Georgia Tech

CREATING THE NEXT

Georgia Tech Supply Chain and Logistics Institute
Interdisciplinary Research Center

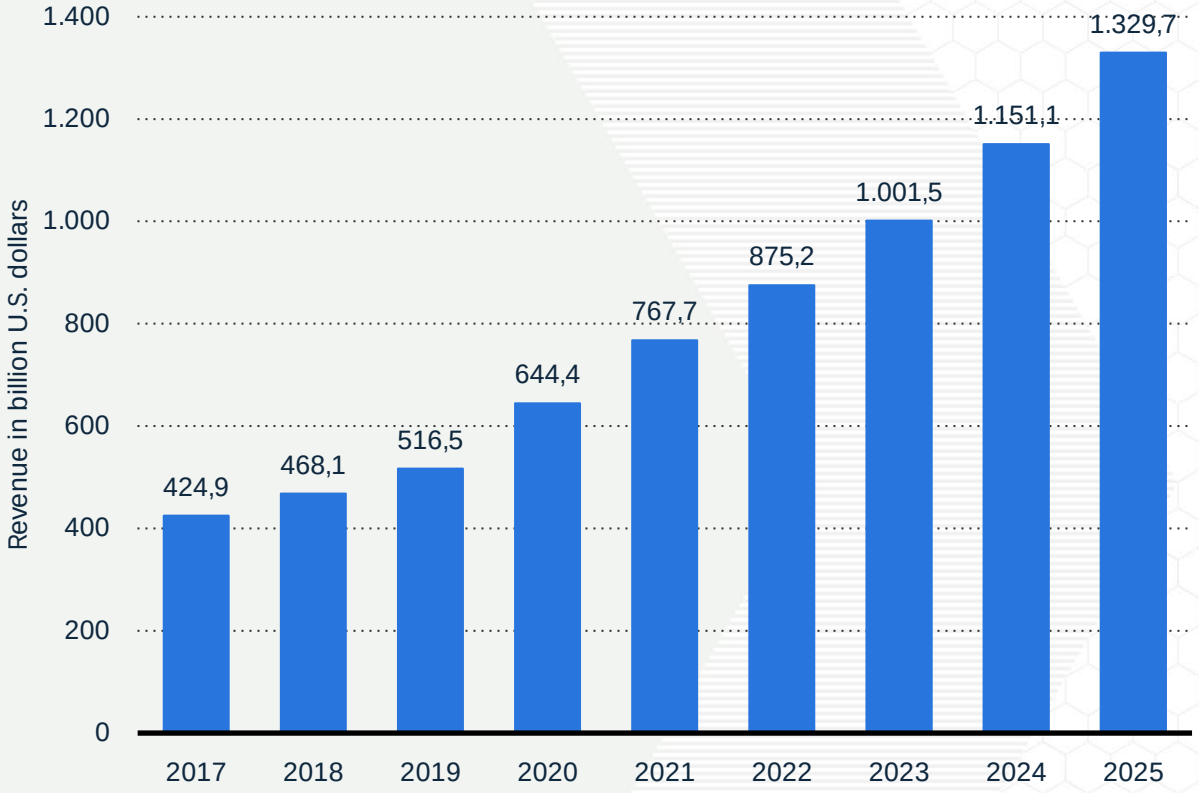
Physical Internet Center
Supply Chain & Logistics Institute

