Integrating Collection-and-Delivery Points in the Strategic Design of Last-Mile E-Commerce Distribution Networks

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Summary: The rapid growth in e-commerce volumes, coupled with customer expectations of faster, flexible and cheaper parcel deliveries is increasing the pressure on retailers to design the most efficient delivery network. Collection-and-delivery points (CDPs) allow for the aggregation of demand and enable reductions in travel time and costs. CDPs also help minimize additional tours arising due to failed deliveries or failed pickups for returns. We propose a mathematical framework that integrates CDPs in the design of the overall distribution network, including the location of upstream transshipment facilities. The model considers different route options and accounts for changes in demand density due to the placement of CDPs. It considers demand aggregation at the CDP for both forward and return flows, and the impact of failed deliveries and failed return pickups on the routing cost. The results demonstrate that failed deliveries and failed return pickups increase both the last-mile cost and the overall cost of distribution. The introduction of CDPs effectively reduces these costs by aggregating the demand.

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KEY INSIGHTS

1. The cost of last-mile distribution increases with an increase in the number of failed deliveries and failed return pickups.
2. CDPs save cost by aggregating many points of customer demand into a single point of delivery.
3. CDPs also save distribution cost by aggregating the demand for returned products and multiple failed pickups for returned merchandise.

Introduction

The rise of mobile technologies has led to rapid growth in the e-commerce industry in both developed and emerging markets. Global e-commerce volumes are expected to grow from US$ 2.8 trillion in 2018 to US$ 5.8 trillion in 2022. Most of this growth is expected from emerging markets, where there will be 3 billion internet users by 2022. The growth in emerging markets is driven by the unprecedented rise in the urban population in large cities. While the rapid growth of urban population creates further opportunities for the growth of e-commerce, it also poses several challenges for urban planning and sustainable logistics. As retailers strive to minimize delivery times and reduce transportation costs, high population density puts pressure on road traffic in residential areas, making home delivery in large cities even more challenging. At the same time, customer expectations are changing towards anytime-anywhere shopping. Today consumers not only want the flexibility to order products online, delivered at a fast pace but also want the convenience to pick up or return the products at convenient physical locations.

The need to transport goods to consumers' homes rather than to retail stores, combined with the customers' need for faster delivery leads to a higher demand fragmentation, which results in lower level of vehicle utilization in the last mile. The lower vehicle utilization increases the number of freight movements and related delivery costs. The last mile refers to the final stage in the distribution network which brings the goods or parcels to the consumers' doorsteps. In 2016, the total cost of the last-mile of parcel delivery was approximately US$ 80 billion and it continues to be the most expensive and time-consuming step in the overall fulfilment process. The customer expectations of faster and flexible parcel deliveries, at low costs, is increasing the pressure on retailers to design the most efficient delivery networks.

Multi-echelon networks

Retailers can design their delivery networks either as single-echelon or multi-echelon. A single-echelon system offers a direct shipment from the origin to the destination while a multi-echelon system manages the distribution through one or more intermediate facilities where each echelon refers to one level of the distribution network. In single-echelon networks, origin facilities are far from the destination, leading to suboptimal vehicle utilization and route selection, thus making the deliveries slow and expensive. In a multi-echelon network, SFs function as transshipment nodes which offer an opportunity for consolidation of inbound shipments and deconsolidation of outbound shipments. These nodes also allow the usage of two different transportation modes, a bigger vehicle for line-haul inbound transportation and a smaller vehicle for outbound customer delivery. The introduction of a transshipment area along with the usage of vehicles of two different capacities for each echelon not only reduces delivery time and cost but also reduces pollution and congestion. Multi-echelon distribution systems are currently being deployed by several online retailers in both the developed and emerging markets. While satellite facilities in a multi-echelon system offer a solution for consolidating freight and lowering the distribution cost, they do not offer customers the flexibility to pick up parcels from a convenient physical location at a convenient time.

