EPFL LUTS

Optimization of multi-modal and multi-purpose transport and logistics systems

Patrick Stokkink

Lecture 12 (Guest lecture)

CIVIL-457

About me

Bachelor and Master in Econometrics and Operations Research

PhD in Transportation (Civil Engineering)

Assistant Professor in Transportation and Logistics

About me

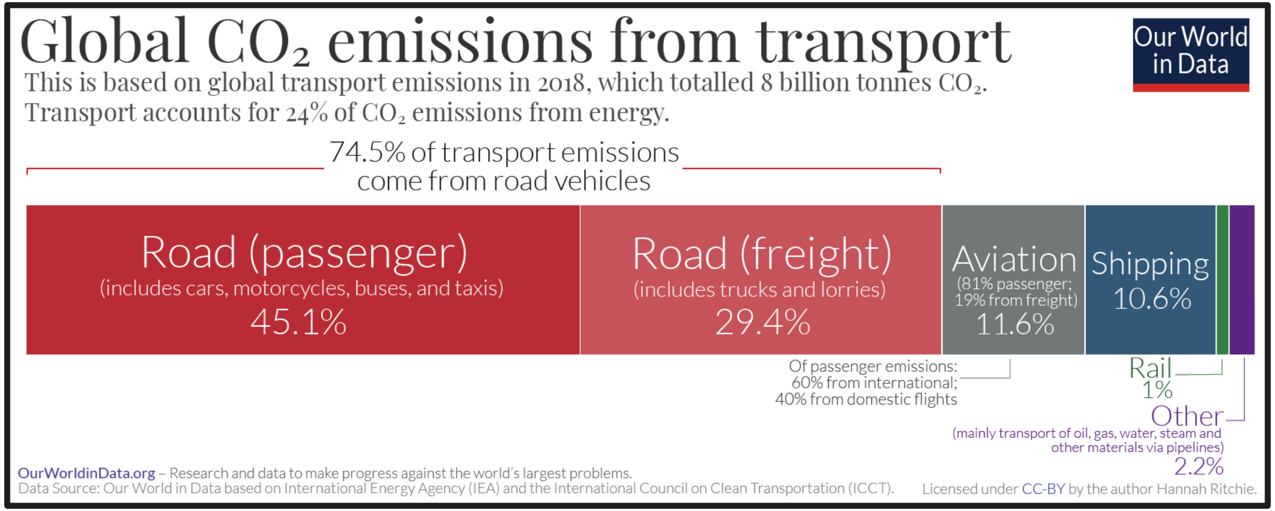
My work:

- Developing innovative and sustainable approaches to last-mile passenger and logistics transport
- Integration of passenger and freight transport
- Large-scale optimization and simulation techniques (Operations Research)

Digesting the title – some definitions

Optimization of multi-modal and multi-purpose **transport and logistics systems**

- In this course, you mainly looked at passenger transport
- Another large share of emissions is produced by logistics transport (= transport of freight or goods)



Digesting the title – some definitions

Optimization of **multi-modal and multi-purpose** transport and logistics systems

- Multi-modal transport: Transportation of goods or passengers by a combination of at least two different modes of transport
- Multi-purpose transport: During your commute, you fulfill another transportation purpose. For example:
  - carpooling (commute + passenger transport)
  - crowd-shipping (commute + goods transport)

Digesting the title – some definitions

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Optimization of multi-modal and multi-purpose transport and logistics systems

Three levels of optimization:

Big-picture and long-term decisions
Limited availability of data
Examples: locating facilities, initial investment in infrastructure

Short-term decisions (months – year)
More but still limited availability of data
Examples: scheduling public transport lines, hiring staff, deploying trucks

Day-to-day operations
Large availability of data (not necessarily full!)
Examples: matching passengers to drivers, determining the truck route

Outline of today

- Differences between passenger and freight transport
- Strategic, operational and tactical decisions in crowd-shipping
- Strategic decisions in multi-modal transport
- Mobility hubs

Differences between passenger and freight transport

Why are we interested?

- Their differences allow to optimize the specific needs of each system
- Differences and similarities can illustrate where the two can be integrated (multi-purpose)

- The same mode may operate differently in different countries
  - In Europe, trains are focused on passenger transport first, and freight transport second
  - In the USA, trains are focused on freight transport first, and passenger transport second

- When two modes of transport are combined in multi-modal transport, the differences effect the way in which they cooperate.

What are the differences?