Yujia Xu, Walid Klibi and Benoit Montreuil

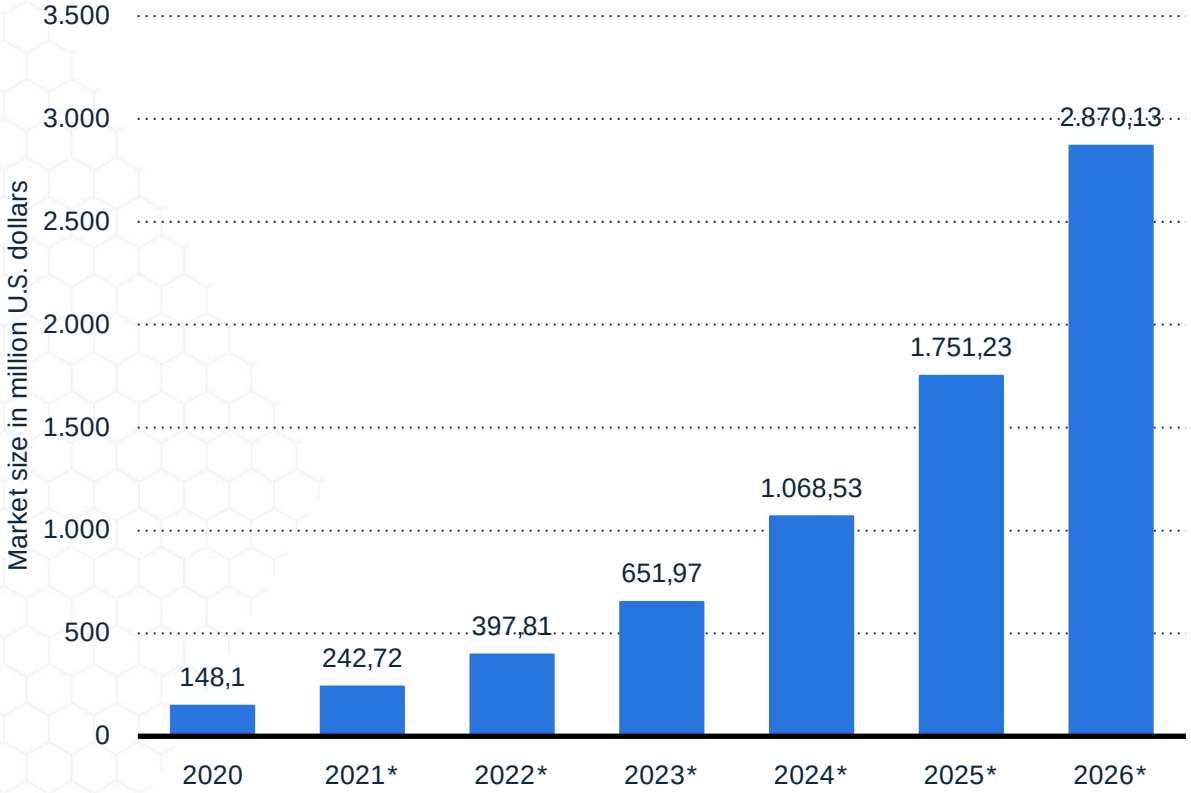
IPIC 2023

9th International Physical Internet Conference

Motivation



Retail e-commerce revenue in the United States from 2017 to 2025 (in billion U.S. dollars)



Size of the global piece picking robots market from 2020 to 2026 (in million U.S. dollars)

Source: Statista

Resources in parcel logistic hubs

Workforces

Workers in parcel logistic hubs (SF Express)

Robots

Pegasus (Amazon)

Skypod (Exotec)

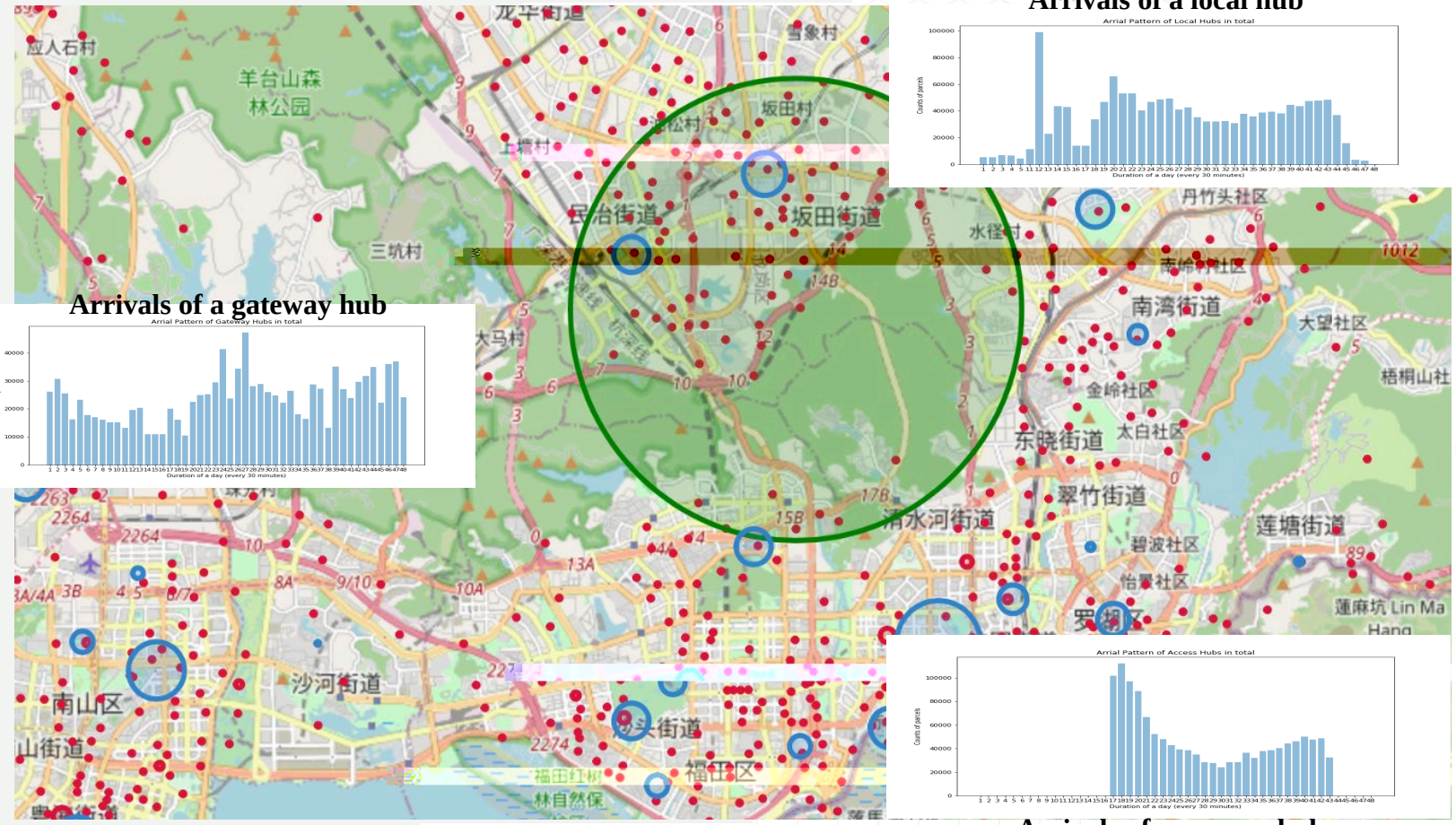
Original Kiva (Amazon)

