
Colombia Bay	Colombia and Ayacucho	West Cluster, North Cluster
Oquendo Bay	Oquendo between Uruguay and L. Cabrera	East Cluster, South Cluster
South Lanza Bay	Lanza and L. Cabrera	South Cluster

Table 7 details the bays and their respective assigned clusters, crucial for the data analysis elaborated in point 5.6.

5.6 Vehicle Routing Problem results

The proposal aims to reduce vehicular congestion in a specific area by creating exclusive logistics bays for companies distributing consumer goods. The bays will be priced similarly to public parking, incentivizing companies to limit cargo vehicle circulation and reduce congestion. Distribution will be optimized using handcarts on efficient routes, reducing distance and stops. Routing strategies will be divided by neighborhood store format, with specific models for kiosks and nanostores. The model aims to generate clusters served from a single logistics bay, with a focus on kiosks, ensuring positive commercial density.

Regarding the mobility of handcarts, a standard human speed of 7 km/h is contemplated, and a maximum capacity of 150 kg is estimated for the carts used during the operation. These changes seek to improve efficiency in the distribution of goods, reduce costs, and promote more sustainable practices in urban freight transportation. A total of seven potential spaces is presented, which, within the existing infrastructure in the city center, can be proposed for the development of logistics areas dedicated to loading and unloading operations for vehicles belonging to companies that need to make deliveries in the city center. Calama and Lanza streets are transversal elements within this existing infrastructure, each containing more than one potential space along their length. Table 8 presents the bays considered for logistic operations.

TABLE 8 - BAYS FOR LOGISTICS OPERATIONS

IDENTIFIER	LENGTH IN LINEAR METERS	CAPACITY IN NUMBER OF VEHICLES
West Calama Bay	55,63	4
North Lanza Bay	31,37	2
Colombia Bay	26,32	2
Oquendo Bay	61,81	4
South Lanza Bay	30,60	2
Middle (West and East) Calama Bay	26,06	2
East Calama Bay	24,05	2

For the territorial balance research, a CARTO analysis was utilized to create a clustering model that provides a better understanding of the geographic distribution of the kiosks. Figure 5 visually represents this approach, with kiosks color-coded: light blue for the ‘West clusters’ and red for the ‘East cluster’.

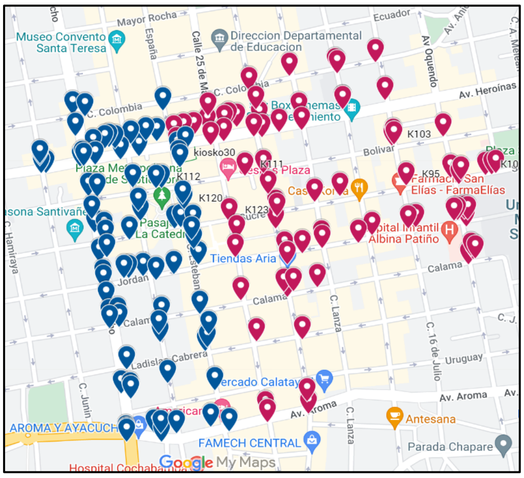


Figure 5: Territory design for kiosks in Google Maps.

This geospatial analysis presented in Figure 5 provides important information for understanding the concentration and distribution of kiosks. This information is crucial for strategic planning and balanced development of the territory.

5.6.1 West Cluster

The West cluster consists of kiosks in the sectors of the main square and two important intersections of Ayacucho Avenue with Heroínas Avenue and Aroma Avenue. Table 9 collects the data of the processes of the proposed bays and the current model, compared to the main parameters of the operation.

TABLE 9 - COMPARISON OF ECONOMIC RESULTS BETWEEN WESTERN CLUSTER MODELS

	CURRENT MODEL	WEST CALAMA BAY	COLOMBIA BAY
Contacts	70	72	69
Client coverage in the area	86,42 %	88,89 %	85,19 %
Incomes	Bs 5 250	Bs 5 400	Bs 5 175
Freight cost	Bs 627,94	Bs 635,44	Bs 624,19
Unit costs per costumer	Bs 8,97	Bs 8,83	Bs 9,05
Total operating time	7 h	6,26 h	6,23 h

In the first instance, based on the unit cost of serving a nanostore, the Calama West Bay model presents the best result, reducing the unit cost by approximately 2%. One of the most important improvements appears in the operation time, with a 10% of time reduction in the case of Bahía Calama Oeste and 11% in the case of Bahía Colombia.

