# Modeling Large Scale eCommerce Distribution Networks

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Sponsor: MIT Megacity Logistics Lab

MIT MEGACITY LOGISTICS LAB

## Overview

Research lab under the MIT Center of Transportation and Logistics

## Research Focus

Understanding and transforming the supply chains that interface with continuously growing urban centers

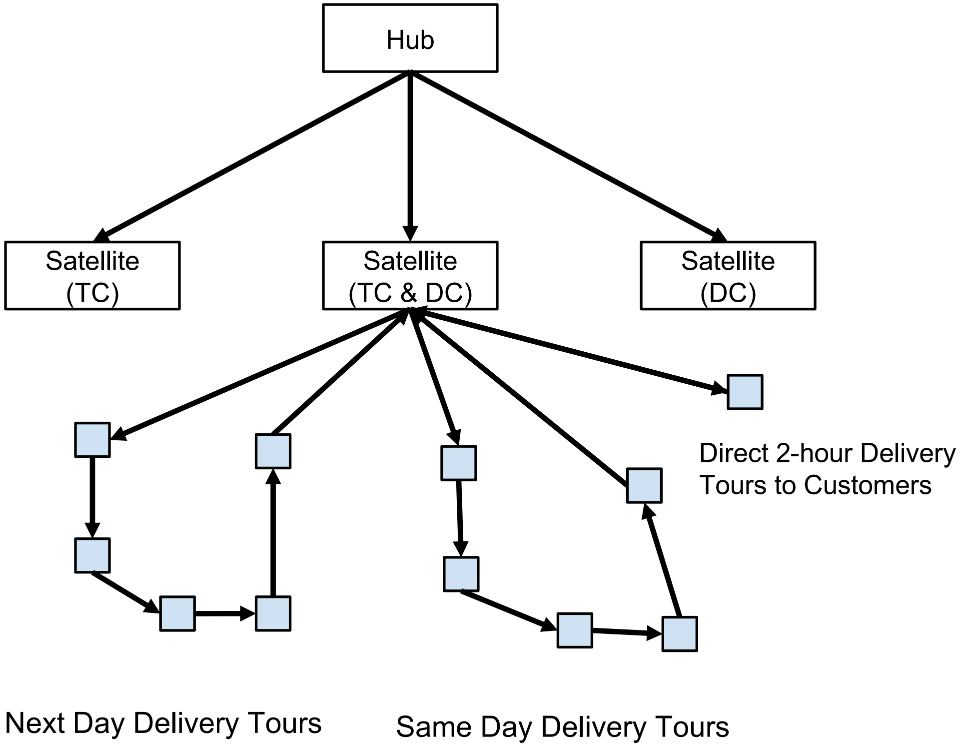
# Problem Description

- A large e-commerce company in Brazil offers three types of delivery services (next day, same day, and 2-hour deliveries) to thousands of customers in a major metropolitan area. And increasingly faster deliveries are required.
- How can they minimize fulfilment and last mile delivery costs from their central distribution center to their end customers?
- Considerations: satellite facility location and type selection, routing, and inventory control decisions at the facilities.

# Problem Motivation


Source: http://megacitylab.mit.edu/

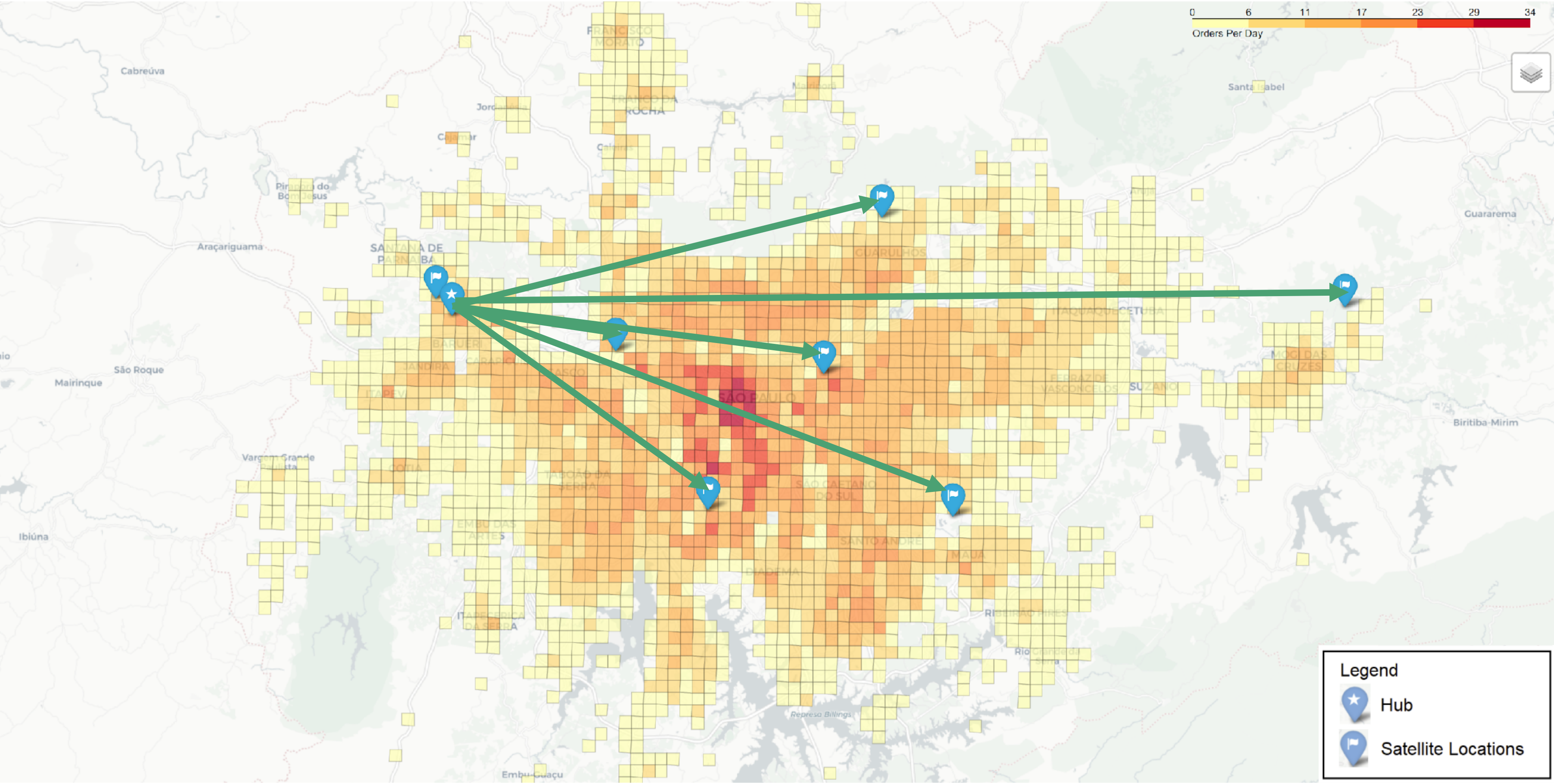
# Network Structure




**Terminology:**

- Hub
- Satellite Facility
  - Transshipment Center (TC)
  - Distribution Center (DC)
- Point of Deliveries
  - Standard
  - Express
  - Instant

