Optimization of Last Mile Delivery Using Shared Locker Systems

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Contents

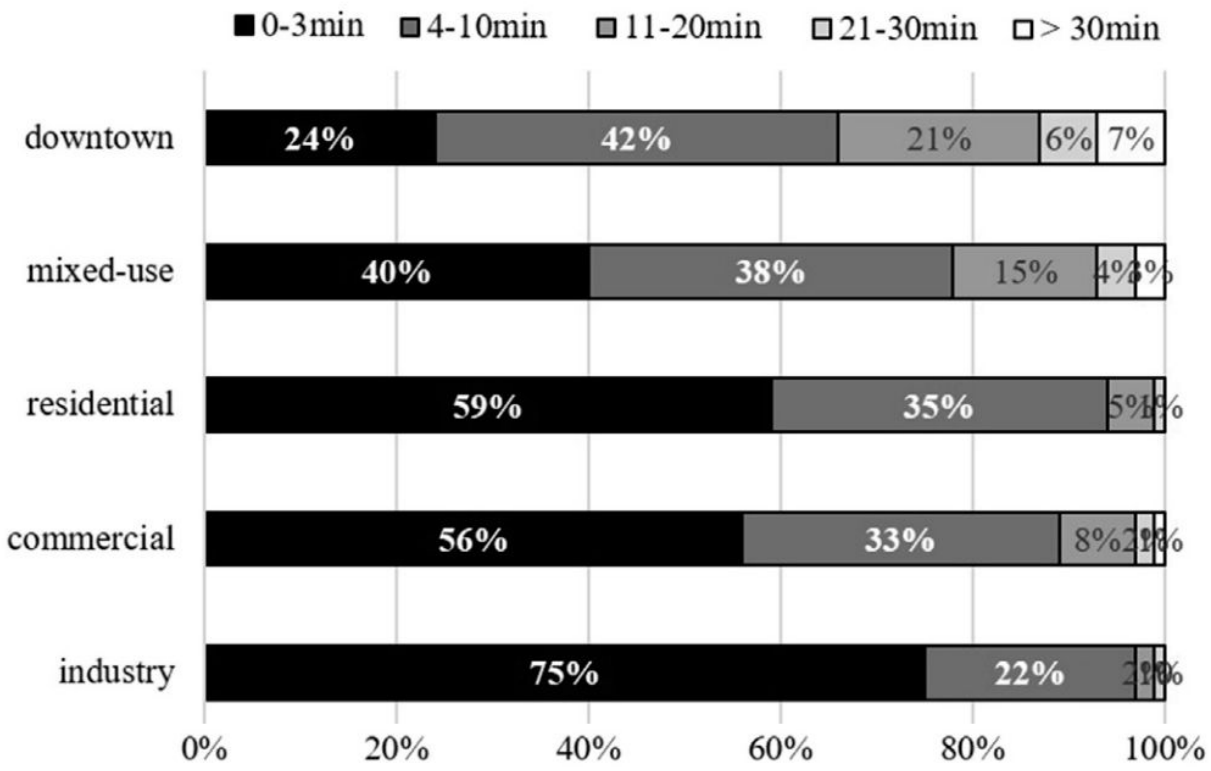
E-commerce Growth

- Global urban population increase
- Growth of business-to-consumer (B2C) e-commerce

- In the US:
  - **16 Billion+** packages
  - **16%** of US retail sale is on-line
  - **82%** of Americans are e-shoppers