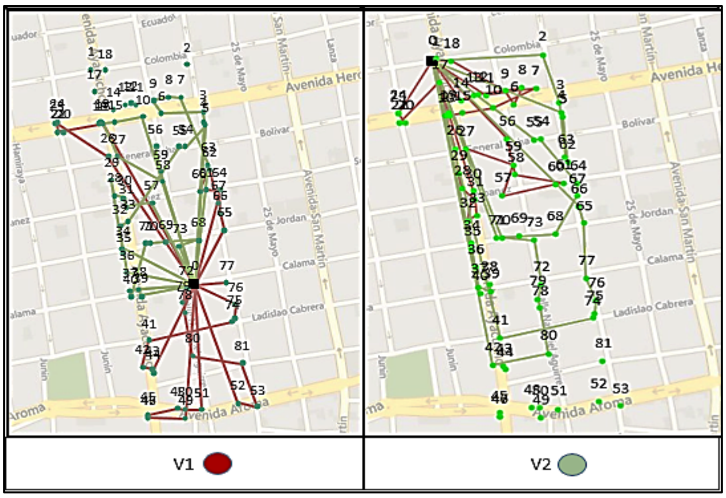
The workload is measured with the results for operating time, distances traveled, and the number of clients served with the model. Table 10 shows the results of these variables in both models, as well as the delivery quantities and unit costs of serving the kiosks analyzed in two vehicles under variables “Vehicle N° 1” (V1), “Vehicle N° 2” (V2), and “Vehicle N° 3” (V3).

TABLE 10 - COMPARISON OF WORKLOAD RESULTS BETWEEN MODELS OF THE WESTERN CLUSTER.

	WEST CALAMA BAY	COLOMBIA BAY
Distance traveled V1	5,72 km	5,17 km
Distance traveled V2	5,63 km	9,14 km
Total distance traveled	11,35 km	14,31 km
Number of customers visited	72	69
Operating time V1	4,7 h	4,5 h
Operating time V2	4,7 h	4,65 h
Load delivered	1 440 kg	1 380 kg

The difference of 2,96 km in total distance traveled between the two models is remarkable, especially observing the trips made in route by vehicle N° 2 operating from Colombia Bay. This vehicle oversees supplying products to the furthest points in the southern sector and therefore travels a much longer distance than vehicle N° 1 (3,97 km more), making more trips to the kiosks on Ayacucho Avenue and Ladislao Cabrera Street.

Neither of the two routes can supply all 81 customers in the territory. In the case of the west Calama Bay, it reaches the points on Heroínas Avenue, leaving aside the supply to the kiosks situated on the north side of the avenue and those located on Colombia Street. On the other hand, the Colombia Bay model does not deliver products to kiosks in the southern end of the territory, to businesses on Uruguay Street and Aroma Avenue. The operational limitations of each model, in terms of geographic coverage and route efficiency, are visually represented in Figure 6. This comparison shows how the route from West Calama Bay fails to reach kiosks on Colombia Street, while the route from Colombia Bay omits kiosks located in the southern area, such as those on Uruguay and Aroma Avenues. These gaps are crucial for evaluating service coverage and route balance in the western cluster.



(a) (b)

Figure 6: Western cluster route comparison. (a) West Calama Bay, and (b) Colombia Bay.

The model chosen for the western cluster is based on the profits offered by the route, the cost of serving a kiosk, client coverage rate, and workload distribution. The distribution model from Colombia Bay has an imbalance in total distances traveled by handcarts, with a handcart needing 9,14 km to cover 34 clients. This distance is not optimal for the process or the distribution team, potentially reducing service levels. The number of contacts per route could increase by up to 9,72% for auto-sales routes in the West cluster.