The answer is rather straightforward:

- Passengers make their own decisions – Goods do not
- Passengers are more flexible in terms of movement
- Passengers are less flexible in terms of time schedules
- Passengers are affected stronger by detours, waiting times, etc.
- Goods always need to be accompanied by someone who transports them (or autonomous vehicles), passengers can travel on their own
- Etc.

What is the effect of these differences?

- In the remainder of the lecture, you will see how these differences can have a key effect on the operations!

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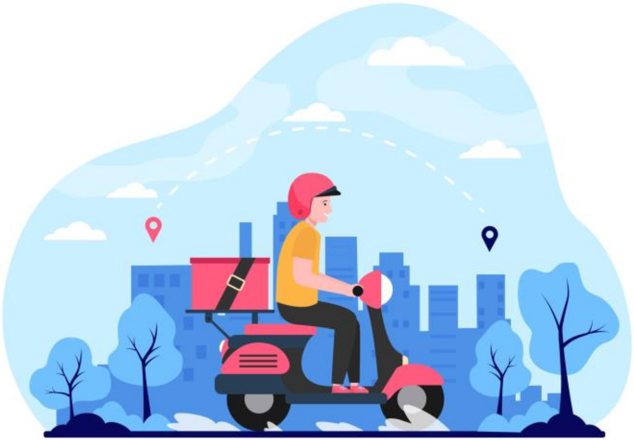
Strategic decisions in a crowd-shipping

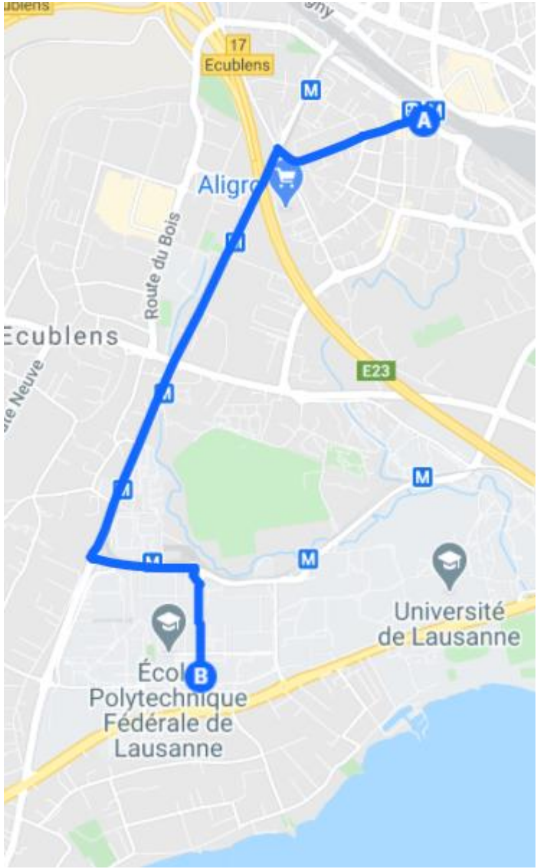


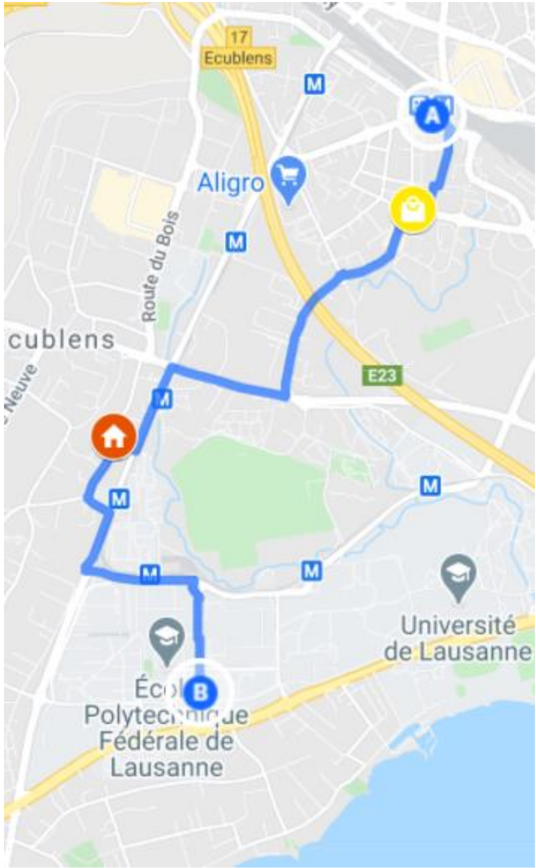
Crowd-shipping

- **Last-mile delivery**: The final part of the journey of a package. Typically, from a warehouse to front door of the customer.
- Last-mile delivery constitutes to the majority of the emissions of the supply chain.