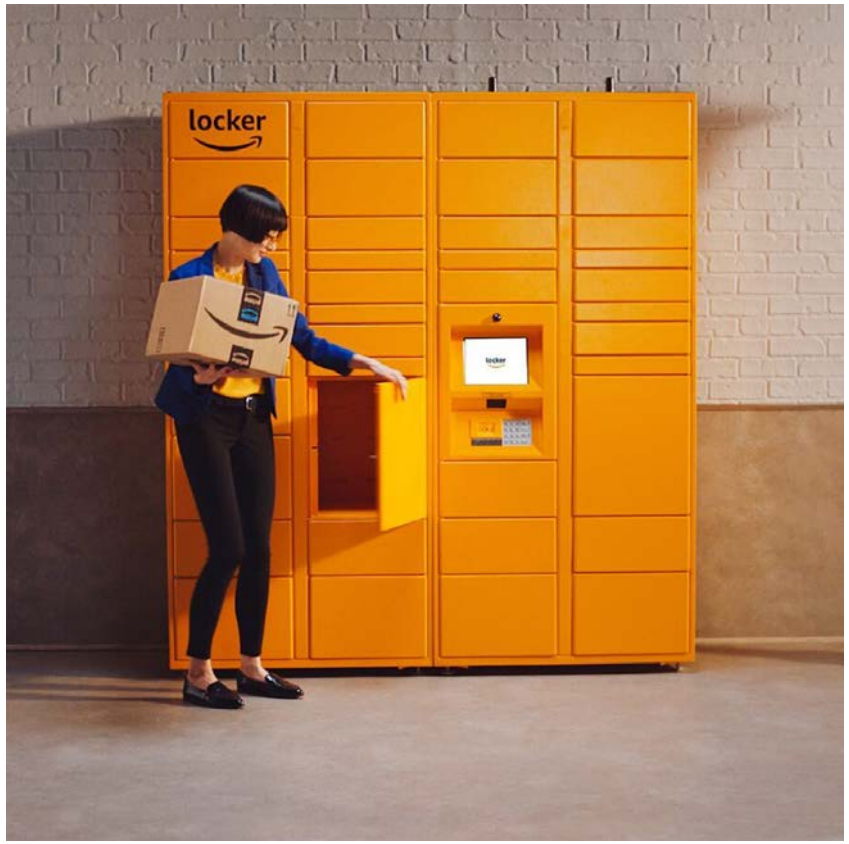
Package Delivery Growth and Challenges

- Online transactions boom the economy, but also challenge the urban logistics:
  - 70% increase in goods delivery vehicles in the UK
  - Steady increase of goods delivery vehicles kilometers
  - Greater occupation of curbside space/lane and disturbance of (especially nonmotorized) traffic
  - $1.1 Billion market loss

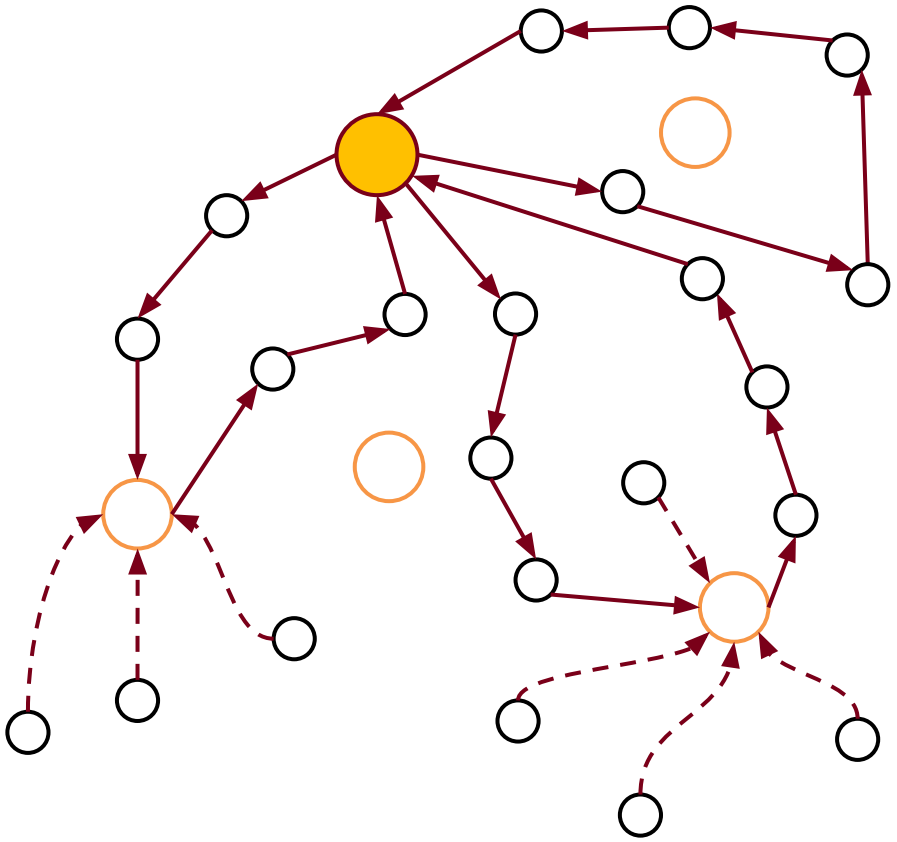


High cost associated with home deliveries

- Home is the most preferred delivery mode (67% in 2015 by UPS)
- Home-attended deliveries are associated with high operational cost (due to failed deliveries)
- Innovative delivery modes:
  - collection and delivery point (CDP)
  - **shared lockers (SL)**
  - delivery with robots/drones



