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

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Supply Chain MANAGEMENT

Growth in e-Commerce creates challenges for last-mile delivery

- Increasing adoption of internet and smartphones
- Global e-commerce volumes are growing rapidly
- Consumers want the convenience to pick up or return products at physical locations
- Retailers strive to minimize delivery times and reduce transportation costs

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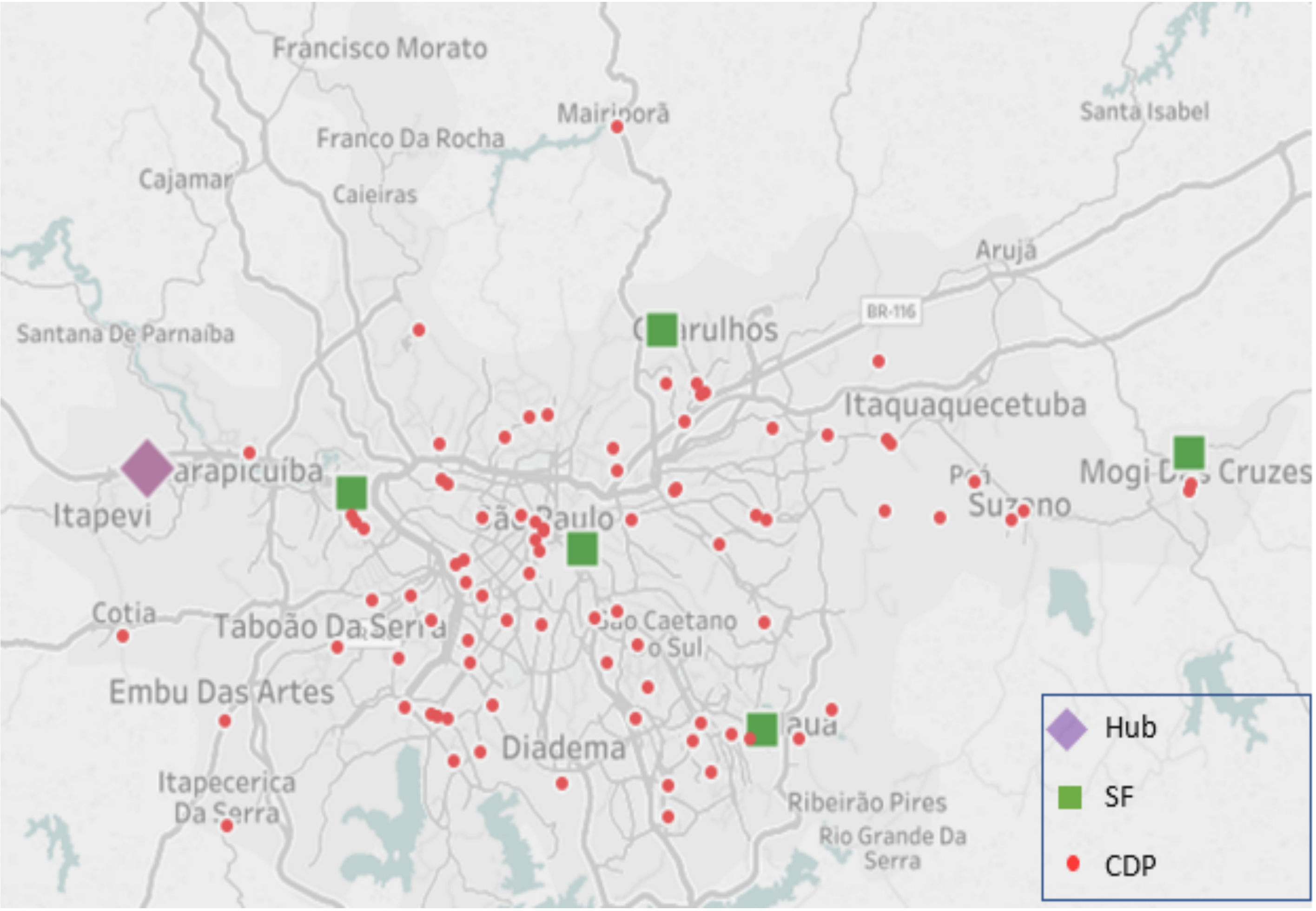
Collection-and-delivery points (CDPs) offer a solution for both retailers and consumers