5.6.2 East Cluster

The bays proposed for kiosk service in the sector were located on Lanza Street, in the northern sector, and on Oquendo Avenue. Both bays have the potential to become a convenient location for the supply of products in the university area and southeast of the historic center. Table 11 collects the data of the processes of the proposed bays and the current model, compared to the main parameters of the operation.

TABLE 11 - COMPARISON OF ECONOMIC RESULTS BETWEEN EASTERN CLUSTER MODELS

	CURRENT MODEL	NORTH LANZA BAY	OQUENDO BAY
Contacts	70	76	65
Client coverage in the area	86,42 %	93,83 %	80,25 %
Incomes	Bs 5 250	Bs 5 700	Bs 4 875
Freight cost	Bs 627,94	Bs 650,44	Bs 609,19
Unit costs per costumer	Bs 8,97	Bs 8,55	Bs 9,37
Total operating time	7 h	6,5 h	6,4 h

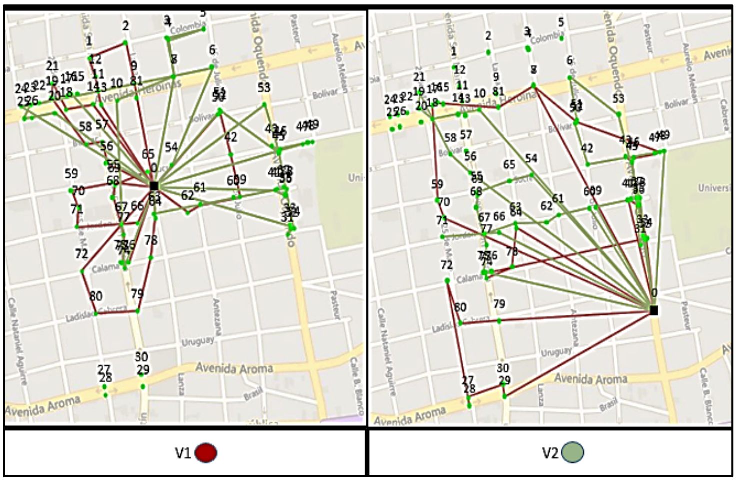
The model from Lanza Bay North generates 18% more profit than the model from Oquendo Bay, the difference in monetary terms is Bs 825. Unit costs per service to a neighborhood store provide a basic parameter for comparing the advantages of a model. In the case of Oquendo Bay, the unit cost is higher than the Bs 8,97 of the current situation. The North Lanza Bay has a unit cost of Bs 8,55 per customer served on route. This means savings in costs per customer of up to 4,68%.

Comparing the distribution of the workload, the results of the operating time, the distances traveled, and the number of customers served with the model were taken. Table 12 shows the results for these variables in both models and the cost variables for serving each customer on a unitary basis.

TABLE 12 - COMPARISON OF WORKLOAD RESULTS AMONG EASTERN CLUSTER MODELS

	OQUENDO BAY	NORTH LANZA BAY
Distance traveled V1	9,49 km	5,68 km
Distance traveled V2	9,52 km	8,91 km
Total distance traveled	19,01 km	14,59 km
Number of customers visited	65	76
Operating time V1	4,7 h	4,5 h
Operating time V2	4,82 h	4,92 h
Load delivered	1 300 kg	1 520 kg

The North Lanza Bay model proposes two cargo vehicles for operations from Oquendo Bay, with vehicle N° 1 traveling 9,49 km and vehicle N° 2 traveling 9,52 km. However, customer coverage is only 80,25%, with an average of 3,42 clients per km. The Lanza Bay operations deliver 1 520 kg of cargo, while from Oquendo Bay, 1 360 kg are delivered. The optimal utilization of these vehicles generates routes of 5,68 km for vehicle N° 1 and 8,91 km for vehicle N° 2, with handcarts completing their routes in a maximum time of four hours and fifty-five minutes. The Lanza Norte sector is chosen for kiosks in the eastern territory, offering cost reduction and improved commercial results. Despite longer operation times, the distance load is better balanced and offers better commercial results for the company's objectives of maximizing sales.



(a) (b)

Figure 7: Comparison of routes in east cluster. (a) North Lanza Bay, and (b) Oquendo Bay.