Collection-and-delivery Points (CDPs)

In e-commerce distribution, CDPs are facilities to which a carrier may deliver parcels for later independent pickup by the customer. CDPs can be either unattended or attended. CDPs not only allow for the aggregation of demand and enable reductions in travel time, travel distance, emissions, and traffic congestion but also reduce the number of failed deliveries or theft of packages delivered at the doorstep and left unattended. The aggregation of many points of customer demand into a single point of delivery not only reduces the cost for the carrier, but it also saves costs linked to multiple delivery attempts originating from failed deliveries. Additionally, CDPs can also offer an option to aggregate the demand for returned products and multiple failed pickups for returned merchandise. Thus, flexible delivery and return options for the consumers and rising cost pressure for retailers due to multiple failed deliveries have led to a rise in the popularity of collection-and-delivery points across the world.

Methodology

We consider a two-echelon distribution network with two levels of logistic facilities. This system is shown in Figure 1. A central distribution hub serves several satellite facilities using first-echelon vehicles that perform dedicated trips to each satellite facility (SF). The SFs make the last-mile delivery in two different ways, either directly to individual customers or to CDPs. This second-echelon transportation is performed by second-echelon vehicles which have a

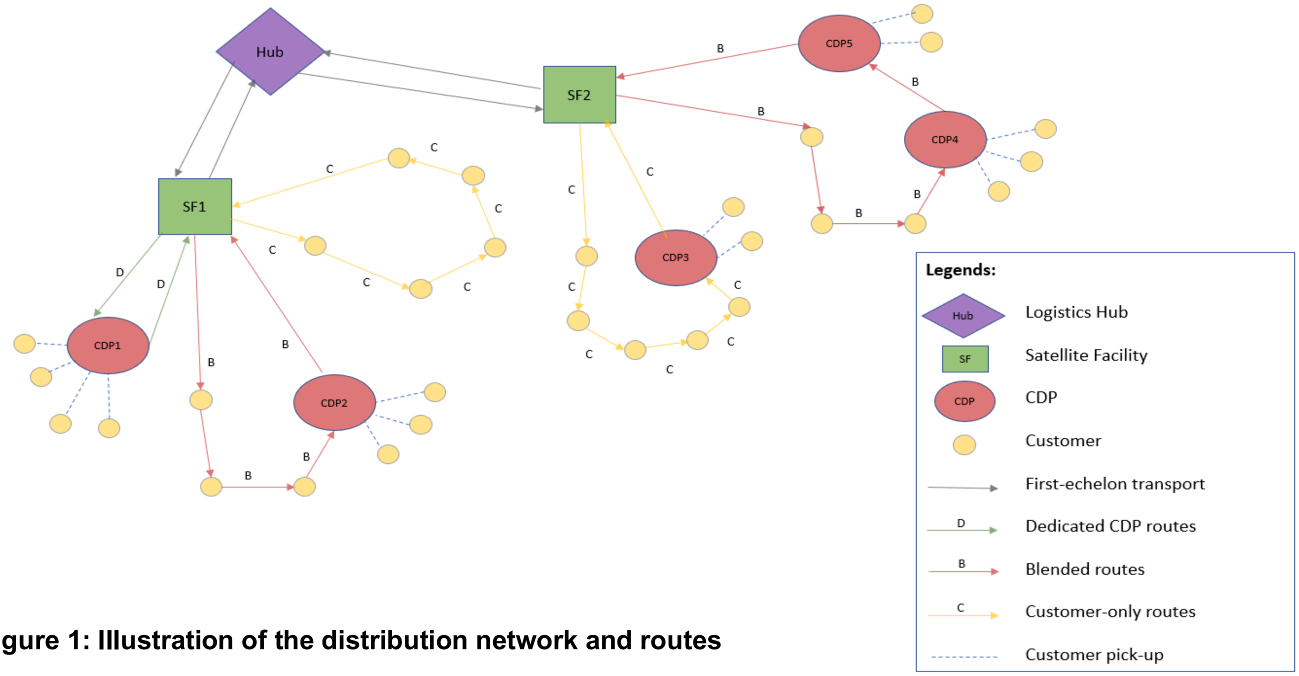


Figure 1: Illustration of the distribution network and routes

lower capacity than the first echelon-vehicles. The deliveries in the second-echelon are to be performed within a given maximum service time. The service-zone is split into multiple demand zones. Each demand zone has a given customer density. The introduction of CDPs in a demand zone changes the demand patterns in the service area. CDPs attract part of the individual customer delivery and returns in their surroundings, resulting in a decrease in the density of individual customers. We assume that customer demand density decreases linearly with the distance from the CDP in that demand zone. There can be three types of routes from the SFs to the demand zones – dedicated CDP routes, customer only routes, and blended routes.