- Flexible pickup schedule for customers
- Aggregation of customer demand
  - For customer delivery
  - For returned products
- Lower delivery cost for carriers

Image Credits:
https://www.amazon.com/primeinsider/tips/amazon-locker-qa.html
http://cad-ltd.co.uk/portfolio/asda-click-and-collect/

Optimal network design considers multi-echelon distribution with CDPs

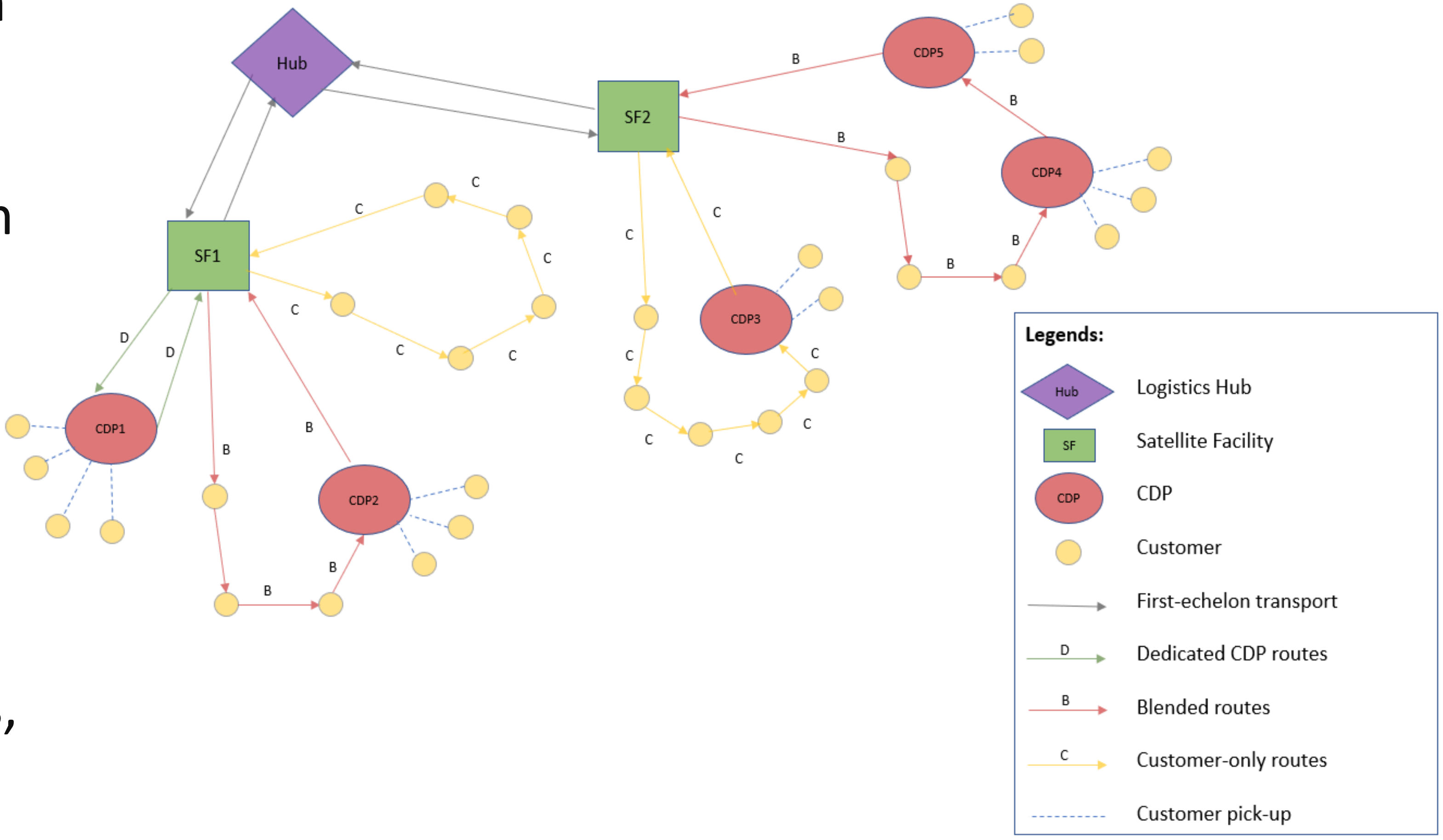
- CDPs aggregate demand and enable reductions in travel time
- CDPs reduce multiple redelivery attempts due to lesser failed deliveries
- CDPs aggregate demand for return flow and multiple failed pickups for returned products
- The presence of CDPs changes the demand density in the region