Skypicker (Exotec)

https://www.allaboutlean.com/amazon-robotics-family/. https://www.exotec.com/fr/.
https://www.lubbockonline.com/story/news/2021/02/01/amazon-announces-sort-center-and-delivery-station-230-full-time-jobs-lubbock/4340077001/

Motivation

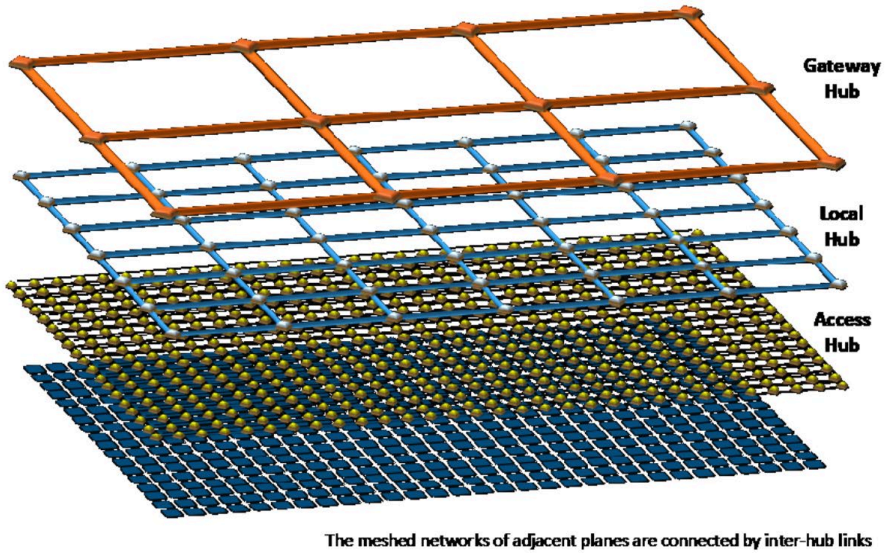
The multi-tier structure of the hyperconnected networks indicates different arrival patterns of hubs, thus provides an opportunity for dynamic adjustment of moving workers spatial-temporally.



Arrivals of a local hub

Arrivals of a gateway hub

Arrivals of an access hub



The meshed networks of adjacent planes are connected by inter-hub links

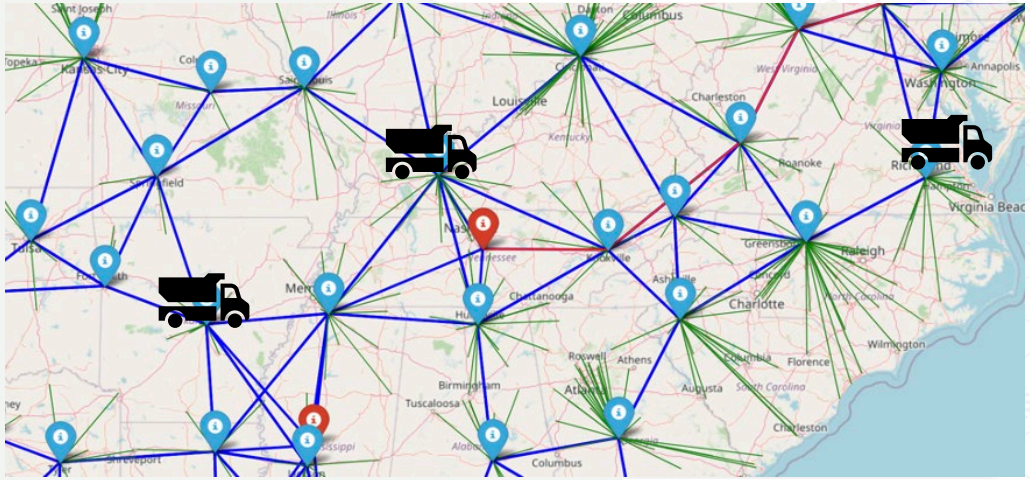
A Multi-tier Urban Logistics Web

Source: Montreuil, Benoit, et al. "Urban parcel logistics hub and network design: The impact of modularity and hyperconnectivity." (2018).

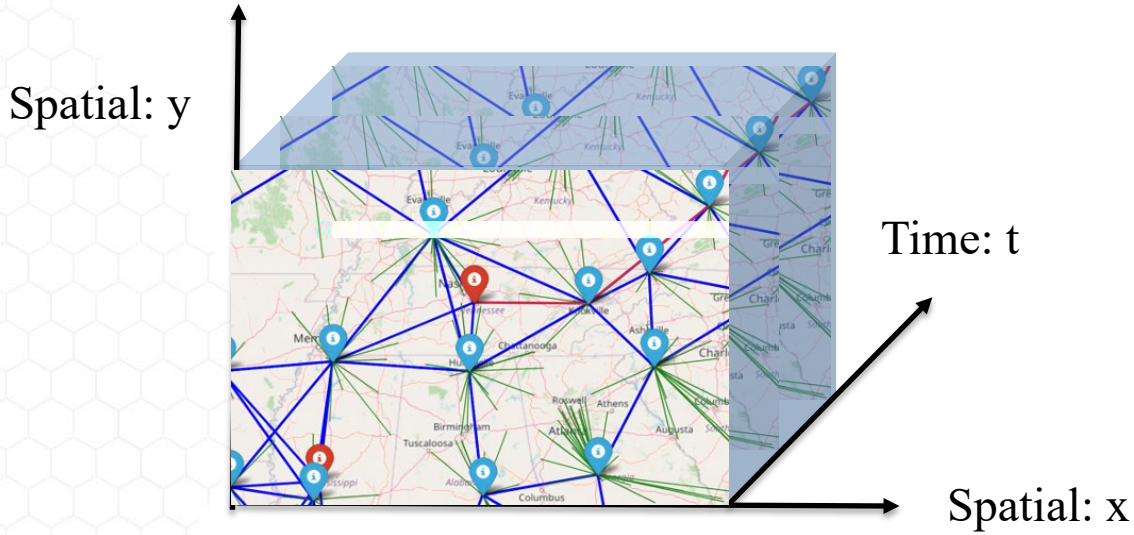
Motivation

Dynamic arrival time predictions in the hyperconnected networks

- The prediction of parcels' arrival time at hubs can be dynamically improved as they approach to the hubs.