Problem Description



- Given
  - Customers demand points
  - Network
  - Candidate shared lockers
- Determine
  - Optimal locations of shared lockers
  - Optimal delivery truck routes (dedicated and/or blended)
  - Optimal customer–locker assignment
- Objective- minimizing total system cost

Optimization Method

Objective Function

- Customers pick-up trip cost discounted using **parameter γ**

$$\text{minimize} \quad \boxed{\text{Company's Delivery Cost}} \; \sum_{i \in C} \sum_{j \in S} c_{ij} x_{ij} + (\gamma - 1) \boxed{\text{Customer's Pick-up Cost "Saving"}} \; \sum_{i \in C} \sum_{j \in S} (c_{ij} + c_{ji})\, y_{ij} + \boxed{\text{Company's Lockers Cost}} \; \sum_{j \in S} c_{jk} z_{jk}$$

  - First Term: Delivery truck cost (including virtual visits)
  - Second Term: Customer pick-up cost savings
  - Third Term: Shared lockers' capital cost

Optimization Method

Constraints

$$\sum_{j \in \mathcal{C}} \sum_{v \in \mathcal{V}} x_{ijv} = 1, \qquad \forall i \in \mathcal{C}$$

$$\sum_{i \in \mathcal{E}} x_{djv} = 1, \qquad \forall v \in \mathcal{V}$$

Flow conservation constraints

$$\sum_{i \in \mathcal{E}} x_{ijv} - \sum_{i \in \mathcal{E}} x_{jiv} = 0, \qquad \forall j \in \mathcal{E}, \forall v \in \mathcal{V}$$

$$\sum_{i \in \mathcal{E}} x_{idv} = 1, \qquad \forall v \in \mathcal{V}$$

$$\sum_{i \in \mathcal{S}} D_i \sum_{j \in \mathcal{E}} x_{ijv} \leq Q_v, \qquad \forall v \in \mathcal{V}$$

Truck capacity constraints

$$y_{ijv} \geq x_{ijv} + x_{jiv} - 1, \qquad \forall i \in \mathcal{C}, j \in \mathcal{S}, v \in \mathcal{V}$$

$$\sum_{j \in \mathcal{S}} \sum_{v \in \mathcal{V}} y_{ijv} = 1, \qquad \forall i \in \mathcal{C}$$

$$y_{ijv} \leq x_{jiv}, \qquad \forall i \in \mathcal{C}, j \in \mathcal{S}, v \in \mathcal{V}$$

Customer assignment constraints

$$\sum_{i,j \in S} x_{ijv} - \sum_{i,j \in S} y_{ijv} \leq |S| - 1, \qquad \forall S \subseteq \mathcal{E}, \forall v \in \mathcal{V}$$

$$\sum_{i \in \mathcal{C}} x_{ijv} + \sum_{i \in \mathcal{C}} x_{jiv} > 2 \sum_{i \in \mathcal{C}} y_{ijv}, \qquad \forall j \in \mathcal{S}, \forall v \in \mathcal{V}$$

Sub-tour elimination constraints

$$\sum_{i \in \mathcal{C}} \sum_{v \in \mathcal{V}} D_i y_{ijv} \leq Q_k z_k, \qquad \forall k \in \mathcal{S}$$