MIT Center for Transportation & Logistics

Location routing problems combine location and routing optimization

- Two-tier network design with different vehicles in each tier
- Line-haul transportation from Hubs to Satellite Facilities
- Smaller vehicles to transport goods in the last mile
- Option of Dedicated CDP routes, Customer-only routes, and Blended routes



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

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

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

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

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

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

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

$$f_{ij}(\mathbf{w}) = \begin{cases} f_{ij}^D(\mathbf{w}) + f_{ij}^B(\mathbf{w}) + f_{ij}^C(\mathbf{w}), & \text{for } i \in D, \\ f_{ij}^C(\mathbf{w}), & \text{otherwise}, \end{cases} \qquad \forall i \in I, j \in J, \tag{17}$$

$$f_{ij}^B(\mathbf{w}) = f_{ij}^{B^P}(\mathbf{w}) + f_{ij}^{B^T}(\mathbf{w}), \qquad \forall i \in D, j \in J. \tag{18}$$

$$f_{ij}^D(\mathbf{w}) = w c_{ij}^D(\mathbf{w}) \Big(\mu_{ij}^{D,F}(\mathbf{w}) (t^{L,v} + t^{P,v}) + \frac{2 r_{ij} \kappa^{\beta,l}}{s^{\beta,l}} + \mu_{ij}^{D,R}(\mathbf{w}) (t^{P,v} + t^{L,v}) \Big), \qquad \forall i \in D, j \in J, \tag{19}$$

where

$$\mu_{ij}^{D,F}(\mathbf{w}) = \frac{\xi^\beta}{\theta_i^D(\mathbf{w})}, \qquad \forall i \in D, , \tag{20}$$

$$c_{ij}^D(\mathbf{w}) = \left\lceil \frac{\sum_{k \in D} \psi_{ik}^{D,F}(\mathbf{w})}{\mu_{ij}^{D,F}(\mathbf{w})} \right\rceil, \qquad \forall i \in D, j \in J, \tag{21}$$

$$\mu_{ij}^{D,R}(\mathbf{w}) = min\left[\frac{\sum_{k \in D} \psi_{ik}^{D,R}(\mathbf{w})}{c_{ij}^D(\mathbf{w})}, \mu_{ij}^{D,F}(\mathbf{w}) \right], \qquad \forall i \in D, j \in J. \tag{22}$$

$$\mu_{ij}^{B,F}(\mathbf{w}) = \sum_{k \in I} \psi_{ik}^{D,F}(\mathbf{w}) - c_{ij}^D(\mathbf{w}) \mu_{ij}^{D,F}(\mathbf{w}), \qquad \forall i \in D, j \in J, \tag{23}$$

$$\mu_{ij}^{B,R}(\mathbf{w}) = \sum_{k \in I} \psi_{ik}^{D,R}(\mathbf{w}) - c_{ij}^D(\mathbf{w}) \mu_{ij}^{D,R}(\mathbf{w}), \qquad \forall i \in D, j \in J, \tag{24}$$

$$f_{ij}^{B^P}(\mathbf{w}) = w \Big(\mu_{ij}^{B,F}(\mathbf{w}) (t^{L,v} + t^{P,v}) + \mu_{ij}^{B,R}(\mathbf{w}) (t^{P,v} + t^{L,v}) \Big), \qquad \forall i \in D, j \in J. \tag{25}$$

