

Last-Mile Distribution Network Optimization in Emerging Markets: A Case Study in São Paulo, Brazil

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Summary: As more of the world's population moves to cities, urban last-mile delivery in megacities becomes one of the most complex challenges in a global supply chain. Companies must consider several variables when designing their distribution networks, such as facility and vehicle selection, and external factors including rising customer expectations, and agglomeration of population in emerging megacities. In this context, we propose an optimization model to determine the most responsive, minimum-cost last-mile distribution network of a beverage company in São Paulo, Brazil. To validate the solution, we analyze a set of different scenarios addressing challenges in emerging markets.



Prior to coming to MIT, Oswaldo worked in the telecommunications industry conducting data-driven optimization of sales and operations planning, and participating in transversal projects in analytics, M&A and public-private partnerships. He received his BS in Industrial Engineering from Pontificia Universidad Católica del Perú.



Before coming to MIT, Kenneth worked as a project management consultant with Excellis Health Solutions. While there he worked with clients across pharmaceutical supply chains to become compliant with track and trace legislation. He holds a BS from the University of Delaware in Operations in Management.

KEY INSIGHTS

- 1. Increasing driver service time through overtime or sub-contracting creates cost savings but with diminishing returns**
- 2. Second-tier distribution facilities reduce average route distance, but fixed facility costs need to be low to justify adding another echelon to the network**
- 3. Network flexibility**

Motivation

Megacities in emerging markets pose a challenge to any company involved in last-mile distribution. In addition to the complex vehicle routing problems companies must solve to effectively plan delivery routes, developing countries' megacities add an extensive range of issues, such as traffic congestion, inadequate road infrastructure, road blockades, chaotic urban sprawl, tight government regulations, labor relations, and fuel price volatility.

Thus, companies must consider these factors to develop last-mile delivery network designs that not only minimize costs, but that also provide responsiveness across a wide variety of scenarios in emerging markets without the need for significant re-design.

Methodology

The model developed is based on a mixed-integer linear programming (MILP) model that minimizes the total costs of daily operations. These costs involve routing cost, vehicle and equipment cost, fixed and variable costs associated with facilities, and the handling costs. Moreover, due to the large number of customers, the distribution area is discretized into a large number of adjacent rectangular segments, known as pixels. Each pixel is defined by a set of parameters describing its geographical and demand characteristics, such as demand density, average drop size, and pixel area.

To develop the proper model, it is necessary to collect relevant data collection and use this information to develop the correct formulation.