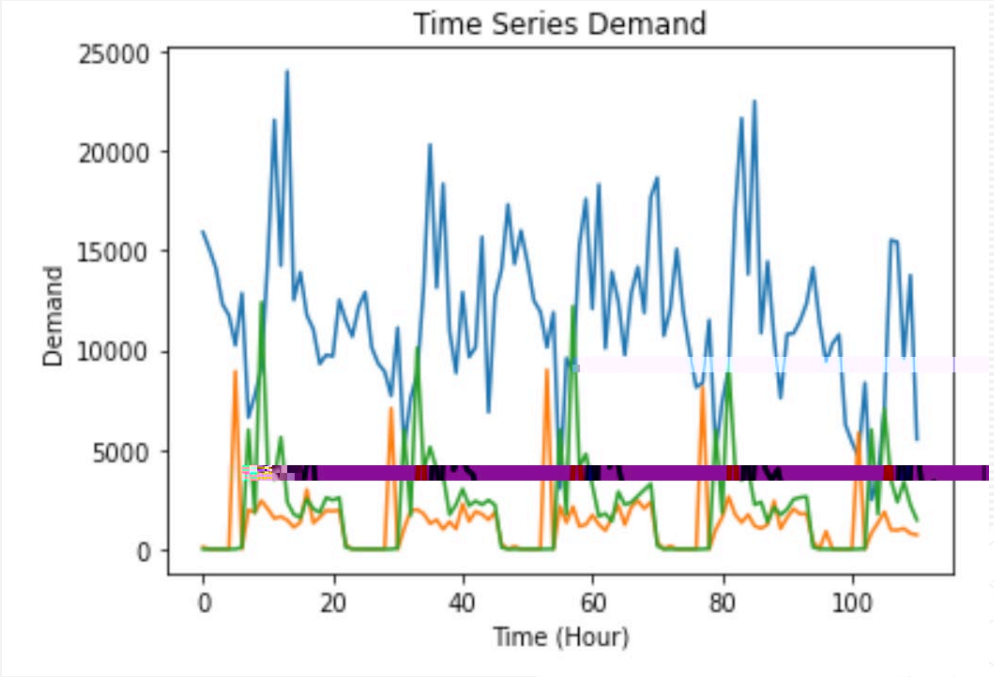
: Trucks' real- time locations

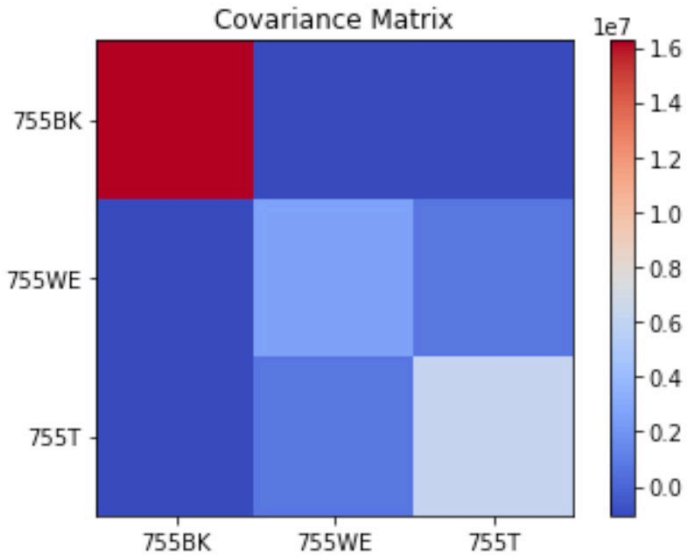


- Currently, most labor scheduling is **periodic** and **limited to single facility**, thus the number of required resources in each hub is constrained to meet the demand peak with high variance.

- Our proposed dynamic resource scheduling and relocation system in networks is fed from updated data with sensors and dynamically updated hub arrival workload predictions.