$$f_{ij}^X(\mathbf{w}) = w c_{ij}^X(\mathbf{w}) \Big(\frac{2 r_{ij}}{s^{\beta,l}} + n_{ij}^X(\mathbf{w}) t^{C,f} + \big(n_{ij}^X(\mathbf{w}) + \pi^X(\mathbf{w})\big) \frac{\kappa^{\beta,l} \kappa_i^{\beta,s}}{s_i^{\beta,s} \sqrt{\frac{(\gamma_i^F(\mathbf{w}) + \gamma_i^R(\mathbf{w})) A_i + \pi^X(\mathbf{w})}{A_i}}} + \frac{n_{ij}^X(\mathbf{w})}{1 + \delta} (\lambda^F \beta w_i) t^{P,v} \Big), \qquad \forall i \in S^X, j \in J \tag{26}$$

where

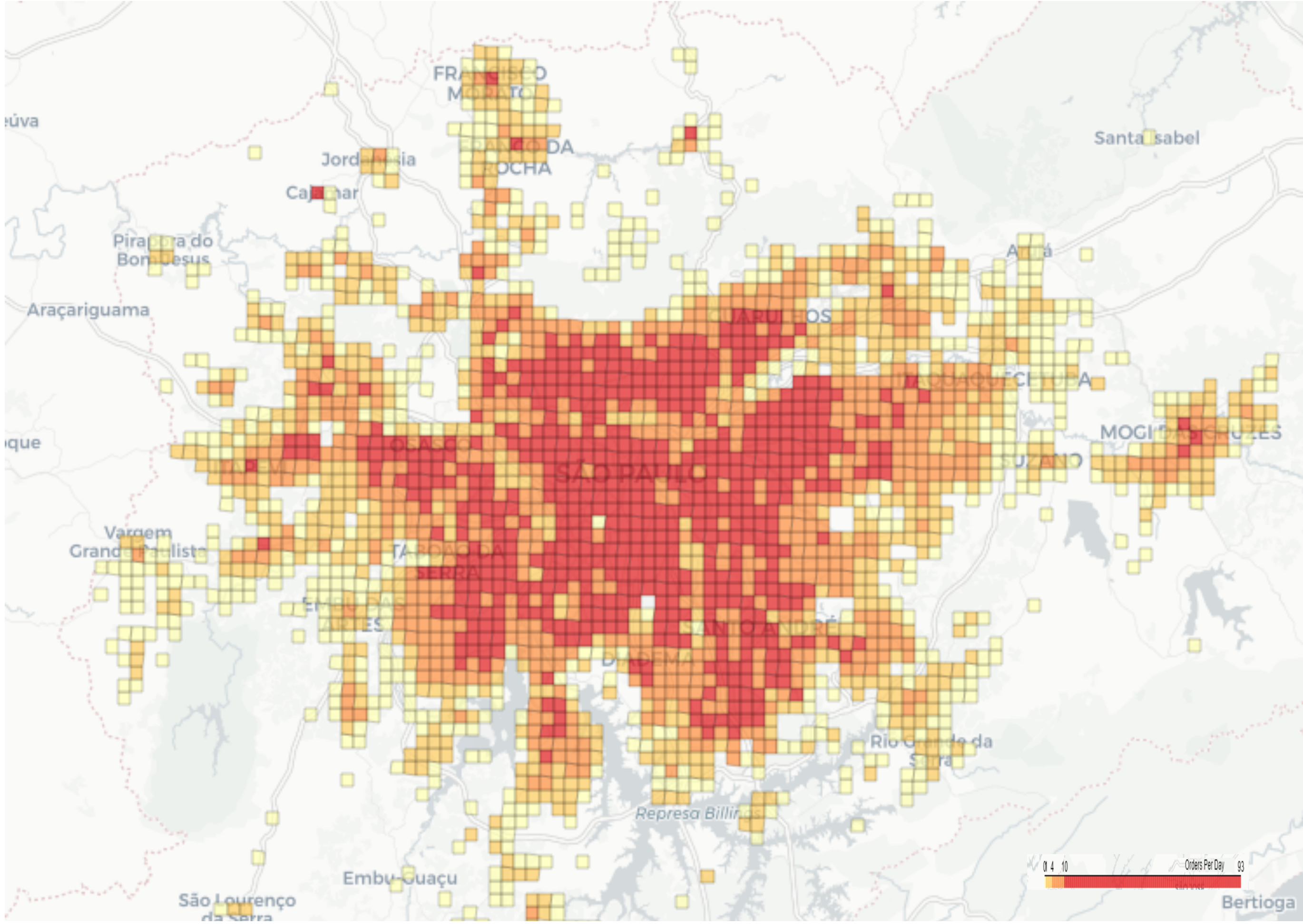
$$\zeta_{ij}^X(\mathbf{w}) = \frac{\xi_{ij}^{\beta,X}(\mathbf{w})}{\theta_i^C \rho_i}, \qquad \forall i \in S^X, \tag{27}$$