Locker capacity constraints

$$x_{ijv} \in \{0, 1\}, \qquad \forall i, j \in \mathcal{E} \cup \{d\}, v \in \mathcal{V}$$

$$y_{ijv} \in \{0, 1\}, \qquad \forall i \in \mathcal{C}, j \in \mathcal{S}, v \in \mathcal{V}$$

$$z_k \in \{0, 1\}, \qquad \forall k \in \mathcal{S}$$

Variable definitions

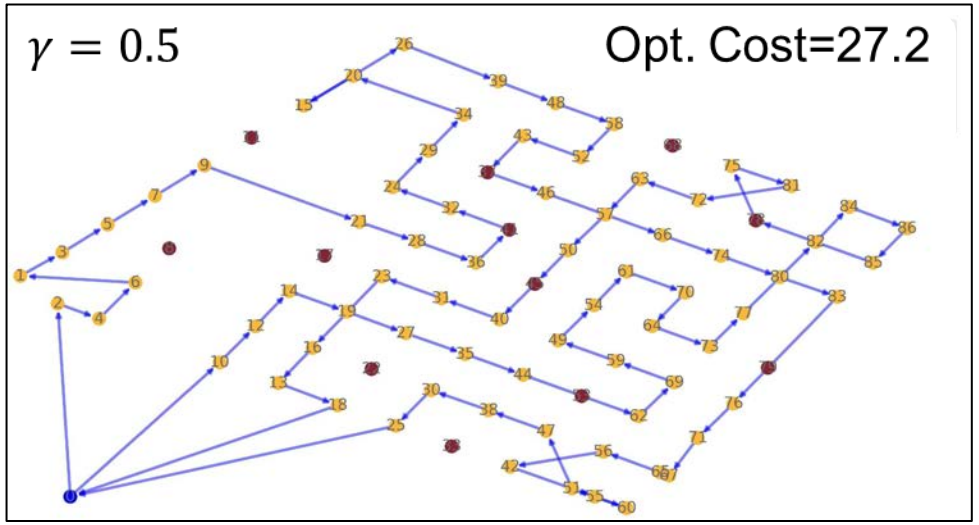
Case Study

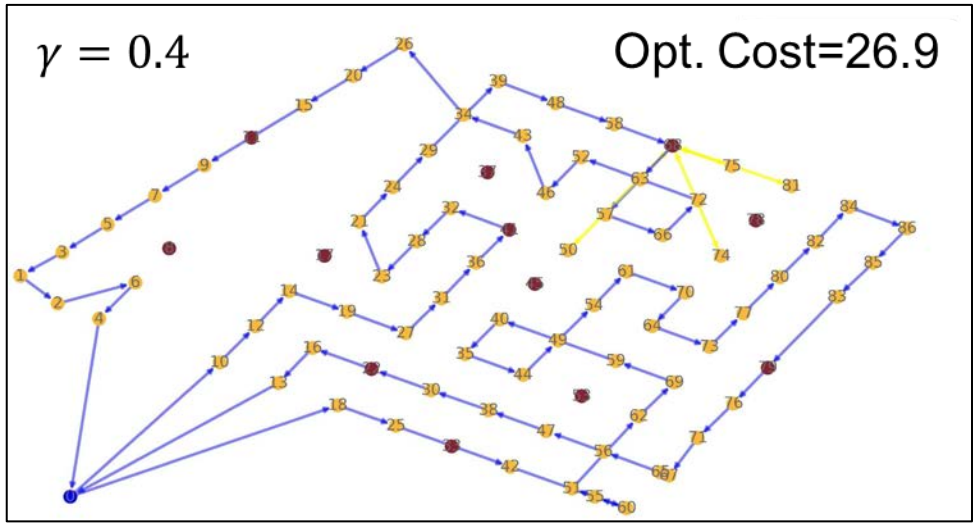
Test Network and Parameter Settings

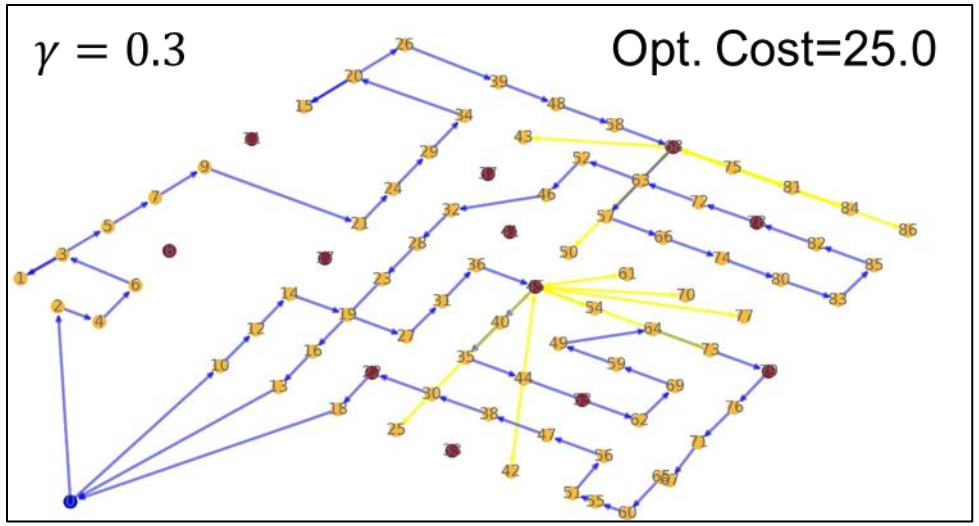
- Downtown Minneapolis Network
  - One-way streets
  - 74 demands sites at block corners (random demand values)
  - 2 delivery trucks with $3.0/mile operating cost
  - 12 candidate lockers with $300 capital cost amortized to 5 years
  - Customer pick-up cost parameter γ ranging from 0.25 to 0.5