The trade-offs in service coverage between the two proposed models are illustrated in Figure 7, which compares the routes from North Lanza Bay and Oquendo Bay. Figure 7 shows that the routes from Lanza Bay to the north do not supply products to the points of sale in the south, on Aroma Avenue. And although the kiosks in the south are supplied from Oquendo Avenue, the sector with the highest density of kiosks is located to the north in the vicinity of Heroínas Avenue, which implies that by deciding not to serve these businesses, the opportunity to generate sales with 16 of the kiosks in the cluster is lost. These visual differences emphasize the need to balance geographic reach with commercial opportunity.

5.6.3 North Cluster

The direct sales service model, based on orders generated through pre-sales, requires distributors to make mandatory visits to all 31 customers in the area. The income results, completing the visits to all the points of sale is Bs 9 300 in income for the proposed models and the current model. The main variations from one model to another are in the distribution of the workload among the vehicles and the distances they travel.

Table 13 shows the comparison data between bays. It is highlighted that for the operation from the space located in Colombia Bay, light load vehicles (V1, V2 and V3) travel a total of 30,21 km, in a maximum total time of four hours and forty minutes.

TABLE 13 - COMPARISON OF WORKLOAD RESULTS BETWEEN NORTHERN CLUSTER MODELS

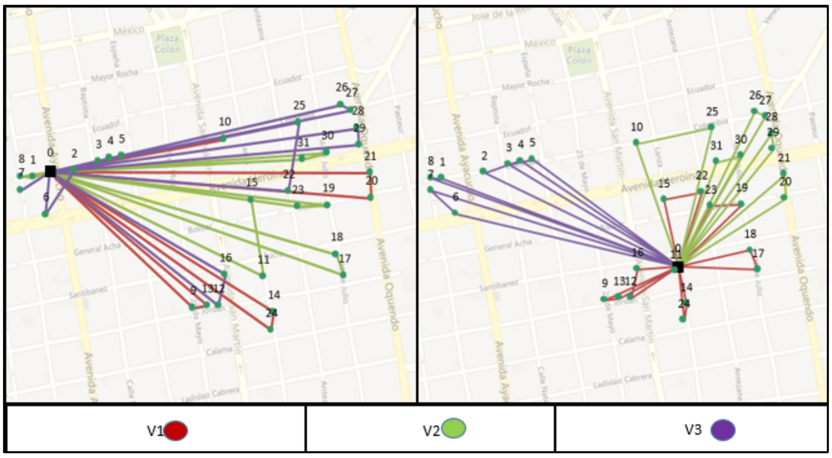
	COLOMBIA BAY	NORTH LANZA BAY
Distance traveled V1	10 km	3,78 km
Distance traveled V2	10 km	6,44 km
Distance traveled V3	10,21 km	8,12 km
Total distance traveled	31,21 km	18,34 km
Number of customers visited	31	31
Operating time V1	4,3 h	4,92 h
Operating time V2	4,3 h	4,16 h
Operating time V3	4,67 h	3,55 h
Load delivered	1 612 kg	1 612 kg

The distance traveled from Colombia Bay is 70,17% greater than the total distance that handcarts must travel from North Lanza Bay.

The performance indicator of kilograms delivered per kilometer is calculated based on the distances traveled by vehicles. Colombia Bay has a better delivery rate of 51,65 kilograms per kilometer, while Lanza Norte Bay has a better rate of 87,89 kilograms per kilometer. Operations end 15 minutes ahead of schedule in Colombia Bay compared to Lanza North Bay. The average operating time per vehicle in North Lanza Bay is four hours and twelve minutes, which is fourteen minutes less than the first bay's average of four hours and twenty-six minutes.

North Lanza Bay serves neighborhood stores in the northern cluster with a visit rate of 1,69 customers per kilometer driven by vehicles. The 30,21 km travel for each delivery becomes a high workload for distribution personnel. The proposed model reduces the operating cost of serving a single neighborhood store from Bs 996,44 to Bs 31,50 per neighborhood store, reducing approximately 2% in unit costs for nanostores.