$$T_{ij}^{X,f} = \frac{2 r_{ij}}{s^{\beta,l}}, \qquad \forall i \in S^X, j \in J, \tag{28}$$

$$T_i^{X,v} = t^{C,f} + \frac{\kappa_i \kappa^b}{s_i^{\beta,s} \sqrt{\frac{(\gamma_i^F(\mathbf{w}) + \gamma_i^R(\mathbf{w})) A_i + \pi^X(\mathbf{w})}{A_i}}} + \frac{(\lambda^F \beta w_i) t^{P,v}}{1 + \delta}, \qquad \forall i \in S^X, \tag{29}$$

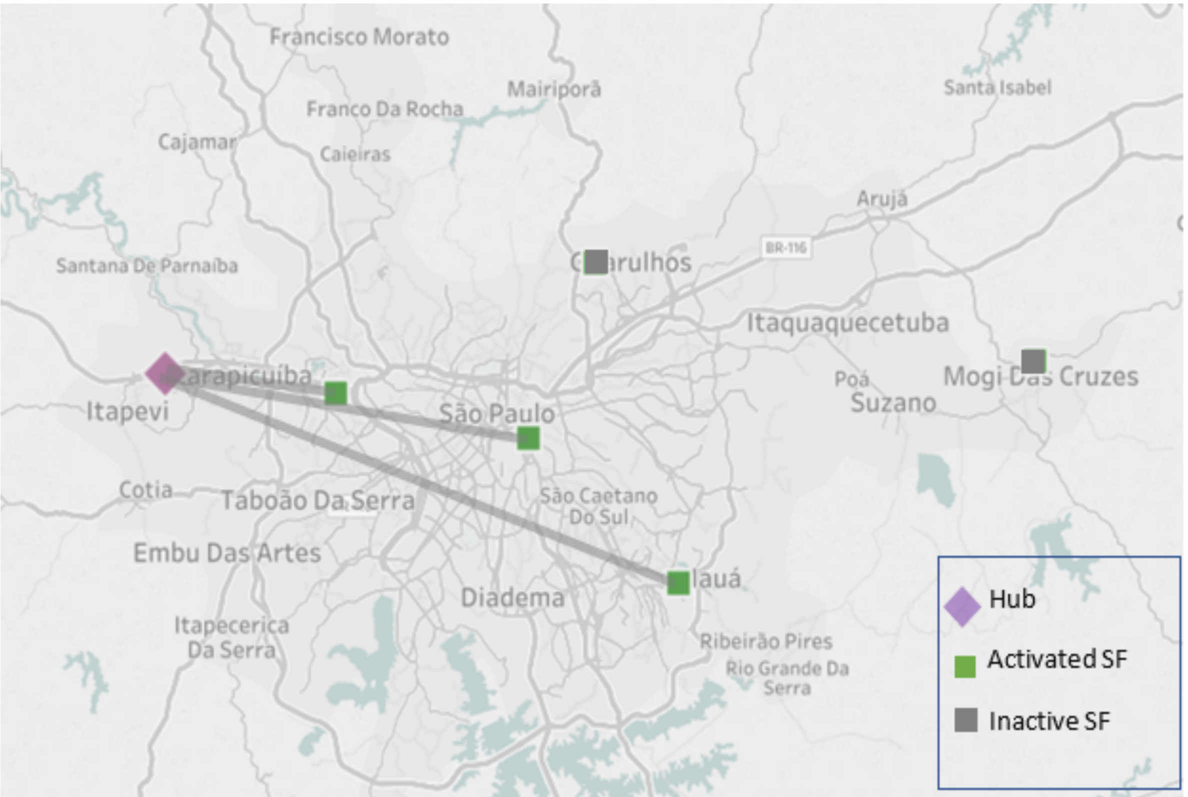
Methodology applied on the network design of a leading e-commerce retailer in Brazil