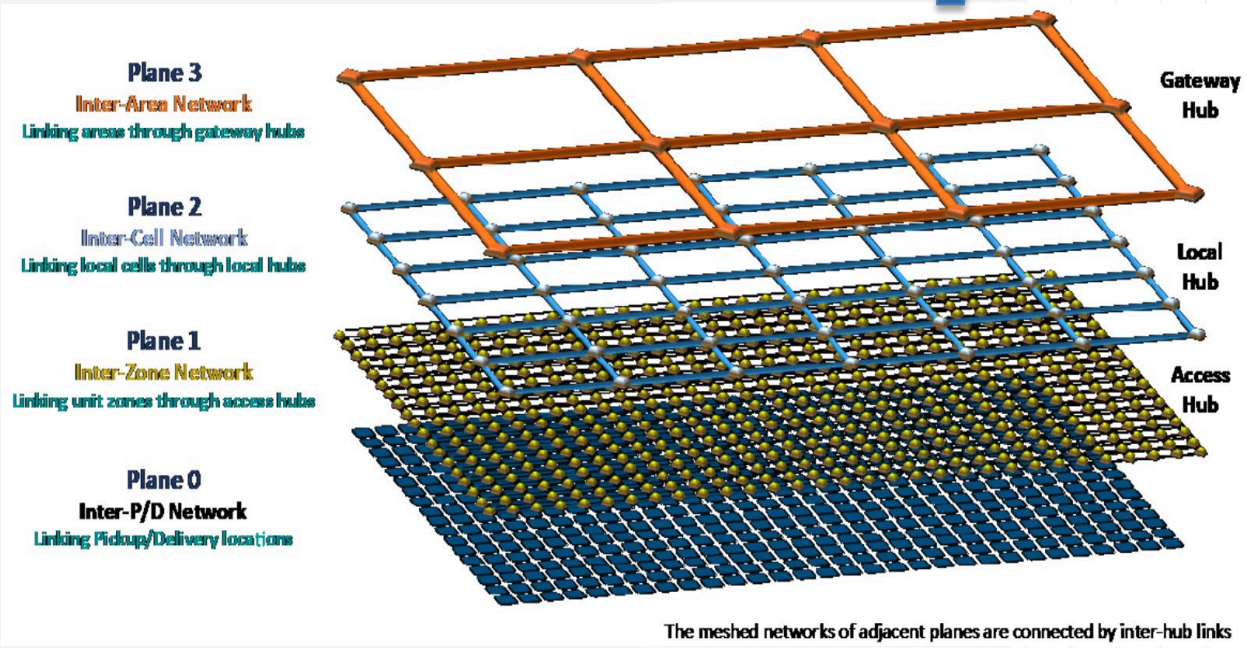
Model preparatory techniques – Demand analysis



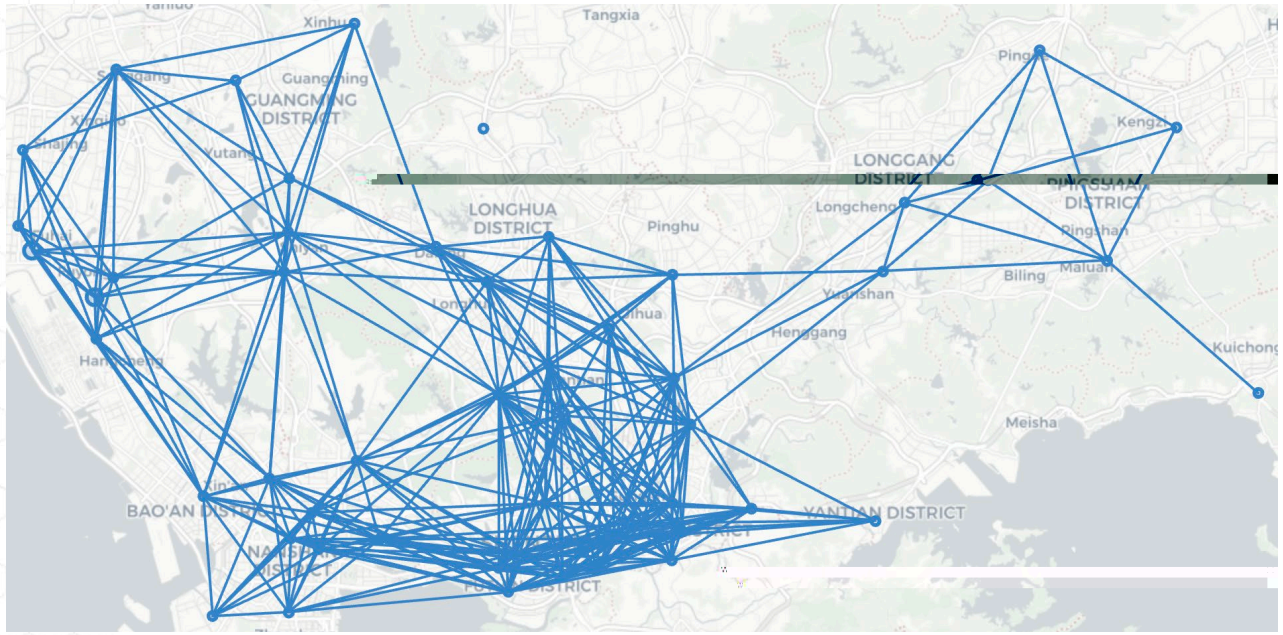


Model preparatory techniques – Connected graphs

Travelling cost and Demand (parcel arrivals) analysis



Hyperconnected logistic networks



Generated connected graph given a parcel logistic network of a logistic company in Shenzhen, China