In Figure 2, we propose a framework that:

- models a two-echelon LRP to select SF locations
- considers demand aggregation at the CDP for both forward delivery and return flows
- considers the change in customer demand density due to the introduction of a CDP in a demand zone
- considers the impact of failed deliveries and failed return pickups on the routing cost

$$\min_{y_j, w_i, x_{ij}} K(\mathbf{y}, \mathbf{w}, \mathbf{x}) = K^F(\mathbf{y}) + K^P(\mathbf{w}) + K^T(\mathbf{x}, \mathbf{w}) + K^R(\mathbf{x}, \mathbf{w}) \tag{1}$$

where

$$K^F(\mathbf{y}) = \sum_{j \in J} y_j c_j^{F,f} + \sum_{j \in J} c_j^{F,v} \sum_{i \in I} x_{ij} \Big(\big(\gamma_i^F(\mathbf{w}) + \gamma_i^R(\mathbf{w})\big) A_i \rho_i + \sum_{k \in I} \psi_{ik}^F(\mathbf{w}) + \sum_{k \in I} \psi_{ik}^R(\mathbf{w}) \Big), \tag{2}$$

$$K^P(\mathbf{w}) = \sum_{i \in D} c_i^{P,f} w_i + \sum_{i \in D} c_i^{P,v} \Big(\sum_{k \in I} \psi_{ik}^F(\mathbf{w}) + \sum_{k \in I} \psi_{ik}^R(\mathbf{w}) + \big(\gamma_i^F(\mathbf{w}) \lambda^F \beta w_i\big) \rho_i A_i \Big), \tag{3}$$

$$K^T(\mathbf{x}, \mathbf{w}) = 2 \frac{\kappa^\alpha}{\xi^\alpha} \sum_{j \in J} \frac{d_j c_j^{\alpha,hr}}{s^{\beta,l}} \sum_{i \in I} x_{ij} \Big(\big(\gamma_i^F(\mathbf{w}) + \gamma_i^R(\mathbf{w})\big) A_i \rho_i \theta_i^C + \theta_i^P(\mathbf{w}) \big(\sum_{k \in I} \psi_{ik}^F(\mathbf{w}) + \sum_{k \in I} \psi_{ik}^R(\mathbf{w}) \big) \Big), \tag{4}$$

$$K^R(\mathbf{x}, \mathbf{w}) = \sum_{j \in J} \sum_{i \in I} x_{ij} f_{ij}(\mathbf{w}), \tag{5}$$

$$\psi_{ik}^F(\mathbf{w}) = \gamma_k^{0,F} A_k \rho_k \max[\tau^F - \eta^F r_{ki}, 0], \qquad \forall i \in D, k \in I, \tag{6}$$

$$\psi_{ik}^R(\mathbf{w}) = \gamma_k^{0,R} A_k \rho_k \max[\tau^R - \eta^R r_{ki}, 0], \qquad \forall i \in D, k \in I, \tag{7}$$

$$\gamma_k^F(\mathbf{w}) = \big(\gamma_k^{0,F} - \sum_{i \in D} \frac{\psi_{ik}^F(\mathbf{w})}{\rho_k A_k}\big)\big(1 + \lambda^F(1 - \beta.w_k)\big), \qquad \forall k \in I, \tag{8}$$

$$\gamma_k^R(\mathbf{w}) = \big(\gamma_k^{0,R} - \sum_{i \in D} \frac{\psi_{ik}^R(\mathbf{w})}{\rho_k A_k}\big)\big(1 + \lambda^R\big), \qquad \forall k \in I, \tag{9}$$

$$\gamma_k^{0,R} = \delta.\gamma_k^{0,D}, \qquad \forall k \in I, \tag{10}$$

$$\theta_i^D(\mathbf{w}) = \frac{\sum_{k \in I} \psi_{ik}^F(\mathbf{w}) \theta_k^C}{\sum_{k \in I} \psi_{ik}^F(\mathbf{w})}, \qquad \forall i \in D, \tag{11}$$