- Sao Paulo metropolitan region
- ~15,000 daily customer deliveries
- Area of ~2,400 square km
- 1 distribution hub
- 5 candidate Satellite Facilities
- 85 CDP sites

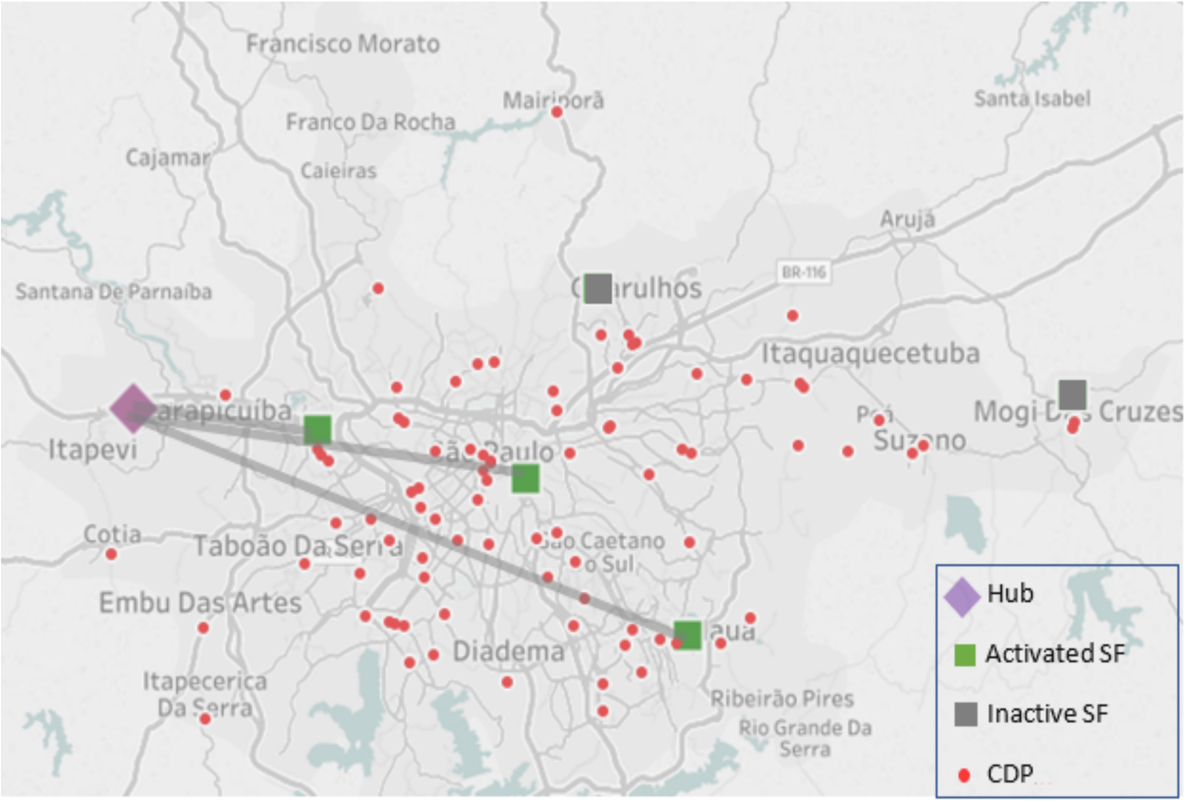


Optimal network (SF) configuration is the same with and without CDPs

Network without CDPs



Network with CDPs



CDPs result in significant cost savings in last-mile distribution

Parameters*	Without CDP		With CDP		Last-mile cost savings	Total cost savings
	Last-mile distribution cost	Total Cost	Last-mile distribution cost	Total Cost		
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]*