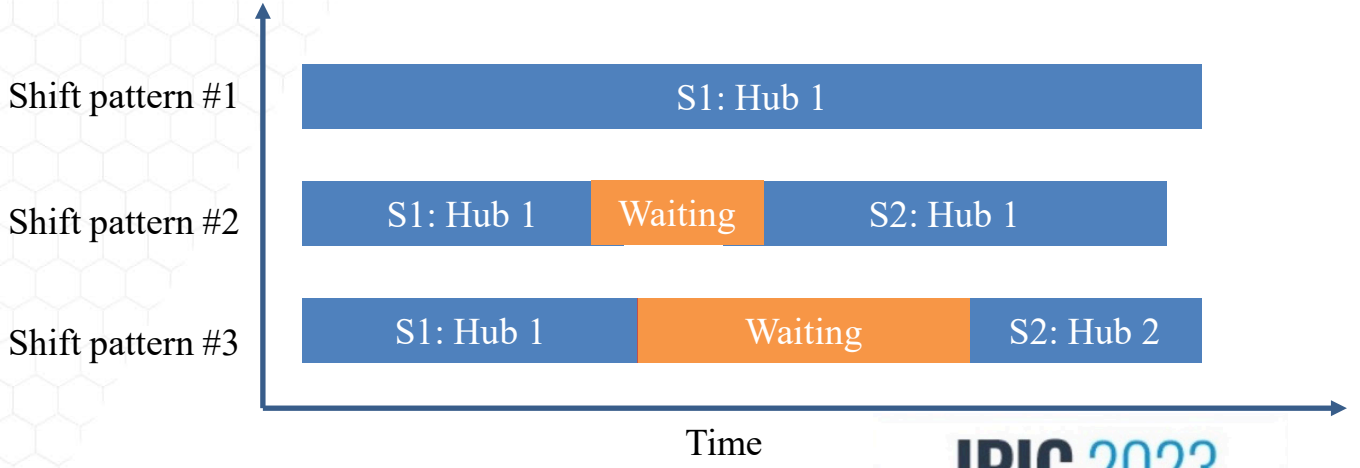
Source: Montreuil, Benoit, et al. "Urban parcel logistics hub and network design: The impact of modularity and hyperconnectivity." (2018).

Model preparatory techniques – Shift patterns

- **Shift regulations and time constraints** for resources at hub could include
  - Maximum daily working/picking time
  - Maximum idle time at hubs
  - Maximum time in transit
  - Maximum weekly time on duty
  - …

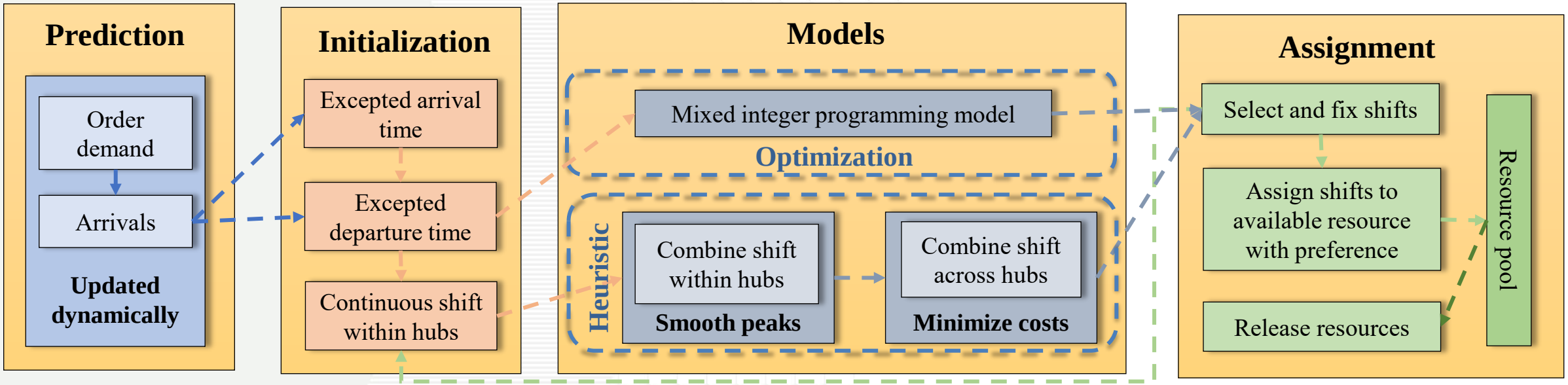
  Thus, possible daily shifting patterns among the planning horizon given the regulations can be generated can be generated using enumeration method.

- **Advantages**
  - Return solutions quickly.
  - Reduce the number of parameters and constraints of the the following scheduling model, e.g., the costs of each shift.
  - Help the model adapted to different kinds of resources given different shift regulations, e.g., workforce and robots.



Problem Description and Methodology

Objective:
A dynamic **predictive-reactive** resource scheduling and relocation system to cover predicted **workload** with shifts considering **parcels' maximum dwell time** to respond quickly to changes of predicted workload at hubs and thus, to provide guidance for centralized resource assignment.