The total operating time, considering transfer and pick-up times from the central zone, is reduced to six hours and thirty minutes, a difference of 18,75% of the time required for a normal 8-hour workday. This time can be managed by the company or used to correct inefficiencies in other processes, such as waiting times in loading processes in factories and distribution centers.



(a) (b)

Figure 8: Comparison of routes in north cluster. (a) Colombia Bay, and (b) North Lanza Bay.

A visual comparison of the proposed models is provided in Figure 8 this highlights the importance of horizontal dispersion in workload balance. The routes from Colombia Bay maximize vehicle ranges, but each vehicle travels 10 km, which is long for working conditions. This distance is not beneficial for the company, as a percentage of the distances are made on the way back to the truck and by an empty vehicle. In northern Lanza Bay, routes distribute vehicles towards different orientations, establishing the truck as a central node for travel.

5.6.4 South Cluster

For neighborhood stores in the southern cluster, profits and incomes from distribution operations do not vary, due to the obligation to supply all customers. The amount of Bs 9 300 in sales revenue is reached. The balance of the workload and the operation and service times will be decisive for the choice of the optimal model. The routes proposed from the bays located on Lanza and L. Cabrera streets, and Oquendo Avenue, have similar returns. However, the workload will be evaluated to determine the optimal model for the service strategy in this cluster. Table 14 shows the results for the variables of the model in the operation of neighborhood stores in the southern cluster.

TABLE 14 - COMPARISON OF WORKLOAD RESULTS BETWEEN SOUTHERN CLUSTER MODELS

	SOUTH LANZA BAY	OQUENDO BAY
Distance traveled V1	4,26 km	3,92 km
Distance traveled V2	3,51 km	8,44 km
Distance traveled V3	5,53 km	7,02 km
Total distance traveled	13,30 km	19,38 km
Number of customers visited	31	31
Operating time V1	3,97 h	4,97 h
Operating time V2	4,62 h	4,93 h
Operating time V3	3,73 h	2,83 h
Load delivered	1 612 kg	1 612 kg

The routes from South Lanza Bay have total distance traveled, between the three lightweight vehicles, of 13,30 km, with a rate of 121,20 kg delivered per kilometer traveled. The total distance for Oquendo Bay is 19,38 km, with a rate of deliveries per kilometer of 83,18 kg/km.

To measure the balance of the workload balance in the distances marked by each vehicle, the index of the number of customers per kilometer and per vehicle was proposed. In this way, the routing models are evaluated based on the balance parameter for the operations carried out by the assistants driving lightweight vehicles and visiting customers in the territory studied, seeking to optimize the use of human resources in this model. The results for the variables and indexes are shown in Table 15.

TABLE 15 - CALCULATION OF THE EQUILIBRIUM INDEX FOR SOUTH LANZA AND OQUENDO BAYS

BAY	VARIABLE	VEHICLE Nº 1	VEHICLE Nº 2	VEHICLE Nº 3
South Lanza Bay	**Costumers**	10	12	9
	Distance traveled (km)	4,26	3,51	5,53
	Customer per km/vehicle rate	2,35	3,41	1,63
Oquendo Bay	**Costumers**	13	12	6
	Distance traveled (km)	3,92	8,44	7,02
	Customer per km/vehicle rate	3,32	1,42	0,85

At the south Lanza Bay, the rate of customers per kilometer traveled is that of vehicle Nº 2, visiting more than 3 customers for every kilometer it travels. The route followed by this vehicle in the model is the shortest and, nevertheless, the one with the highest rate of customers. The opposite happens with vehicle Nº 3, whose route is the longest and is the vehicle that visits the least number of clients.

On the other hand, Oquendo Bay has a significant imbalance in vehicle N° 3, which travels over 7 kilometers to deliver products to 6 clients, serving only 19% of the cluster's clients. This imbalance affects the service time of other vehicles, with vehicle N°3 having a service time of 2 hours and fifty minutes, allowing other vehicles to work for approximately five hours. The maximum total service time for Oquendo Bay is 4 hours and fifty-eight minutes, while for South Lanza Bay it is 4 hours and thirty-seven minutes.