# Demand and Network Overview



# Methodology

Mixed Integer Linear Programming (MILP) model:

- Multi-echelon capacitated location-routing problem
- Routing cost estimated using continuum approximation (Winkenbach, Kleindorfer, & Spinler, 2016)
- Inventory holding and ordering cost at satellite facilities if it is used for order fulfillment

min:

$K_C^H$ handling cost at central distribution hub

+ $K^F$ fixed cost of enabling satellite facilities

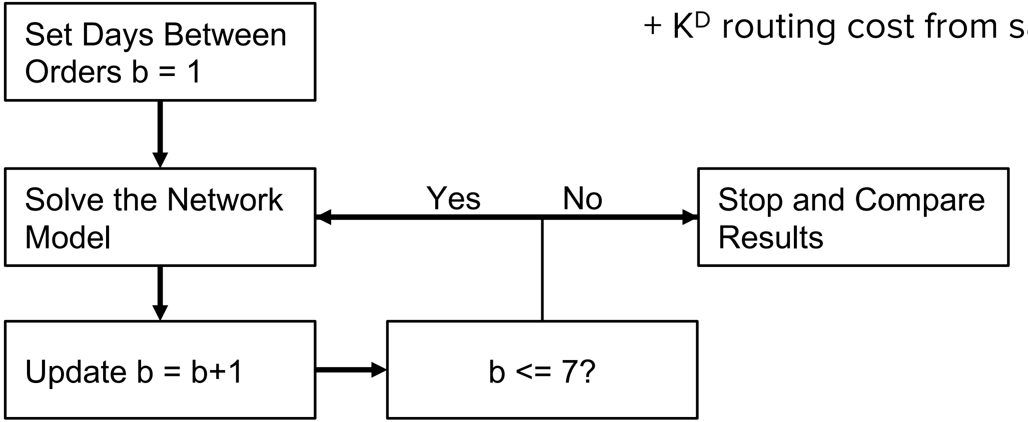
+ $K_S^H$ handling cost at satellite facilities

+ $K^{IH}$ inventory holding cost at satellite facilities

+ $K^{IO}$ inventory ordering cost at satellite facilities

+ $K^T$ transportation cost from central to satellites

+ $K^D$ routing cost from satellite to demand zones

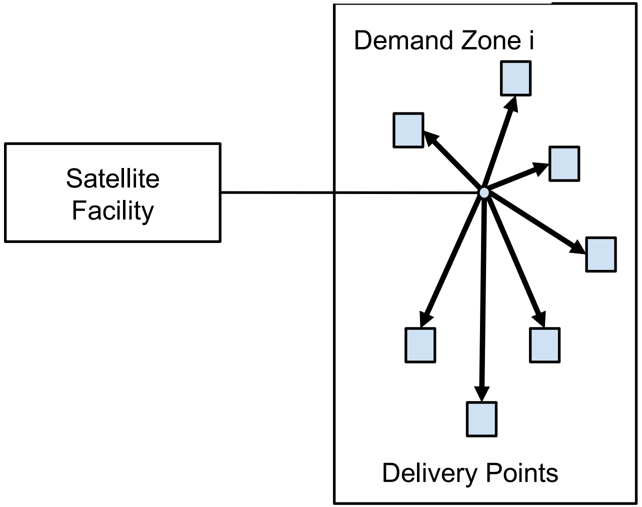


# Routing Cost Approximation

## Same Day and Next Day Delivery Routing Cost (Continuum Approximation):

$f_{ijs}$ = f(demand zone area, delivery density, linehaul distance, vehicle carrying capacity, speed and cost)

$$= wc_{ij}\left(t^{L,f} + \frac{2r_{ij}}{s^{\beta,l}} + n_{ij}\left(t^{C,f} + \frac{k_i k^b}{s_i^{\beta,s}\sqrt{\gamma_i}}\right)\right) + c^f q_{ij}$$




## 2-Hour Delivery Routing Cost:

$f_{ijs}$ = f(per-distance cost, demand zone area, delivery density, linehaul distance)

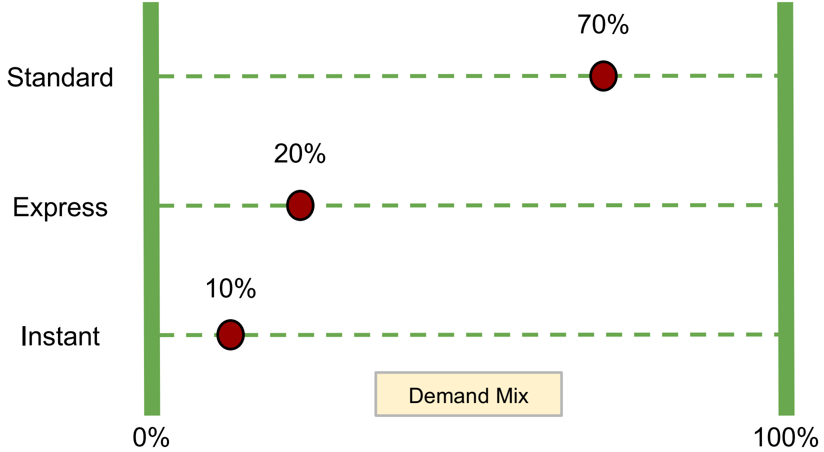
$$= c^{ins} r_{ij} \gamma_{is} A_i$$

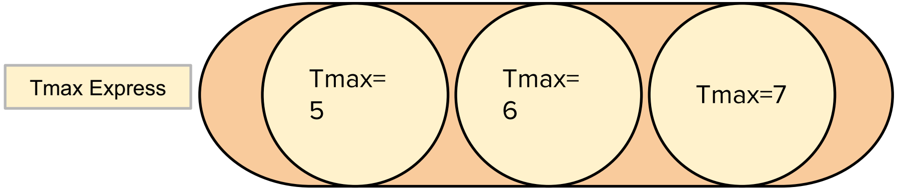
Instant deliveries are fulfilled from satellite locations directly and delivered point-to-point with no consolidation. Therefore, a per-distance cost is used in the model formulation to determine the cost.

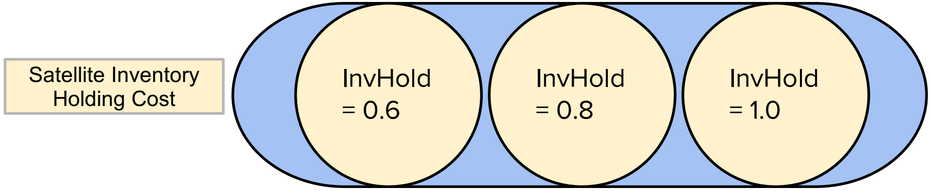
# Scenario

19 unique hypothetical scenarios to examine the effect of different parameters and delivery service types' density on the overall network design and cost.