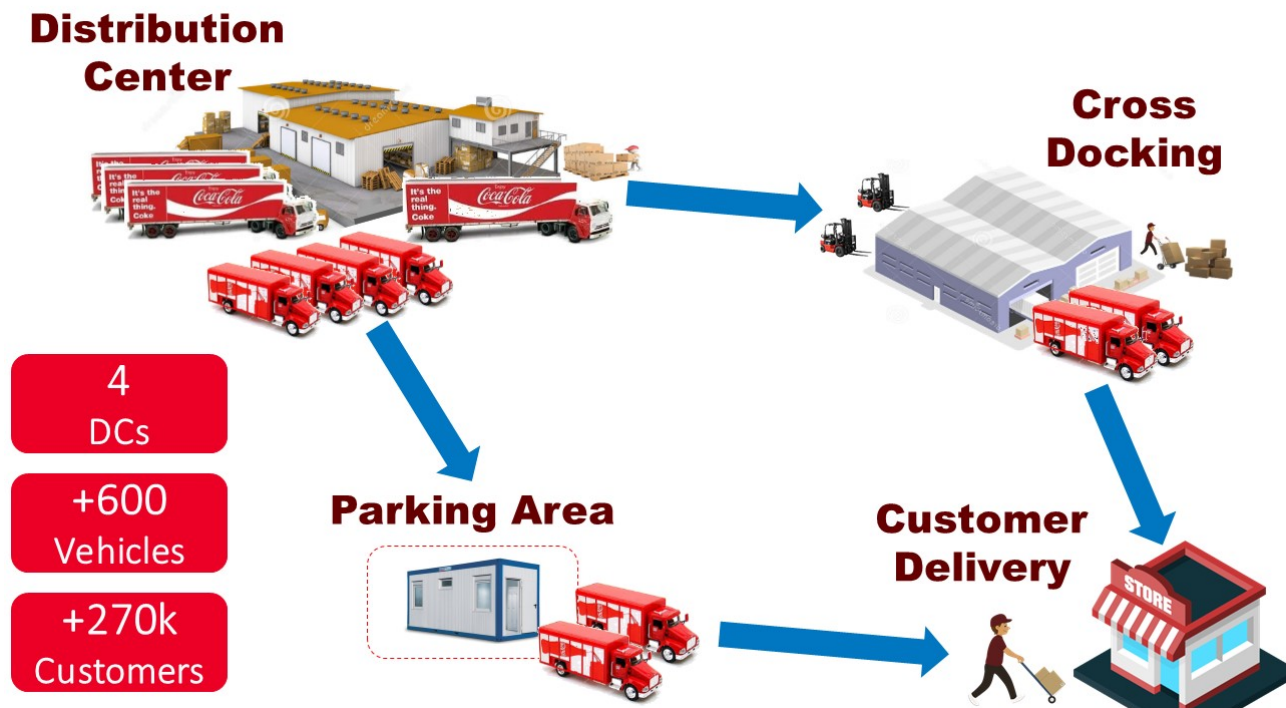


Figure 1: Visual Model of a Distribution Network

Data Collection:

Three types of data need to be collected to model the multi-echelon last-mile distribution network: cost and time parameters; vehicle, facilities and pixel parameters; and demand data:

- Cost and time parameters include global service time, set-up time per vehicle, fixed costs for vehicles and facilities, handling costs, and distance- and time-based costs.
- Vehicle, facility and pixel parameters include vehicle and facility capacities, vehicle speeds, service range of facilities, size of the pixels, distance between facilities and pixels, demand size and drop size per pixel.
- Demand data includes order data collected at the customer and day level over one week and is used to determine facility and vehicle capacity needed to fulfill the orders of all customers in a given area of the city. Using this information, we aggregate demand by customer and create the pixels.

Model Formulation:

The model minimizes the total cost of serving all customer demand in a week using a set of distribution centers and available vehicles.

Decision Variables:

The optimization model has to make decisions about the number and type of vehicles to use or rent, as well as the number and type of facilities to activate. Furthermore, the main operation decision is the demand allocation from a pixel to a particular combination of facility and vehicle type on a certain day.

Objective Function:

The objective function aims to minimize the total network costs. Network costs consists of fixed and variable costs, where the first can be split into fixed capacity costs and fixed vehicle costs, and the second one can be divided into operational routing cost and handling cost. The costs associated with serving each pixel on a given day from a certain facility and vehicle are included in the operational routing cost and are based on the augmented route-cost estimation (ARCE)¹. The ARCE formula

¹ Winkenbach, M., Kleindorfer, P., & Spinler, S. (2016). Enabling Urban Logistics Services at La Poste through

Multi-Echelon Location-routing. *Transportation Science*, 50(2), 520-540.

estimates the optimal routing cost under various constraints, such as multiple vehicle options, destination-specific vehicle capacities and position restrictions, mixed fleets, and global maximum service time constraint (Winkenbach, Kleindorfer, and Spinler, 2016).

Constraints:

The model is subject to a set of constraints applied in the different elements of the network, such as facility capacities; delivery frequencies; number of vehicles; specific allocation of facility, vehicle, a delivery day for each pixel; among others.

Case Study Analysis

In order to develop a standard network design to be used for comparison across scenarios, we first developed baseline scenarios. In the first baseline scenario, we considered only the 4 existing distribution centers and trucks with capacity of either 6 or 10 pallets available within the owned fleet modality, without using overtime hours. This scenario demonstrates the cost of operating the network as a single echelon, with no intermediate depots between distribution centers and customers, and with the optimal number of vehicles owned by the company and driven by company employees. In subsequent scenarios, we vary input parameters to model how the network responds to: increased labor flexibility through overtime and sub-contracting; changes to the physical network footprint; and changes to the fleet of vehicles used for deliveries. Critical scenarios analyzed are shown in the chart in Figures 2 and 3.

Results

To determine network performance, we look at network costs at three levels of detail: facility, vehicle, and distance. We aggregate the facility, vehicle, and routing costs to determine the overall network cost for the week. At the facility level, we analyze which facilities are opened, and how much volume flows through the facilities on a given day to determine the weekly fixed and variable costs of operating the network. At the vehicle level, the model calculates the costs associated with renting a fleet of vehicles with sufficient capacity for the week. At the distance level, we analyze vehicle routing costs across all routes.

