Urban Large-Item Logistics with Hyperconnected Fulfillment and Transportation

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Last Mile Delivery of Large Items in Urban Area

- **Last-mile Delivery**
  - Very last fulfillment, transportation, and delivery to ultimate customer location
  - The most expensive logistic operations
  - Directly related to customer experience

- **City Logistics**
  - Growing needs and concerns owing to urbanization and customer expectation on faster, punctual delivery
  - Considerable social and environmental impact in urban area e.g. traffic congestion, air pollution
  - Traditional solution approaches: Routing, Urban Consolidation Center (UCC), Regulations (time, type of vehicles)

- **Furniture and Large Appliances**
  - Large, heavy item dimensions: Limited number of stops in one route
  - Often requires white-glove services (Delivery and install at delivery location)
Hyperconnected city logistics system can be a future alternative for efficient, environmentally friendly city logistics system capable of meeting evolving customer needs.

**Transformation towards Hyperconnected System**

- **Dedicated**
  - Dedicated Fulfillment & Transportation

- **Hyperconnected**
  - Openly-shared Fulfillment & Transportation
Fulfillment with increased capability through unrestricted access to and dynamic inventory deployment over an open network of fulfillment facilities on demand.
Hyperconnected Fulfillment

- Dedicated Fulfillment
  - Network is optimized for each player
  - Not a Globally Optimal Network

- Hyperconnected Fulfillment
  **Network Efficiency**
  - Increase proximity to demand locations
  - Consolidate shipments from a fulfillment center (FC) to nearby demand locations
  - Re-optimization: pooled demand can justify a new facility in an under-served area

  **Facility Efficiency**
  - Improve capacity utilization of the FCs
Hyperconnected Transportation (Last-mile)

Multi-player routing/shipping modularized by region and by layer through utilization of a network of various types of PI hubs enabling dynamic and broad range of flow consolidation.

Last-mile Dedicated Transportation

Last-mile Hyperconnected Transportation (2-tier)$^{[1]}$

Fulfillment center ▲ PI-hub ○ Demand location → Dedicated route → Tier1 route ... □ Tier2 route with type 1 and 2
Hyperconnected Transportation (Last-mile)

- Enable dynamic consolidation among anonymous players at PI hubs
  - Increase fillrate and decrease empty miles
  - Increase shipping frequency without efficiency trade-off

- Enable specialized route through modularization
  - **Physical modularization**
    - Divide a long route into multiple short routes
    - Flexible routing and dynamic consolidation
    - Dedicate driver in a limited area
    - Specialize to a limited area such as historical city center
  - **Functional modularization**
    - Divide a route into multiple routes in hierarchy
    - Obtain flexibility with respect to transportation mode, time, driver specialty etc.
## Scenario Design

Represent gradual transformation from dedicated to hyperconnected along each thread of fulfillment and delivery

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Scenario Type</th>
<th>Operation Type</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Scenario Type</td>
<td>Peri-urban Fulfillment Center (PF)</td>
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<tr>
<td>1</td>
<td>Dedicated</td>
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<tr>
<td>2</td>
<td>Hyperconnected</td>
<td>Openly-shared</td>
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<td>8</td>
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<td>Openly-shared</td>
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</tbody>
</table>
Agent-based Simulation Testbed

Define scope of simulation, key decision makers, and key operations

Diagram:
- Manufacturer
- Retailer
- Inventory/Order Manager
- Logistic Facility
  - Fulfillment Center
  - Intra-City Fulfillment Center
  - PI hub
- Router
- Vehicle
- Traffic Module
- Demand Generator
- Customer
- Inventory

Legend:
- : Agents
- : Objects
- : Information Flow
- : Product Flow

Actions:
- Retailers place replenishment orders
- Generate replenishment orders and assign inventories to orders
- Send delivery information
- Build daily delivery routes and assign to vehicles
- Control speeds based on stochastic traffic
- Deliver products
- Deliver replenishment

Kim, Kholgade & Montreuil, “Urban Large-Item Logistics with Hyperconnected Fulfillment and Transportation”
Agent-based Simulation Testbed

Each scenario runs for 2.5 years where first 0.5 year is warm-up period.
Key Performance Indices (KPIs)

- Key performance indices (KPIs) need to cover economical, environmental, and social efficiency and sustainability.

- Economic impacts
  - Total induced cost (fuel, labor, equipment ...)
  - Daily travel miles
  - Daily labor hours
  - Fuel consumptions

- Service level capability
  - Delays with respect to time window

- Environmental impacts
  - Greenhouse gas emission (CO$_2$, SO$_2$, NO$_2$)
  - Emission of fine particles (PM$_{2.5}$)
Experimental Results: Economic Impact

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Economic KPI Improvement</th>
<th>Hyperconnected Fulfillment</th>
<th>H. Fulfillment &amp; Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario2: SPFs</td>
<td>-31%</td>
<td>-31%</td>
<td>-23%</td>
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<tr>
<td>Scenario3: SIF</td>
<td>-2%</td>
<td>-32%</td>
<td>-27%</td>
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<tr>
<td>Scenario4: SPFs &amp; SIF</td>
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<td>-32%</td>
<td>-34%</td>
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<tr>
<td>Scenario5: SIH</td>
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<td>Scenario6: SIHs</td>
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<td>-40%</td>
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<td>Scenario7: SPFs &amp; SIH</td>
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<td>-34%</td>
<td>-54%</td>
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<td>Scenario8: SPFs &amp; SIHs</td>
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<td>-20%</td>
<td>-27%</td>
</tr>
</tbody>
</table>

- Travel Mile: -31% to -48%
- Driving Hour: -32% to -49%
- Fuel Consumption: -31% to -54%
- Labor Hour: -19% to -27%
Experimental Results: Economic Impact

- All the economical KPIs are improved significantly with hyperconnected system (~50% reduction in travel miles/fuel consumptions)

- Hyperconnected fulfillment or transportation solely can achieve about 60% of improvement of hyperconnected fulfillment AND transportation system

- Reduction in labor hour is limited due to fixed labor hour for delivery and installment

- Reduction in fuel consumption exceeds the reduction in travel mile with hyperconnected delivery due to the ability of utilizing smaller and more environmentally friendly vehicles in tier 2
Experimental Results: Service-level Capability

- Both delay time and frequency can be reduced significantly especially with hyperconnected transportation.
Experimental Results: Environmental Impact

- Similar to economic KPIs, greenhouse/toxic gas and fine particle emission rates are reduced significantly with hyperconnected fulfillment and/or transportation.
Conclusion

✓ Just openly-sharing existing peri-urban FCs can significantly improve last-mile operations especially when they are widely spread

✓ It is not necessary to build a fulfillment center in the expensive city area to improve last-mile logistics; However, single intra-city PI hub can bring significant improvement

✓ Web of PI hubs can improve last-mile logistics operated with openly-shared FCs; Use of smaller delivery vehicle for last-mile can further improve congestion and reduce negative environmental impacts

✓ Demonstrate the capability and effectiveness of simulation-based scenario analysis for research in Physical Internet
Future Study (ongoing)

- Study the scenarios in a variety of contexts
e.g. city topologies, demand patterns, facility locations

- Investigate the potential of further improvement by separating and synchronizing delivery operation and white-glove services
Thank you 😊
Questions, Comments, and Discussions!
Photos (page 3)


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