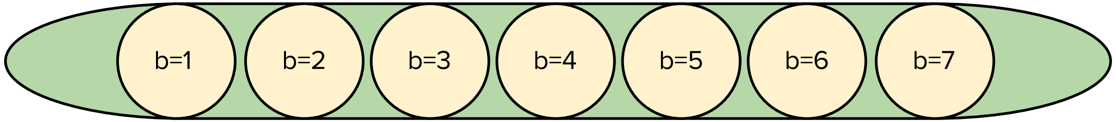
- **Standard %, Express %, Instant %:** percentage of total demand that each service type encompasses.
- **Tmax Express:** the maximum allowable service time for express deliveries utilizing transshipment centers.
- **Satellite Inventory Holding Cost:** per-item daily inventory holding cost of a demand unit if serviced through a distribution center.
- **Days Between Orders:** inventory replenishment frequency to satellite locations if used as distribution centers.



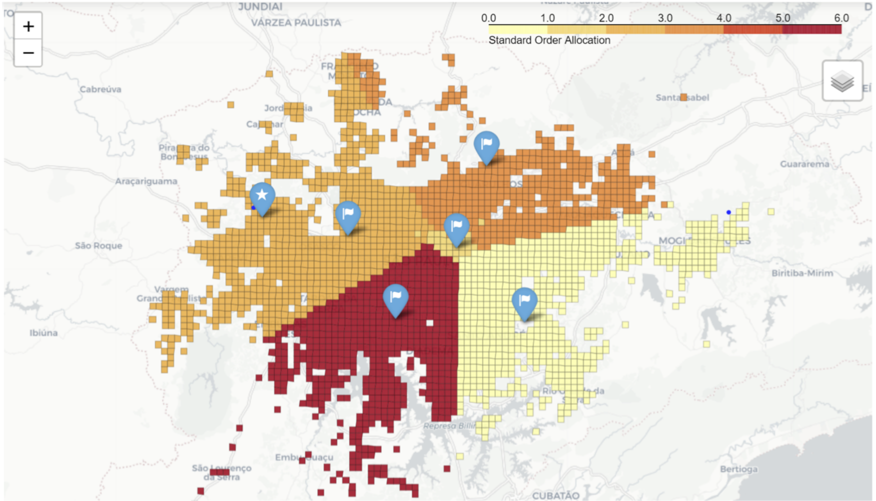

Days Between Orders



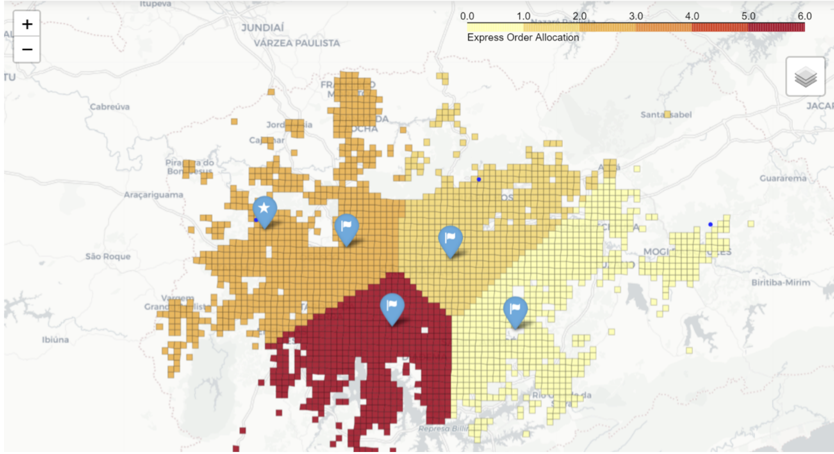
# Results Overview

- Sample Output (70/20/10 Demand Mix)
- Impact of Demand Mix on Network Configuration
- Impact of Service Time on Network Configuration
- Impact of Reordering Frequency on Network Configuration
- Impact of Inventory Holding Cost on Network Configuration
- Summary