Other metrics of interest show how the network covers the service area. At the customer level, the model determines which facility serves a pixel on a given day and which vehicle is used to serve demand in that pixel. We analyze how many pixels and customers are served by a facility and how many vehicles are used. When comparing network performance across multiple scenarios, we evaluate how changes in the network design impact these metrics. All metrics have been scaled and/or transformed to protect confidential company data.

When the drivers are permitted to use 2 hours of overtime, the number of vehicles rented for the week decreases by 22%. Fewer tours are needed to deliver the same number of cases because of the extended service time. In line with this, using 4 hours of overtime reduces the number of vehicles by 34%. However, when the hourly rate of pay for overtime is doubled, the model prefers renting vehicles without overtime; the extended service time does not provide enough productivity to overcome the increased costs.

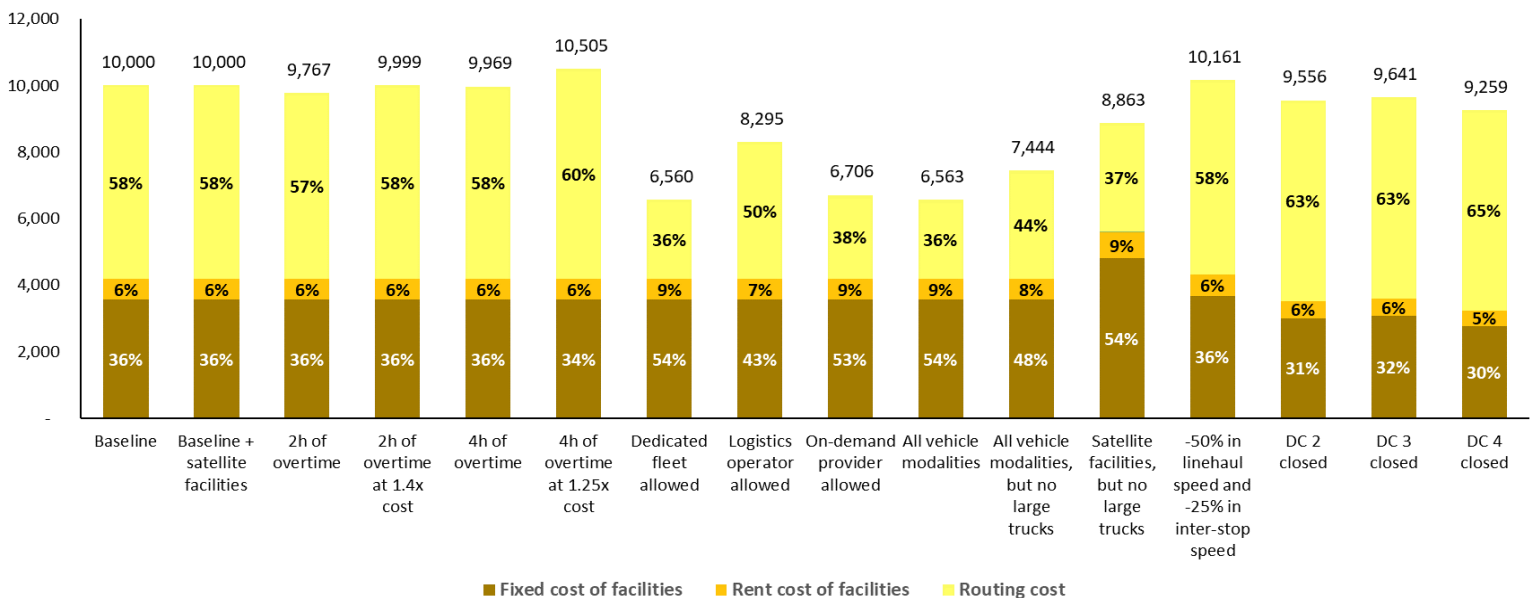


Figure 2: Total Network Costs per Scenario

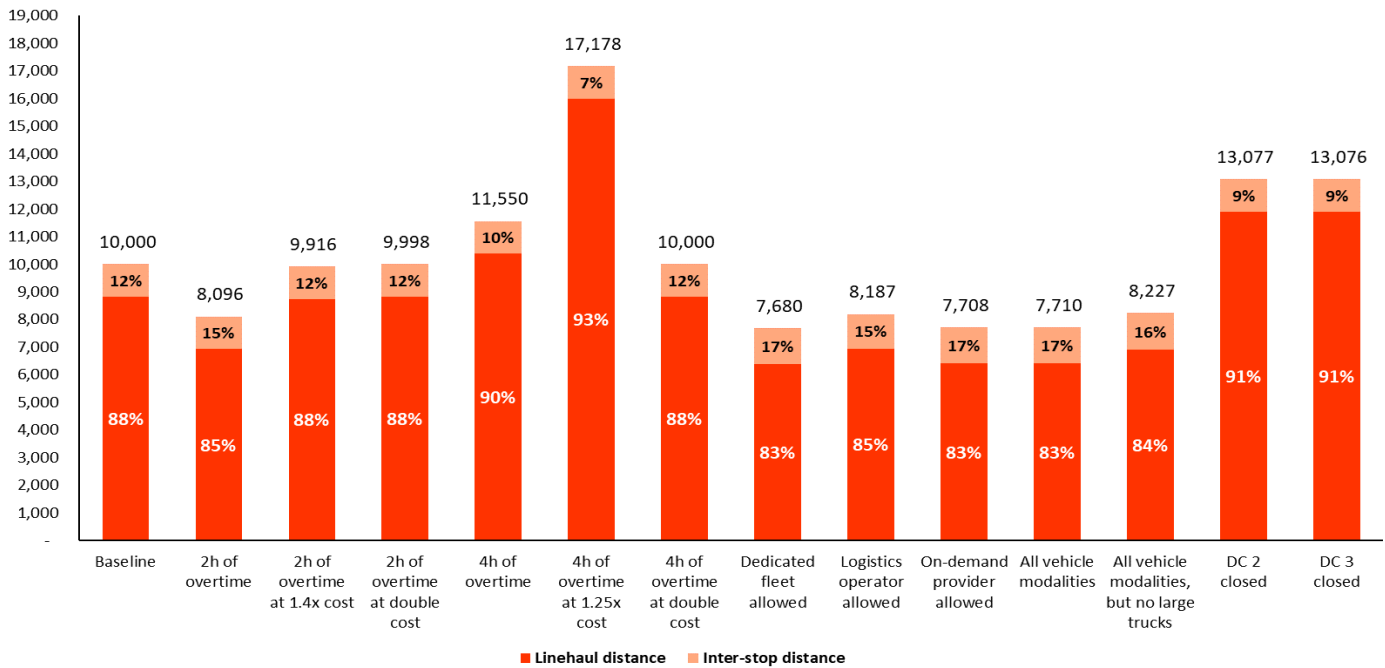


Figure 3: Total Distance Traveled per Scenario

Sub-contracted vehicle modalities offer two more hours of service time compared to the company's own fleet. If the model allows the use of these vehicle modalities, the number of vehicles performing deliveries decreases by an average of 25%. If government regulations prohibit the transit of large trucks (10-pallet, 12-pallet and 16-pallet trucks), the number of vehicles increases by 7% (with respect to the scenario allowing all vehicle modalities). This follows intuition; the distribution network would need a higher number of lower-capacity vehicles to serve the same level of demand.