subject to

$$\sum_{j \in J} x_{ij} = 1, \qquad \forall i \in I, \tag{12}$$

$$\sum_{i \in I} x_{ij} \Big(\big(\gamma_i^F(\mathbf{w}) + \gamma_i^R(\mathbf{w})\big) \rho_i A_i + \sum_{k \in I} \psi_{ik}^F(\mathbf{w}) + \sum_{k \in I} \psi_{ik}^R(\mathbf{w}) \Big) \leq Z_j y_j, \qquad \forall j \in J, \tag{13}$$

$$y_j \in \{0,1\}, \qquad \forall j \in J, \tag{14}$$

$$x_{ij} \in \{0,1\}, \qquad \forall i \in I, j \in J, \tag{15}$$

$$w_i \in \{0,1\}, \qquad \forall i \in D. \tag{16}$$

Figure 2: Equations representing the optimization model

- integrates a routing cost estimation function to make the model scalable
- designs a comprehensive distribution network including the location for upstream facilities.

This model solves over a discrete solution space. We develop continuum approximation based augmented routing-cost estimation (ARCE) function. This method considers unevenly distributed demand zones and divides them into small rectangular segments with uniformly distributed demand. The adapted formulation calculates the cost for the three different kinds of routes using a combination of explicit cost model and the ARCE function. The routing cost formulation differs based on the route selected and is not shown here for the sake of simplicity and brevity.