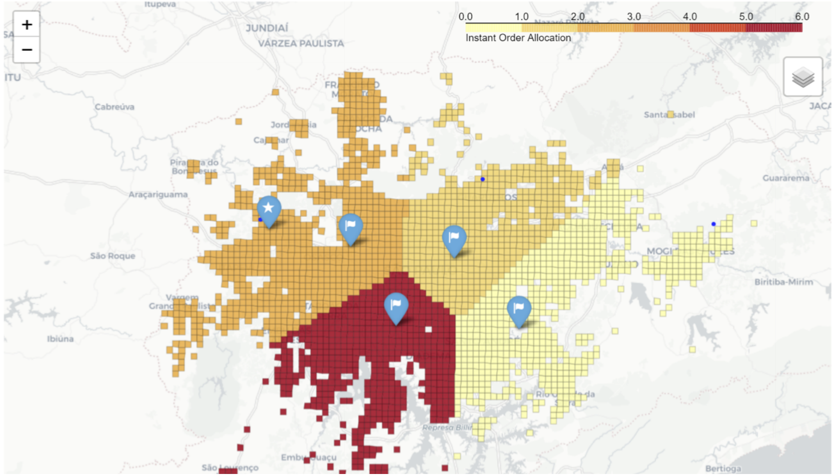
# Sample Result - 70%/20%/10% Mix




Standard Delivery Allocation

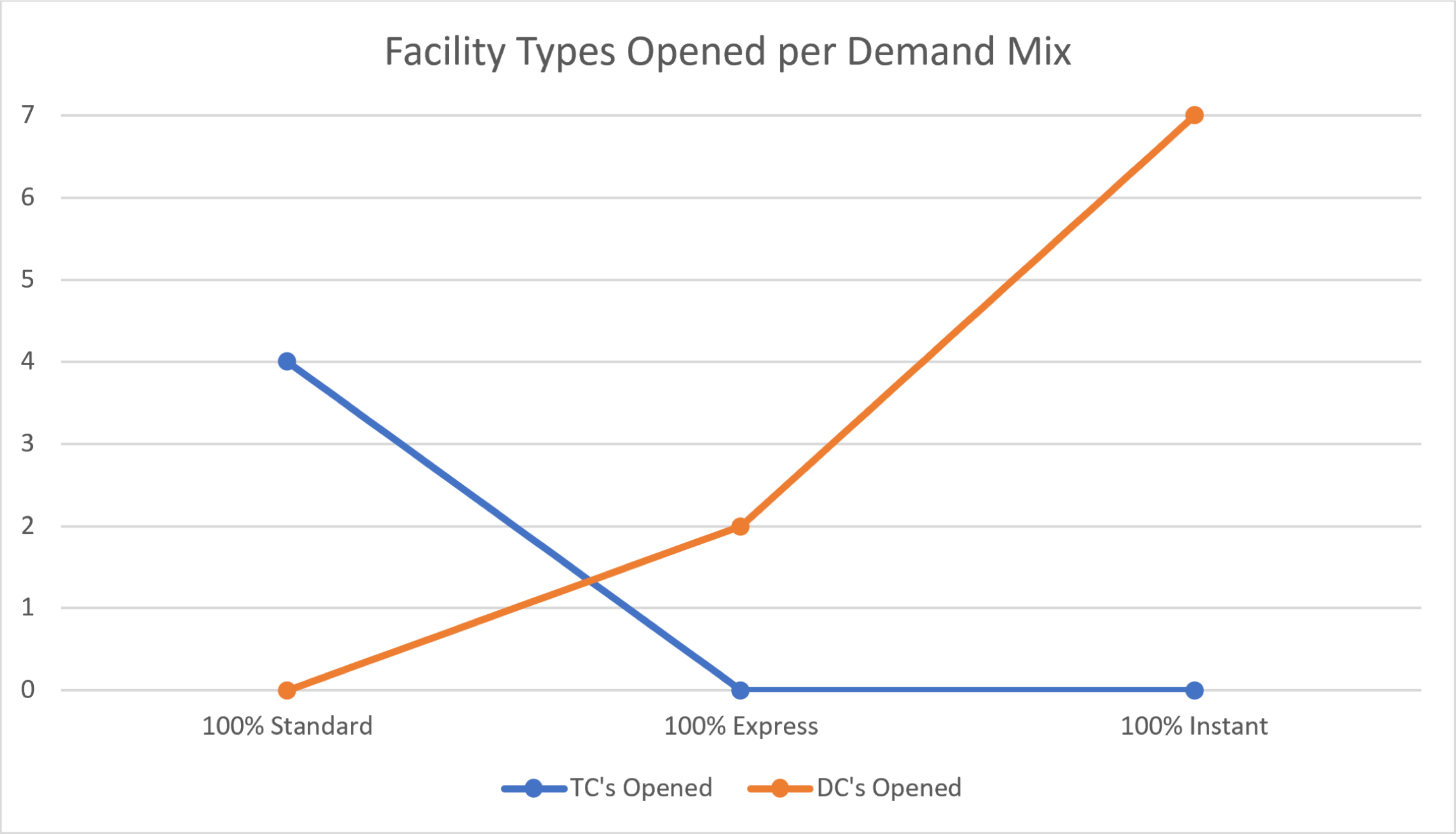



Express Delivery Allocation

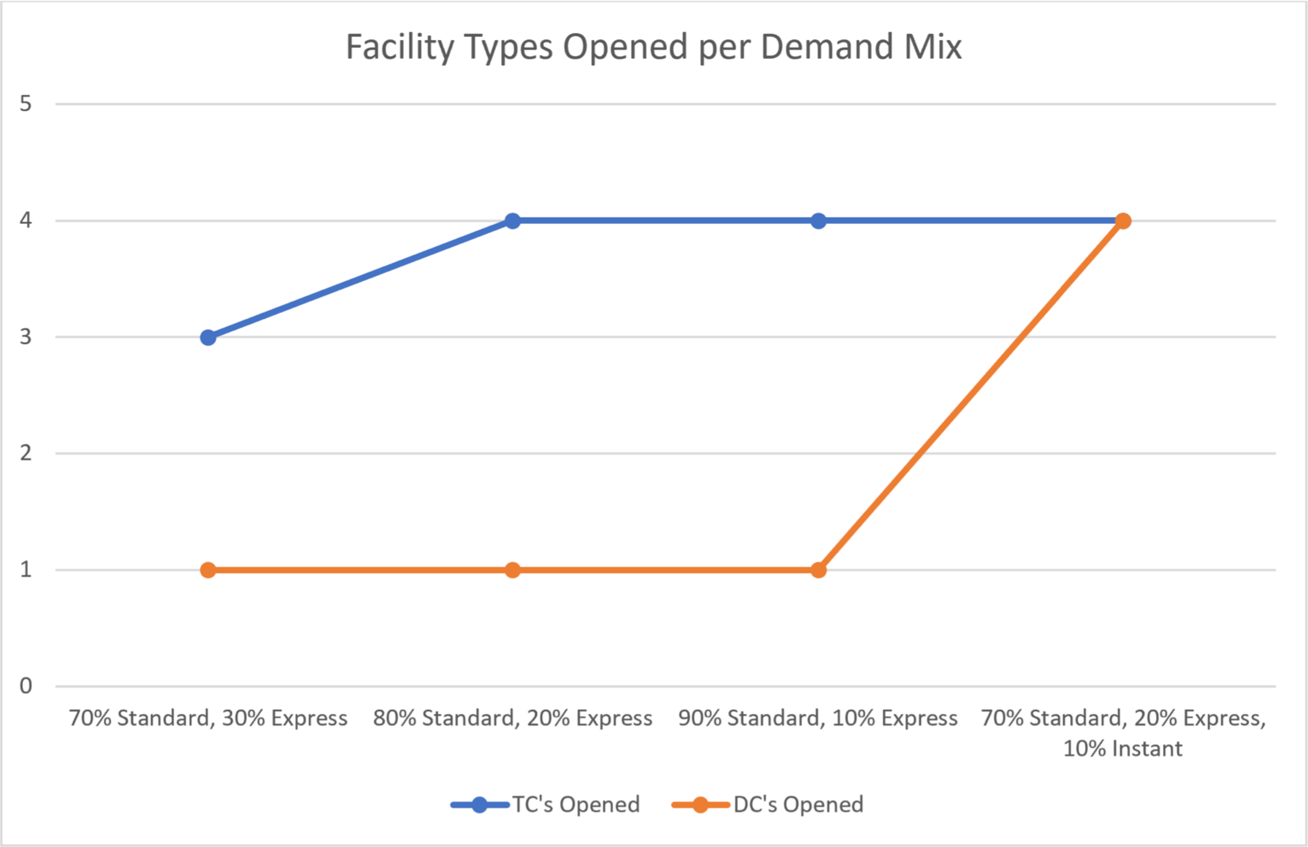