Integrating CDPs in the strategic design of e-commerce distribution networks helps design efficient supply chains

- CDPs offer convenience to consumers and provide competitive advantage to retailers
- Last-mile is the most expensive leg of delivery
- CDPs save last-mile distribution costs by:
  - Aggregating forward and return demand and reducing transit time for carriers
  - Offering an alternative delivery location for failed deliveries and failed return pick-ups

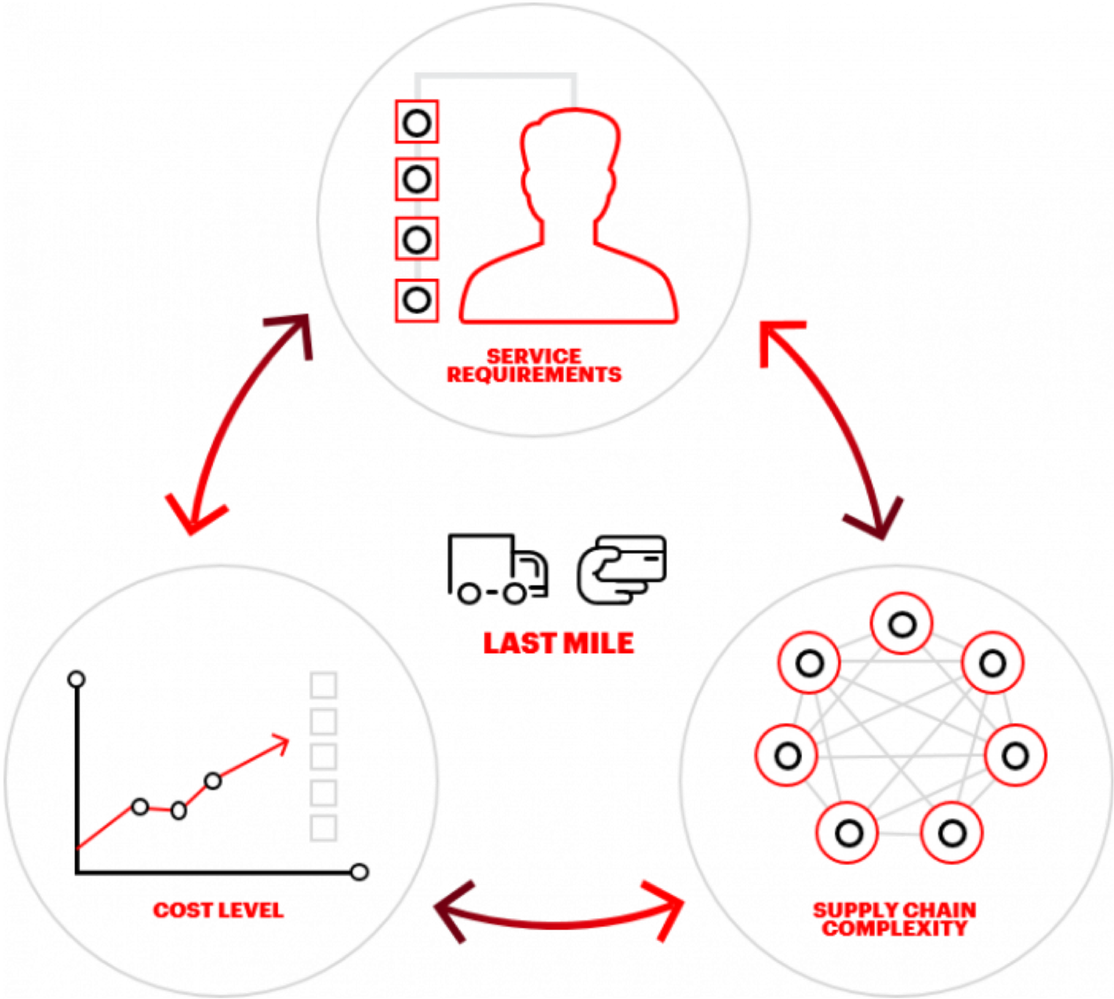


Image Credits:
https://www.accenture-insights.nl/en-us/articles/last-mile-delivery-a-challenge-you-can-embrace