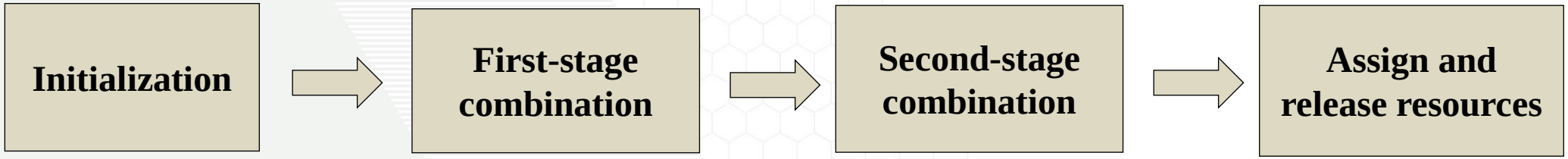


Smoothing demand peaks

Smoothing demand peaks

Heuristic approach

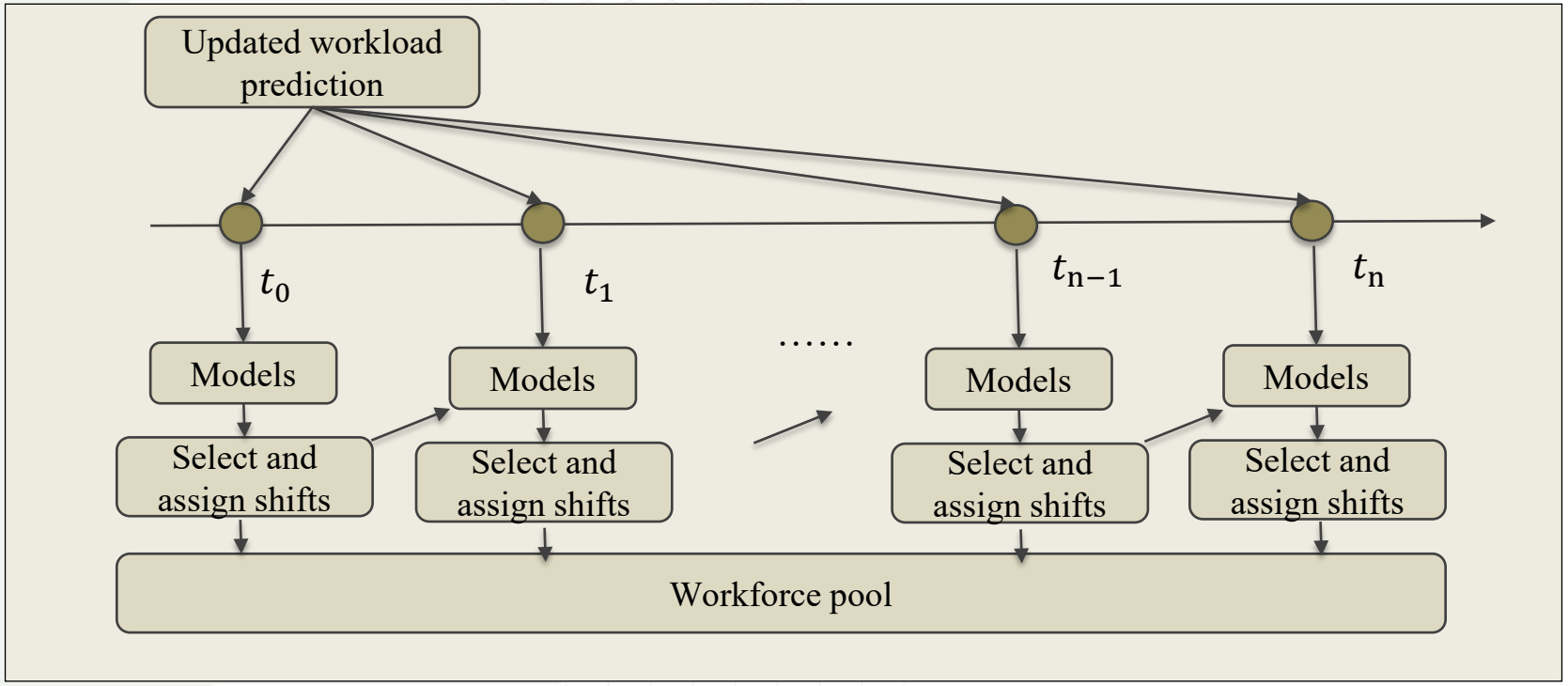
Procedure



- Initialize the resource demand in each time unit considering the predicted number of arrived parcels and labor' working efficiency.
- Combine the workload to minimized number of shifts and maximize shift total length
- Utilize the parcels' dwell time at hubs to **smooth the labor demand peaks**
- **Greedily** merge the shifts across hubs from smallest travelling cost
- Select shifts and assign them to available resources from the pool
- Release resources if resting or charging shifts are finished

Rolling horizon approach

To address the presence of uncertainty, seeking to assign cheap and efficient shifts iteratively by moving forward the planning horizon with updated demand prediction at every iteration.



- Fixing shifts too **early** may lead to overstaffing in presence of significant demand prediction intervals.
- Selecting shifts too **late** may result in high emergency penalty and leave no time for announcement..

Decide shift assignment duration Δ:
If a shift would be start within duration Δ, it would be fixed and assigned to a worker available in the resource pool.

Experimental Results

Reactive scheduling heuristics in real-world parcel logistic networks with rolling horizons

- 52 hubs, including local hubs and gateway hubs from a company's logistics networks in Shenzhen
- Model runs every $\epsilon = 60$ minutes, planning horizon = 24 hours
- 1,173,253 parcels arrived at hubs during the planning
- Two types of resources: workforce, picking robots

Rolling horizon settings

- Since the predictions of parcels' arrival time at hubs can be dynamically improved as they approach to the hubs, in the experiment we assume that the prediction of number of arrivals p of time t_1 conducted at time t_0 can be written as