Instant Delivery Allocation

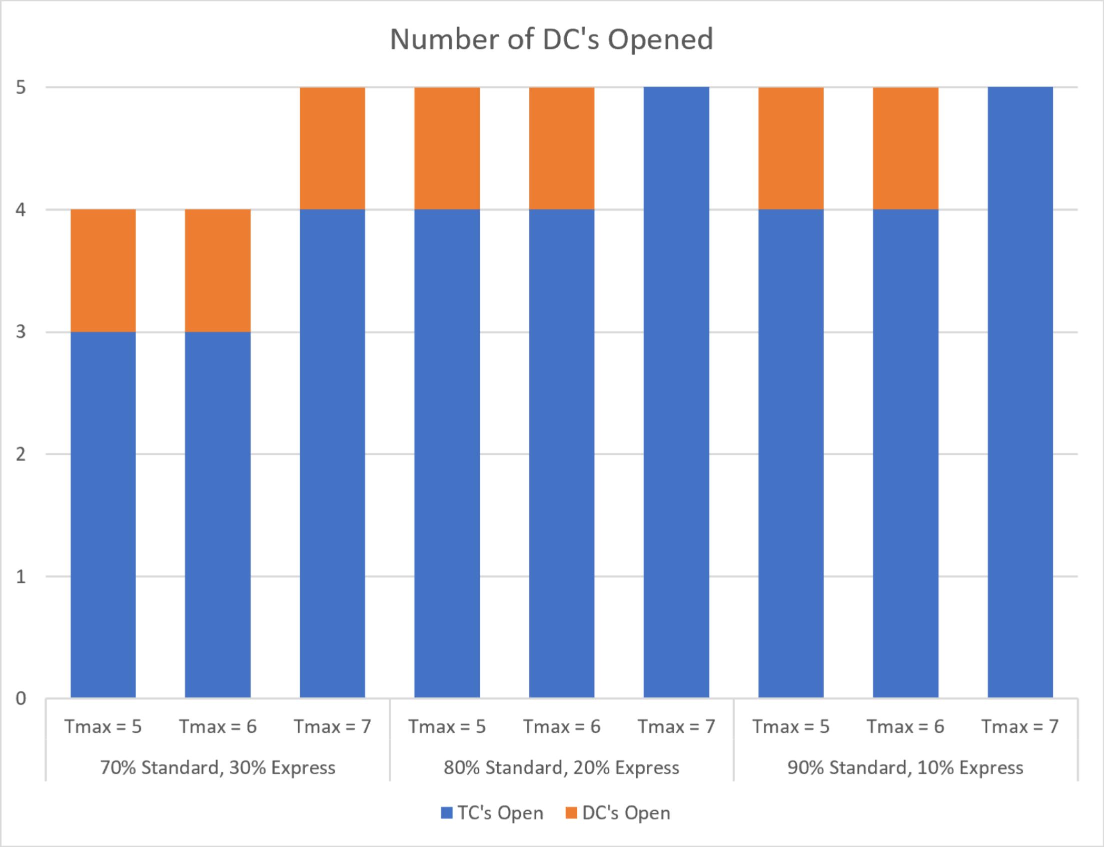
# Impact of Demand Mix on Network Configuration



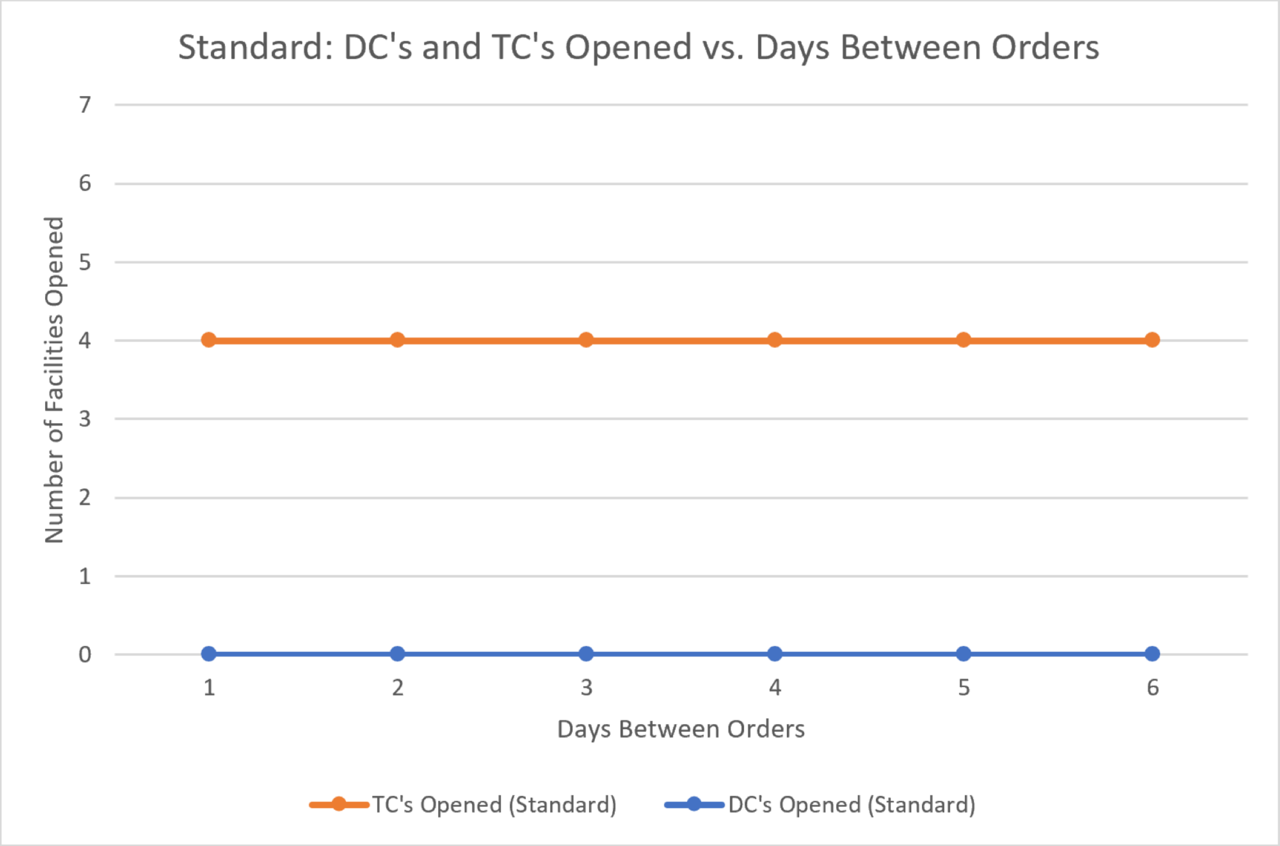
# Impact of Demand Mix on Network Configuration