The distribution patterns and operational imbalances discussed in this section are visually summarized in Figure 9. The figure compares the routes originating from South Lanza Bay and Oquendo Bay, highlighting how the latter leads to excessive travel distances for Vehicle Nº 3 with minimal client coverage. In contrast, South Lanza Bay demonstrates a more balanced and centralized route structure, supporting its selection as the optimal logistics node for the southern cluster.

(a) (b)

Figure 9: Comparison of routes in southern cluster. (a) Oquendo Bay, and (b) South Lanza Bay.

Finally, the bay selected for operations in the southern territory is the space in South Lanza, due to the potential balance it has from its location and the reduction in maximum operating time for lightweight vehicles.

The models show shorter operation times than currently available, suggesting that companies can manage time to improve other stages of the supply and distribution chain. However, it is proposed to explore improvements in service to nanostores. Manufacturing companies could involve themselves in commercial management processes at the point of sale, providing facilities like credit payments and inventory information management. This knowledge will benefit the company, allowing for faster deliveries and managing demand through indirect and involuntary collaboration with point-of-sale staff.

6. DISCUSSION

The results of this study reinforce the fundamental role of nanostores in urban last-mile logistics in Bolivia, where informal retail channels are more strongly present in the market. The proposed clustered routing model demonstrates technical feasibility and efficiency gains; however, operational, social and regulatory constraints must be considered for its implementation.

An important observation is linked to the inefficient use of distribution personnel. Drivers tend to stay with the truck to avoid penalties during vehicle parking, this observation is based on field inferences and not on measurements. Future work should quantify these inefficiencies more accurately.

Unlike other studies discussed in Table 1, which focus on infrastructural and policy interventions, this study offers a model with a balance between the logic of route definition and retail conditions. Importantly, for these models to be successful, they require the support of stakeholders, from distribution companies to government agencies. Corresponding to São Paulo's off-hours delivery methods, the idea of leveraging local retailers as makeshift distribution centers during nighttime hours is functional to improve traffic in the city. However, this strategy has disadvantages such as the need for incentives to nanostores, inventory risks and the complexity of coordination.

While the use of urban bays is advantageous for logistics flow, public policies are required to maintain a balance between commercial efficiency and public regulations. Municipal governments may hinder the allocation of dedicated spaces for freight operations. Unless more concentrated urban mobility objectives are considered.

7. CONCLUSIONS AND FUTURE WORK

At the Latin American level, Bolivia is one of the most dependent countries on traditional retail channels. nanostores largely cover the distribution of products in the center of the city of Cochabamba. This study highlights the importance of supporting these nanostores with commercial strategies and logistics optimization initiatives that benefit suppliers, store owners and the general population.

The proposed model is based on an analysis of grouped routes and the implementation of logistics docks. As a result, improvements in delivery times (up to 11%) and unit cost reduction (up to 4,7%) were shown. While a measurement of CO_2 emissions was not performed, considering that the proposal reduces the simultaneous circulation of freight transport and shortens the distances of for lighter carriage routes, all of which indicate a positive environmental impact.

The proposed route optimization in this context is one of the main achievements of the research. Most of the research previously analyzed focused primarily on infrastructure modifications or transportation optimization. This study, in contrast, applies real data from delivery drivers, logistics companies and nanostores to generate a proposal that is appropriately adapted to cities with similar characteristics. In addition to operational efficiency, other advantages stand out, such as better route management at a critical point, a greater presence of nanostores in distribution planning and a reduction in logistical disruptions, such as parking time, fuel consumption and even product degradation. Another major contribution is to have a more orderly city center and to minimize violations of local traffic laws.

It is important to note that the study has some limitations, as it is based on a fixed delivery demand, does not account for speed variations, and uses static scheduling without considering real-time variables. Although the results of the VRP Solver program were validated with field comparisons, a real-time pilot test was not performed. As future work, this research points to the importance of approaching urban distribution from a systemic perspective and aligning objectives of local governments, retailers and manufacturers. Urban logistics considers quality of life and inclusion, as well as efficiency. Cochabamba and other cities with similar problems have the opportunity to move to sustainable distribution systems using the tactics suggested.

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