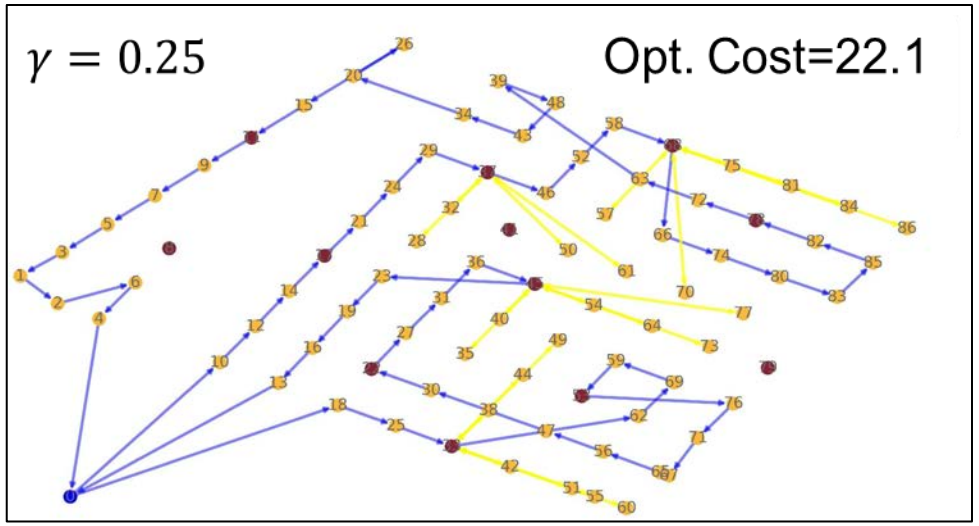
Case Study

Results from Fours Scenarios



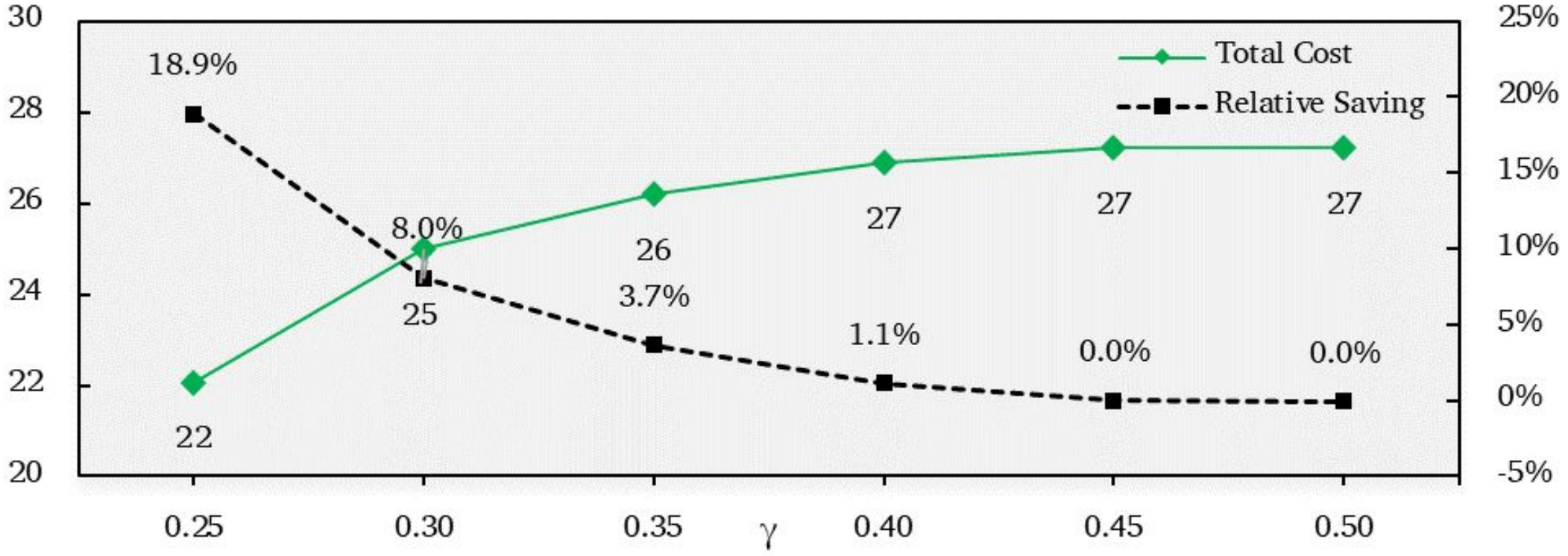






Case Study

System Cost Savings w.r.t. Customer Pick-up Cost

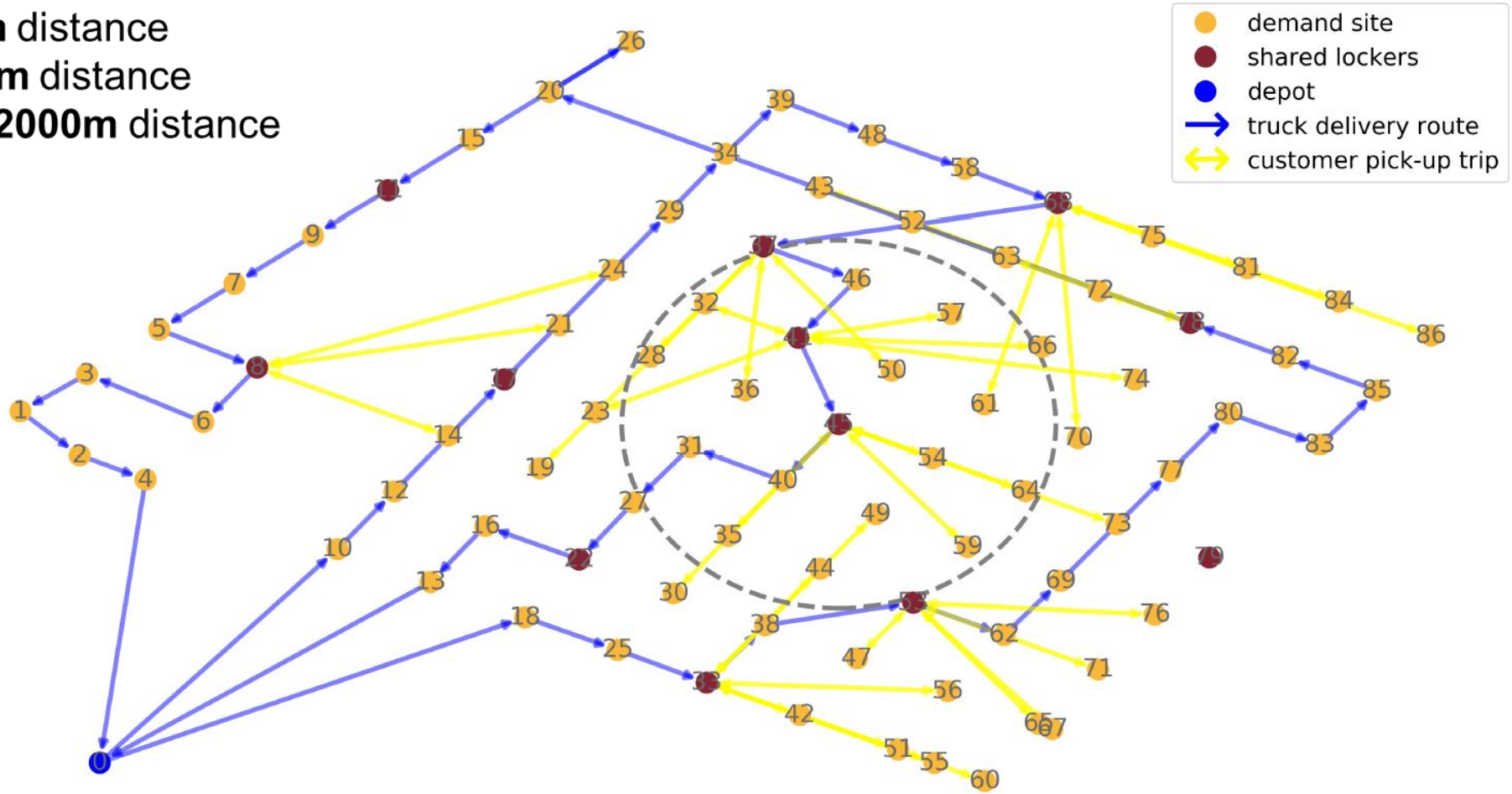


Case Study

Varying Customers Scenario

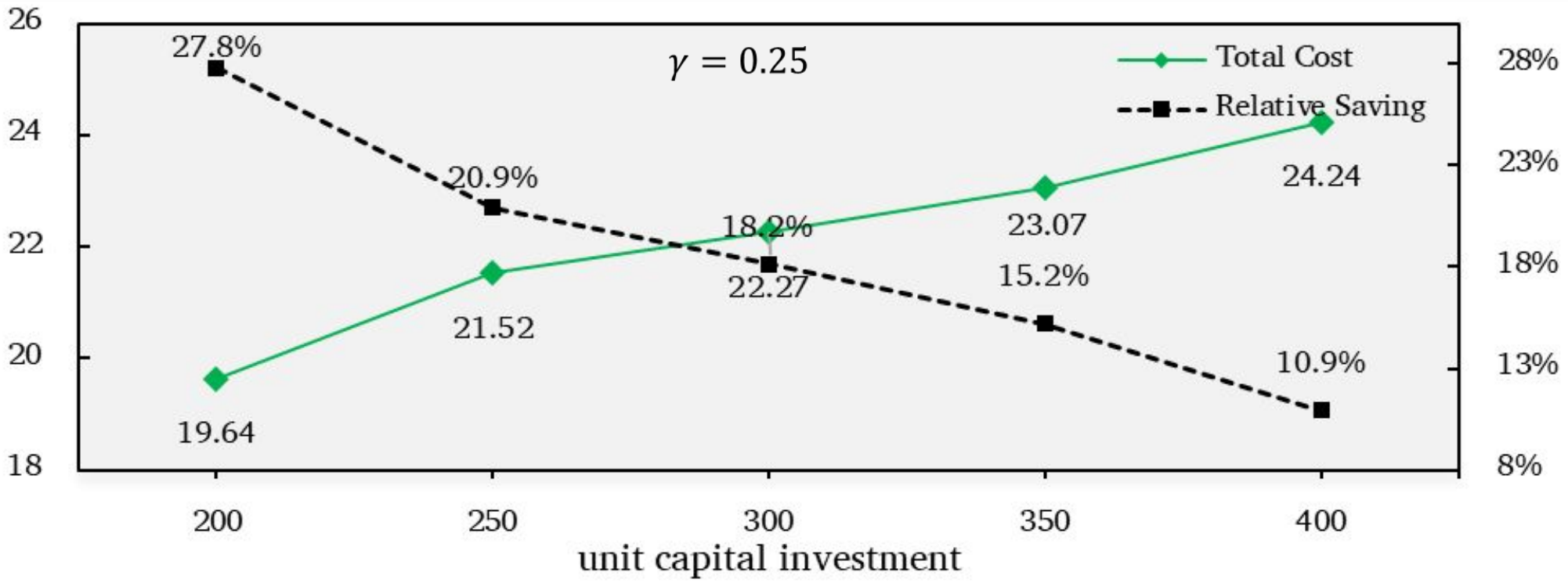
$\gamma = 0.15$ for less than **500m** distance
$\gamma = 0.3$ for **500-1000m** distance
$\gamma = 0.5$ for **1000-2000m** distance
$\gamma = 0.75$ for more than **2000m** distance

Optimal cost = 12.3



Case Study

System Cost Savings w.r.t. Capital Cost



Conclusions

- Jointly optimized 1)shared lockers location, 2)delivery trucks routing, and 3)customers assignment to minimize the total system cost.
- Novel formulation reduces the computational time for real-size network applications.
- The last mile delivery using the shared lockers can save the system cost up to **19-28%,** relative to the traditional home delivery.
- The shared locker system benefits from the economy of scale.