# Impact of Service Time on Network Configuration



# Impact of Reordering Frequency on Network Configuration



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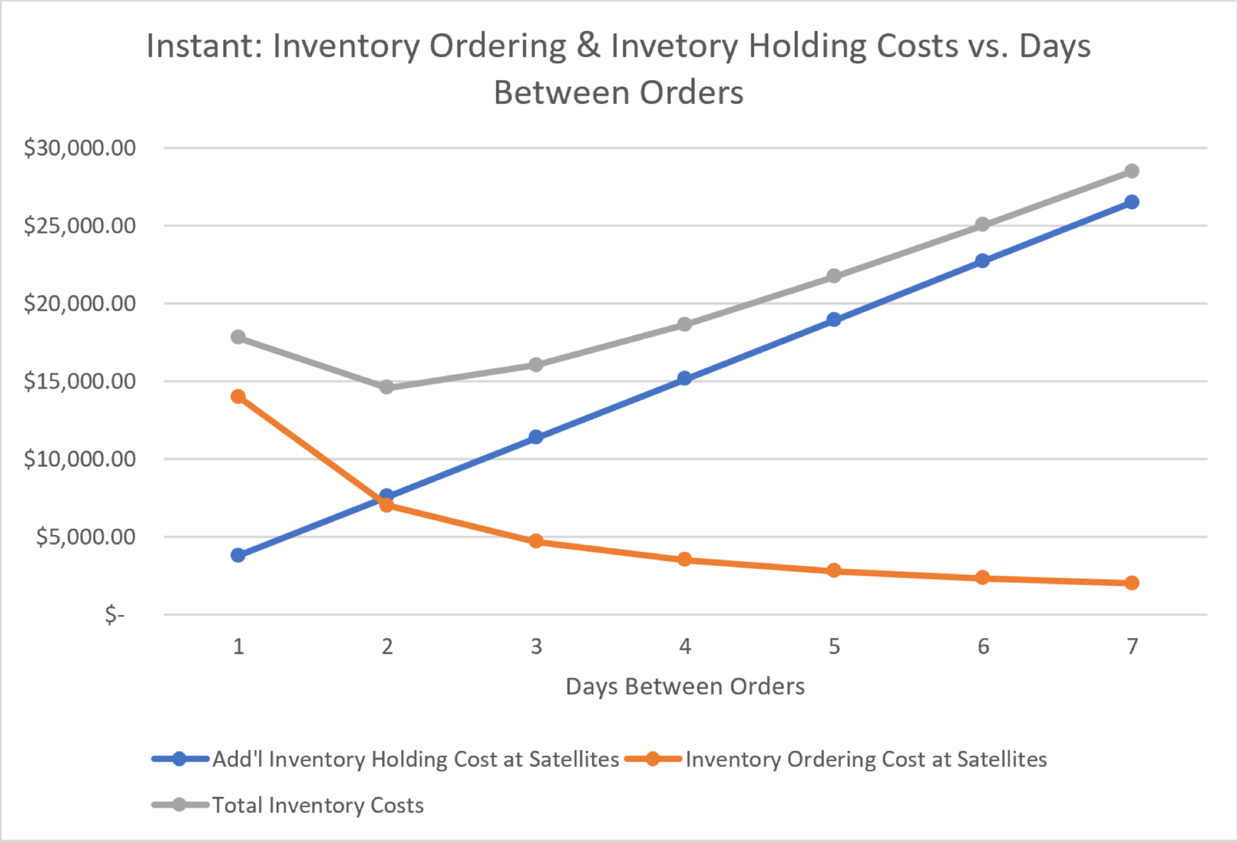

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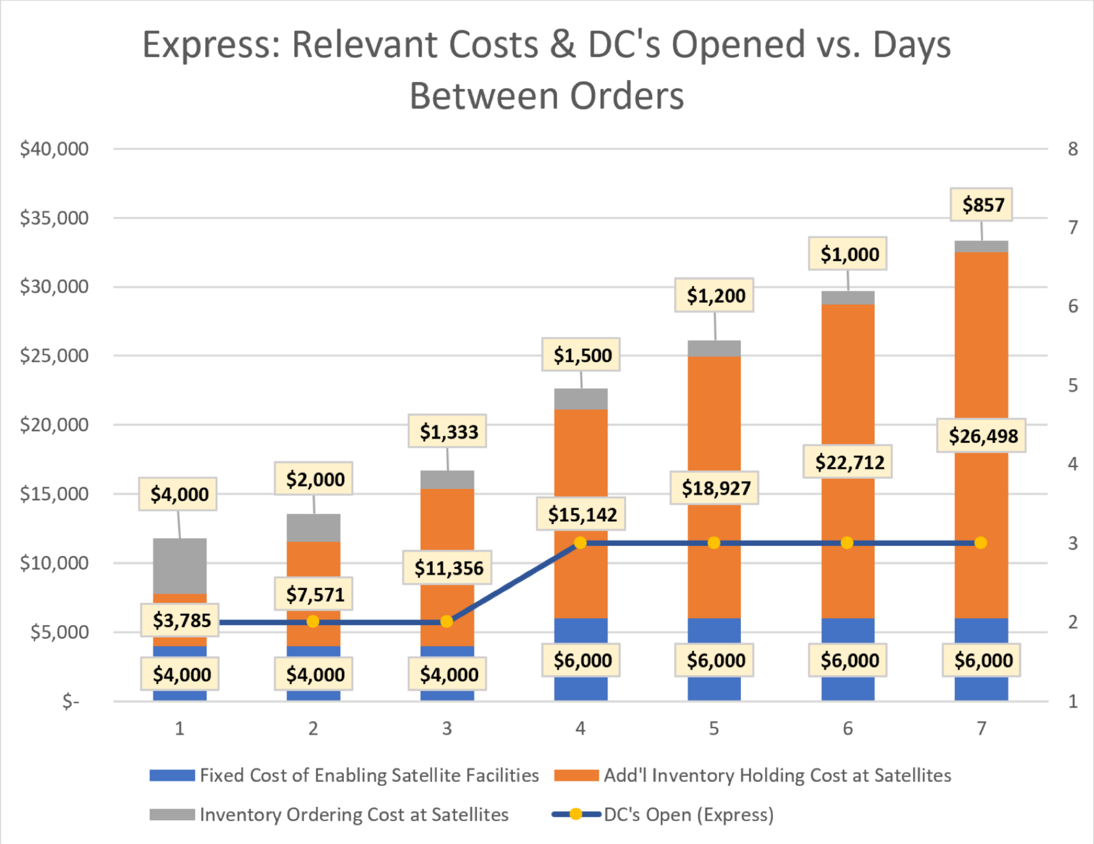