When we add the fixed costs and the rent costs of facilities to the routing cost, we obtain the total network costs. As the fixed and rent cost of facilities do not significantly change across scenarios (both costs are fixed costs), the routing cost is the main cost component in our analysis. As a result, the scenarios that allow the use of sub-contracted vehicle modalities are the ones that offer the lowest distribution costs. For instance, when all vehicle modalities are allowed, the total distribution cost decreases by 35% compared to the baseline scenario.

Conclusions

Our analysis shows that a multi-echelon distribution model is not always necessary in urban settings; a single-echelon system is preferred when second-tier facilities are relatively expensive. With respect to

labor, significant cost-savings, as high as 35%, can be realized by increasing service time of vehicles

through overtime or sub-contracting labor. Common urban problems, including traffic; access to infrastructure; and vehicle travel restrictions tend to increase network costs by small amounts, approximately 10%, and in some cases lead to cost savings of approximately 5%.

To improve the network in the future, the company should aim to maximize the use of sub-contracted vehicle modalities. Since in reality, the delivery network is constrained by the number of available vehicles, the company should re-evaluate the service areas of their current distribution centers and focus on finding new candidate satellite facilities with lower cost structures. These changes would allow the company to maintain service levels with a smaller fleet of vehicles and would likely lead to lower routing costs. While conducting this analysis, they should consider the scenarios we evaluated to ensure their network design can handle disruptions or other changes in their operating environment.