Future Work

- Extending the model:
  - Incorporating uncertain demand
  - Incorporating customers choices
  - Incentivizing customers to use lockers

- Informing practice and policy:
  - Understanding customers choices
  - Package delivery demand data
  - Curbside implications of increased last mile delivery

Acknowledgments

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Questions?

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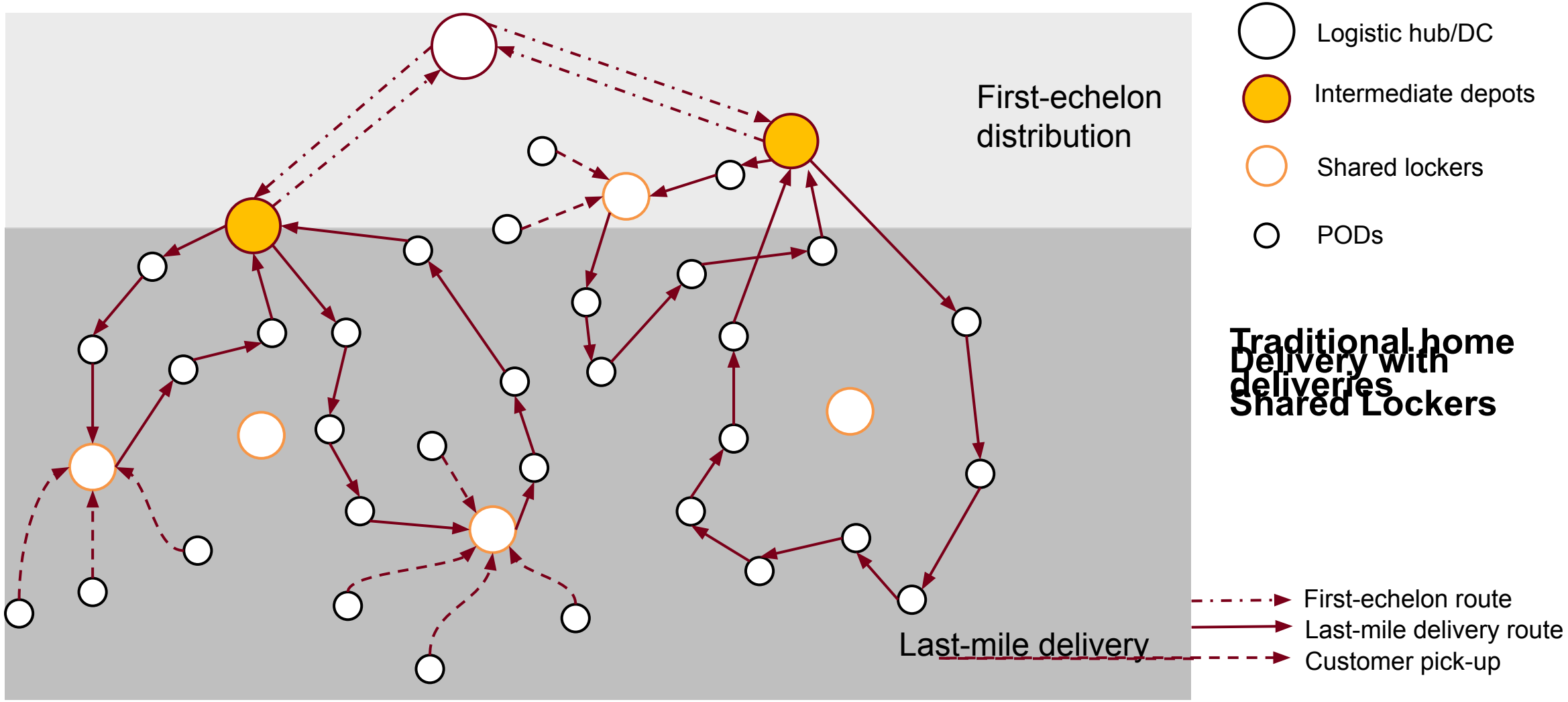
Multi-echelon distribution network



Traditional home deliveries

Delivery with Shared Lockers