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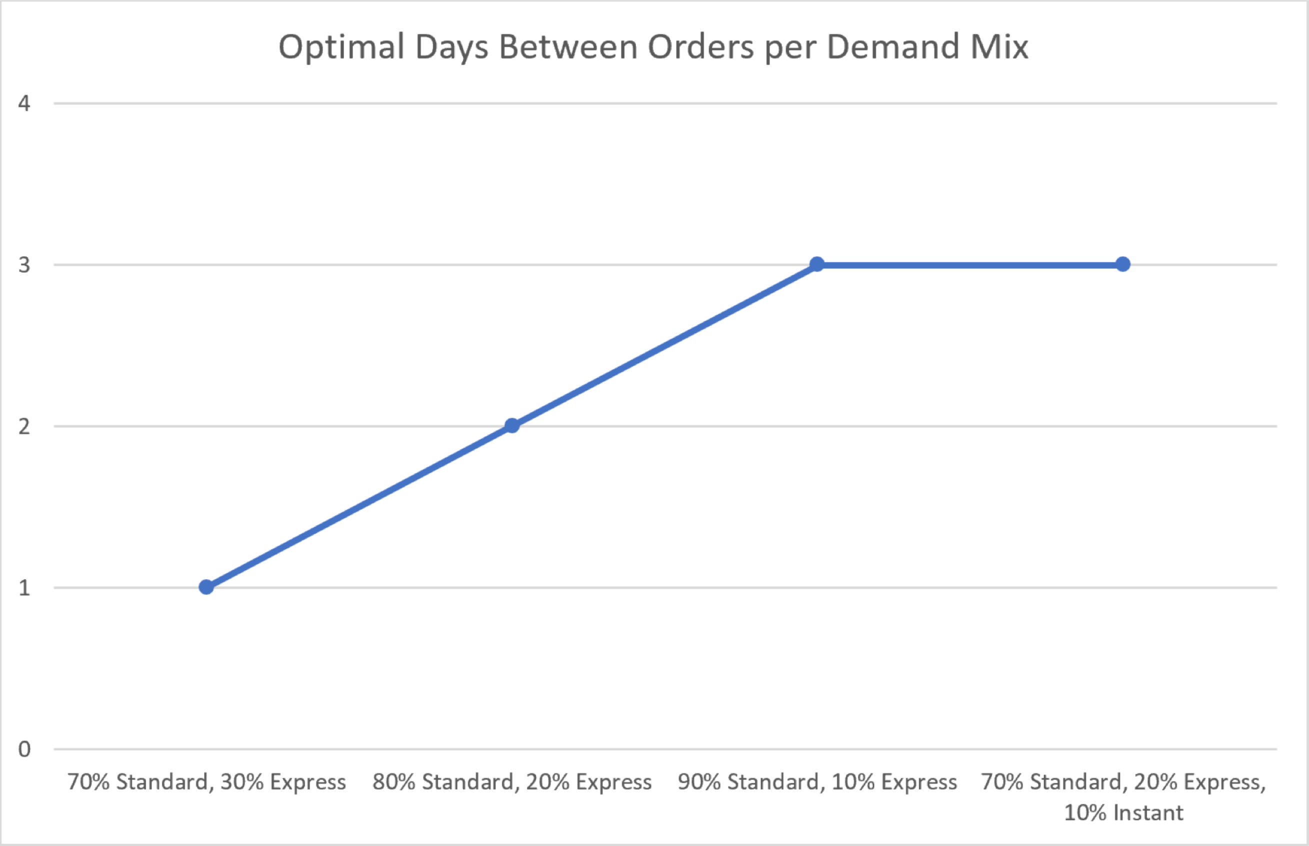

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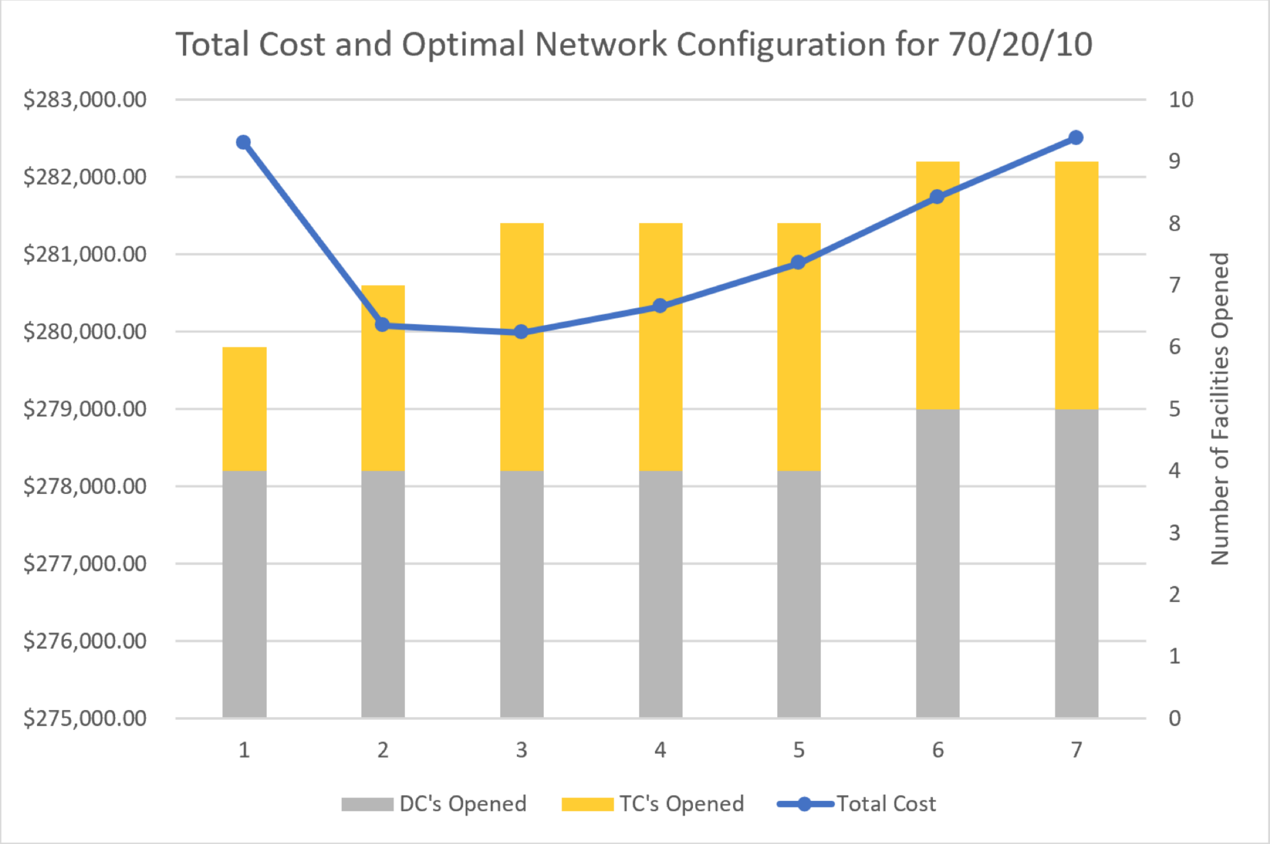
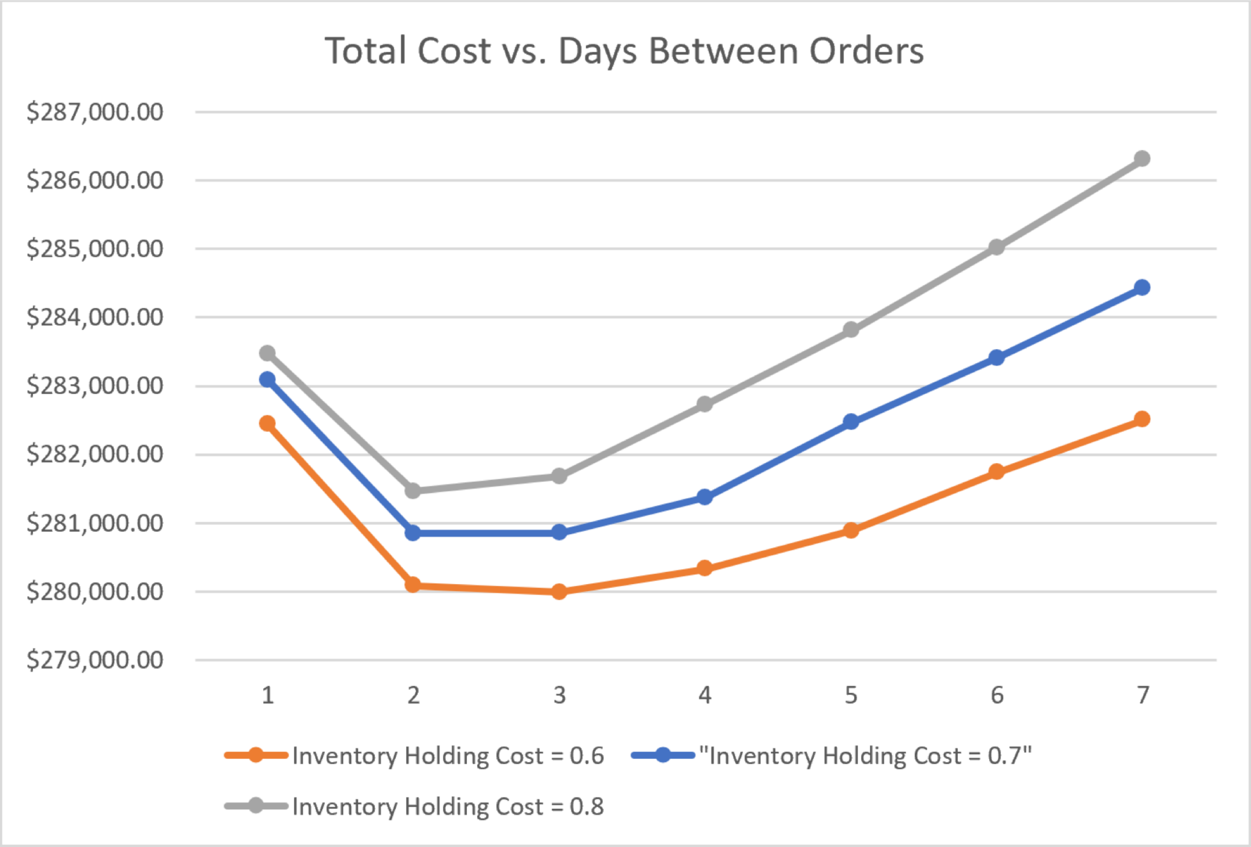