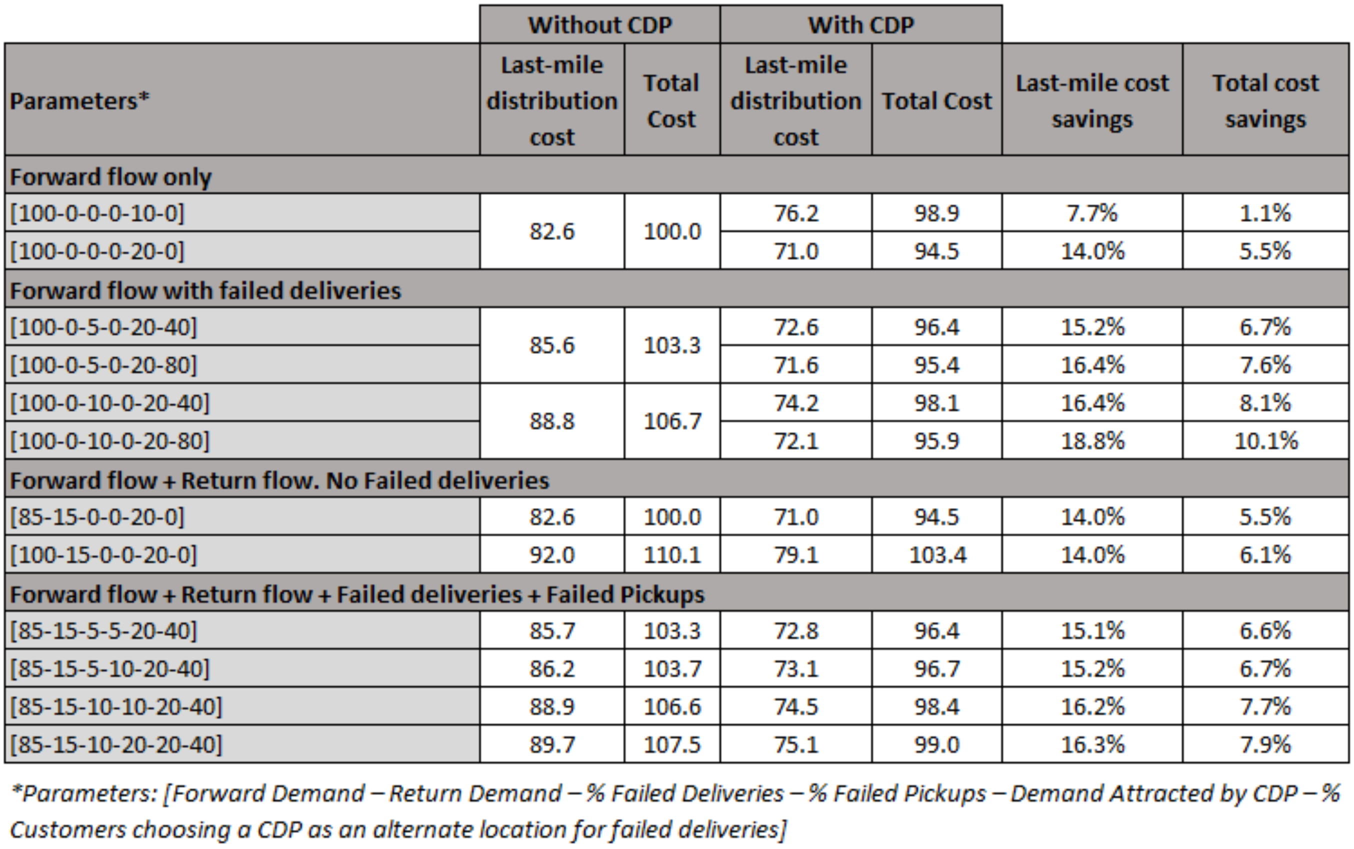
Results

We applied the model on the distribution network of a leading Brazilian e-commerce retailer which operates in the Sao Paulo metropolitan region. Figure 3 lists the cost savings of a network with CDPs compared to a network without CDPs.

The CDPs offer several benefits which lead to this cost savings. Firstly, the CDPs help aggregate demand in the forward flow. In case of failed deliveries, as CDPs offer an alternative location to route multiple failed deliveries, the cost savings go further up. The CDPs offer the benefit of aggregation in the return flow as well. When the impact of returns, failed deliveries, and failed return pickups are collectively applied, we achieve the maximum cost savings.

Conclusion

The results clearly demonstrate how the integration of CDPs results in lowering the overall distribution cost. Additionally, the results show the impact of CDPs in cost reduction due to preventing multiple delivery attempts for previously failed deliveries by giving the customers an option to route such parcels to the CDP. As the number of failed deliveries and failed customer pickups go up, the potential savings increase even further. Retailers can use the overall framework to design the upstream distribution network. The primary factor in deciding the cost savings is the amount of demand attracted to the CDPs, the more the demand, the higher the savings. The retailers should thus find ways to incentivize customers to choose CDPs as delivery options. A possible way to do this is in the form of a pickup discount, whereby the retailers pass-on some of the cost savings to the customers in the form of an additional discount when opting for a pickup from a CDP.



	Without CDP		With CDP			
Parameters*	Last-mile distribution cost	Total Cost	Last-mile distribution cost	Total Cost	Last-mile cost savings	Total cost savings
Forward flow only						
[100-0-0-0-10-0]	82.6	100.0	76.2	98.9	7.7%	1.1%
[100-0-0-0-20-0]			71.0	94.5	14.0%	5.5%
Forward flow with failed deliveries						
[100-0-5-0-20-40]	85.6	103.3	72.6	96.4	15.2%	6.7%
[100-0-5-0-20-80]			71.6	95.4	16.4%	7.6%
[100-0-10-0-20-40]	88.8	106.7	74.2	98.1	16.4%	8.1%
[100-0-10-0-20-80]			72.1	95.9	18.8%	10.1%
Forward flow + Return flow. No Failed deliveries						
[85-15-0-0-20-0]	82.6	100.0	71.0	94.5	14.0%	5.5%
[100-15-0-0-20-0]	92.0	110.1	79.1	103.4	14.0%	6.1%
Forward flow + Return flow + Failed deliveries + Failed Pickups						
[85-15-5-5-20-40]	85.7	103.3	72.8	96.4	15.1%	6.6%
[85-15-5-10-20-40]	86.2	103.7	73.1	96.7	15.2%	6.7%
[85-15-10-10-20-40]	88.9	106.6	74.5	98.4	16.2%	7.7%
[85-15-10-20-20-40]	89.7	107.5	75.1	99.0	16.3%	7.9%

**Parameters: [Forward Demand – Return Demand – % Failed Deliveries – % Failed Pickups – Demand Attracted by CDP – % Customers choosing a CDP as an alternate location for failed deliveries]*

Figure 3: Cost savings generated due to CDPs