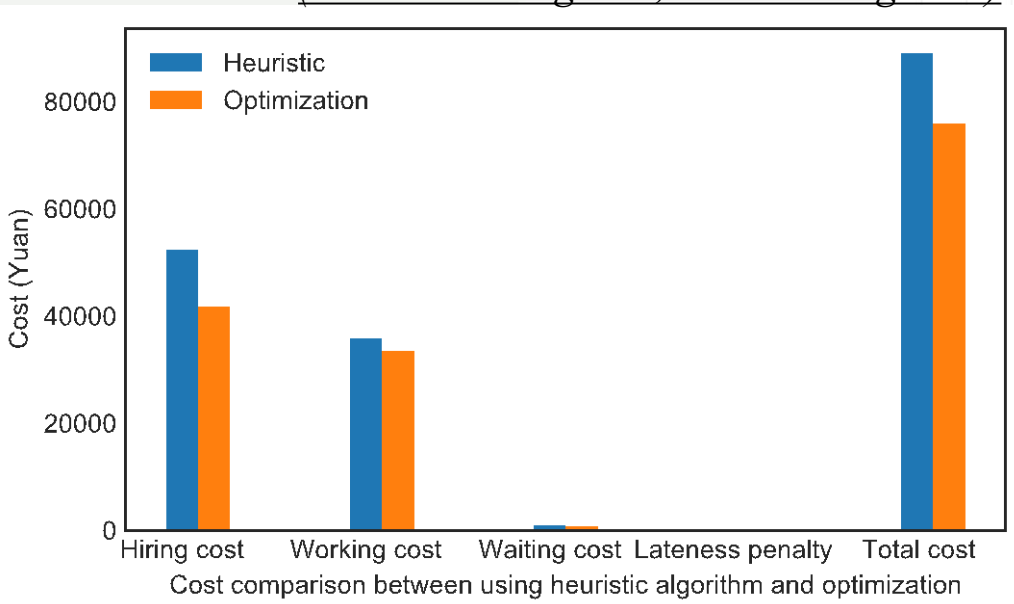
$$p = C * e^{r*(t_1 - t_0)}$$

where $r \sim normal[\mu, \sigma^2]$ and C is the actual number of arrivals at time t_1. μ and σ is set to be 0 and 0.01 in the simulation to generate prediction scenarios.

Experimental Results

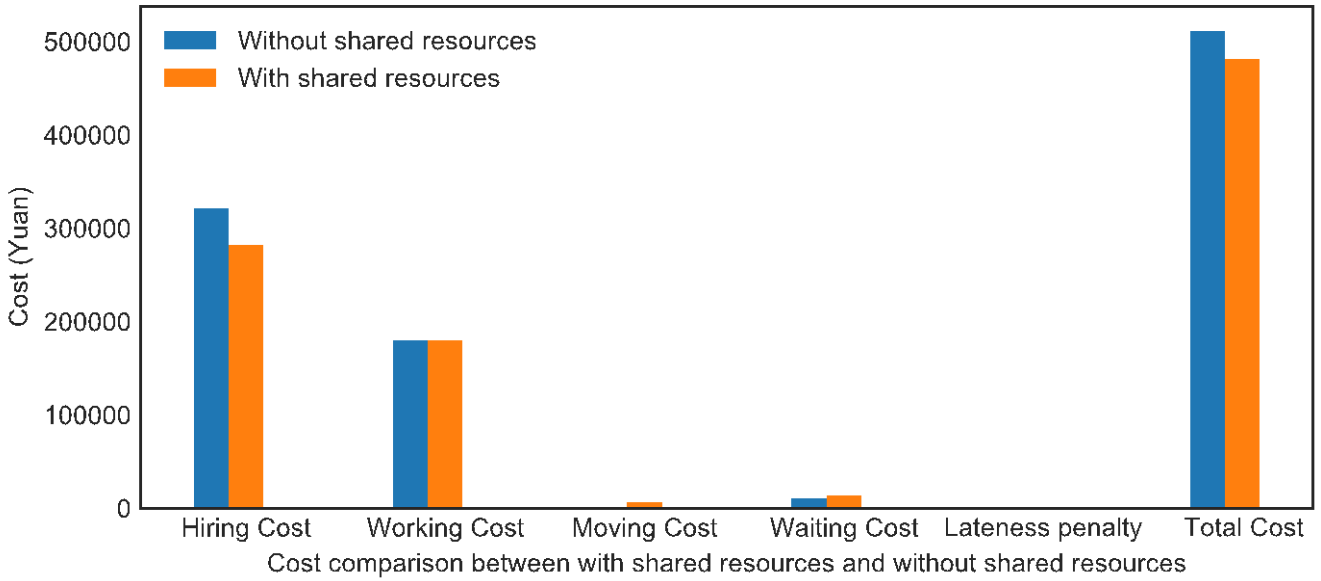
1. Scheduling and allocation costs

(without moving cost, 8 hr working limit)



(a). Allocation within hubs

(with moving cost, 8 hr working limit)



(b). Allocation across hubs

(a). Within a hub, the allocation cost comparisons using optimization and heuristic methods. The heuristic algorithms can achieve near-optimal solution but takes less time for allocations given arrivals of one selected large gateway hub from the logistic company.

(b). Across hubs, the allocation cost comparisons using heuristic methods. Total allocation costs, especially hiring costs are reduced by allowing shared resources moving among the 52 local hubs and gateway hubs.

Experimental Results

Experimental Results

Research in progress

The first stage problem:

$$Min \sum_i \sum_s C_s x_{i,s} + \mathbb{E}[f(X, \Omega)] \quad (1)$$

s.t.

$$\sum_s x_{i,s} = 1 \qquad \forall i \in I \quad (2)$$

Future Research

- Optimization models combing with heuristic algorithms for dynamic resource scheduling and allocation in multiple hyperconnected logistic hubs need to be developed.

- Considerations of different predictive scenarios for decision-making. Stochastic optimization models could be included for combining long-term optimized planning with short-term heuristic adjustments.

- Research on scheduling and allocation algorithms dealing with the combination of multiple kinds of resources in the hyperconnected logistic networks.

- Studies of sequential decision making like reinforcement learning models could be conducted to make reliable and risk-informed decisions under stochastic environment.

Reference

Thank You!