# Impact of Inventory Holding Cost on Network Configuration



# Summary

- Using satellite facilities as distribution centers offers great advantages for faster deliveries.
- Inventory control decisions play a critical role in designing optimal networks and should not be an afterthought
- Constraints in a company's operations must be considered when determining optimal policies
- Facility, process, labor, training, informational technology, and operational management need to be further considered in the network design decisions.

# Q&A

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# Literature Review

| | Large Scale | Multi Echelon | LRP with Explicit Routing | LRP with Continuum Approximation | Inventory Control Decisions |
|---|---|---|---|---|---|
| Liu and Lee (2003) | | | ✓ | | ✓ |
| Lin and Lei (2009) | | ✓ | ✓ | | |
| Boccia et al. (2011) | | ✓ | ✓ | | |
| Croinic et al. (2011) | | ✓ | ✓ | | |
| Ma and Davidrajuh (2005) | | ✓ | ✓ | | ✓ |
| Shen and Qi (2007) | | ✓ | ✓ | ✓ | ✓ |
| Ahmadi-Javid and Azad (2010) | | ✓ | ✓ | | ✓ |
| Winkenbach et al. (2016) | ✓ | ✓ | | ✓ | |
| Merchan and Winkenbach (2018) | ✓ | ✓ | | ✓ | |
| Snoeck et al. (2018) | ✓ | ✓ | | ✓ | |

# Routing Cost Approximation

Same Day and Next Day Deliveries (Continuum Approximation):

$$f_{ijs} = wc_{ij}(t^{L,f} + \frac{2r_{ij}}{s^{\beta,l}} + n_{ij}(t^{C,f} + \frac{k_i k^b}{s_i^{\beta,s}\sqrt{\gamma_i}})) + c^f q_{ij},\ \forall i \in I,\ j \in J, s \in S\{s,e\} \quad (16)$$

where

$$\zeta_i = \frac{\xi}{\theta_i^C \rho_i},\ \forall i \in I \quad (17)$$

$$T_{ij}^f = t^{L,f} + \frac{2r_{ij}}{s^{\beta,l}},\ \forall i \in I,\ j \in J \quad (18)$$

$$T_i^v = t^{C,f} + \frac{k_i k^b}{s_i^{\beta,s}\sqrt{\gamma_i}},\ \forall i \in I \quad (19)$$

$$n_{ij} = \begin{cases} \zeta_i, & if\ T_{s,tc}^m \geq T_{ij}^f + \zeta_i T_i^v \\ \frac{T_{s,tc}^m - T_{ij}^f}{T_i^v}, & if\ T_{ij}^f + \zeta_i T_i^v \geq T_{s,tc}^m \geq T_{ij}^f \\ 0, & if\ T_{s,tc}^m \leq T_{ij}^f \end{cases} \quad \forall i \in I,\ j \in J \quad (20)$$

$$m_{ij} = \begin{cases} \frac{T_{s,tc}^m}{T_{ij}^f + \zeta_i T_i^v}, & if\ T_{s,tc}^m \geq T_{ij}^f + \zeta_i T_i^v \\ 1, & if\ T_{ij}^f + \zeta_i T_i^v \geq T_{s,tc}^m \geq T_{ij}^f \\ 0, & if\ T_{s,tc}^m \leq T_{ij}^f \end{cases} \quad \forall i \in I,\ j \in J \quad (21)$$

$$q_{ij} = \begin{cases} \frac{\gamma_i A_i}{n_{ij} m_{ij}}, & if\ T_{s,tc}^m \geq T_{ij}^f \\ \infty, & otherwise \end{cases} \quad \forall i \in I,\ j \in J \quad (22)$$

$$c_{ij} = m_{ij} q_{ij} \quad \forall i \in I,\ j \in J \quad (23)$$

2-Hour Deliveries:

$$f_{ijs} = c^{ins} r_{ij} \gamma_{is} A_i,\ \forall i \in I,\ j \in J, s \in S\{i\} \quad (24)$$

Instant deliveries are fulfilled from satellite locations directly and delivered point-to-point with no consolidation. Therefore, a per-distance cost is used in the model formulation to determine the cost.