- **Crowd-shipping** or **crowd-sourced last-mile delivery**: Commuters pick up and deliver a package/parcel on their pre-existing routes (possibly with a small detour) and thereby contribute to the last-mile delivery process

Crowd-shipping





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Crowd-shipping

Advantages

- Delivery vehicles are highly polluting and can contribute to congestion in urban areas by causing roadblocks.
  Crowd-shippers can travel by bike or by foot and already have an external travel purpose

- Flexibility: new parcels can be added dynamically, without the constraint of delivery vehicles that need to return to a pickup point
- Cheap: crowd-shippers are typically cheaper than regular staff

Crowd-shipping

What are good locations for pickup points?

- First practice: pickup from stores
- This is problematic if store is at an unfortunate location
- Can we find good intermediate pickup points (depots) to store the parcels for pickup?

Based on:

Stokkink, P., & Geroliminis, N. (2023). A continuum approximation approach to the depot location problem in a crowd-shipping system. Transportation Research Part E: Logistics and Transportation Review

Crowd-shipping

- **Parcel lockers and storage hub locations**
- We already introduced in Switzerland by SwissPost, IKEA and Migros but not combined with crowd-shipping

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Crowd-shipping

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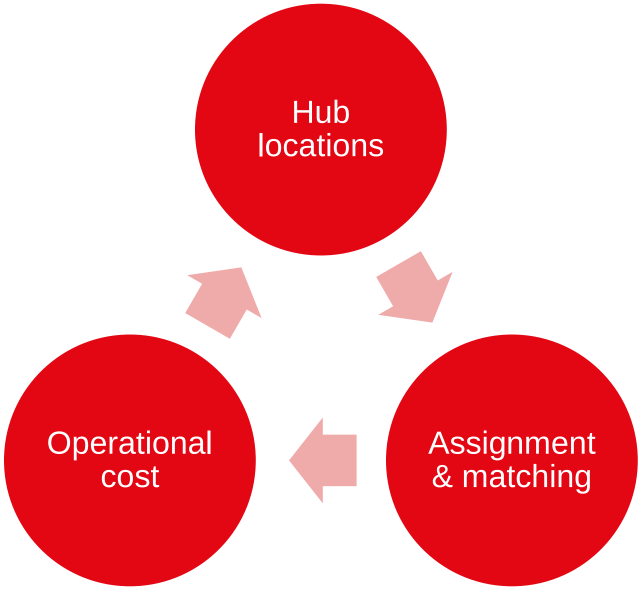
- The idea: parcels are stored at hub locations in the morning and picked up and delivered by crowd-shippers throughout the day
- Question: Where do we construct these lockers?
- Interdependency of operational and strategic decisions



Depot location problem

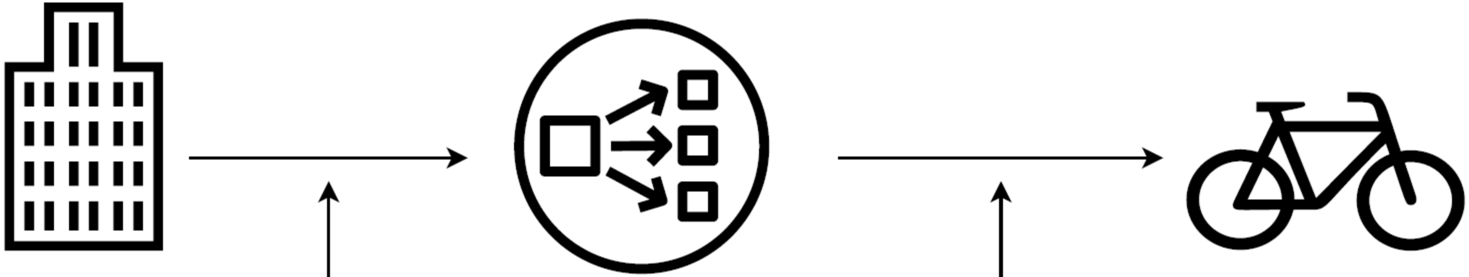
Large Neighborhood Search

Continuum Approximation Approach

(1)
Determine depot locations

(2)
Determine parcel-depot assignment

(3)
Determine crowd-shipper-parcel assignment



Parcel requests are known

Crowd-shippers are known (dynamically)

Depot location problem

Let $\hat{\mu}_r$ be the total demand in region r
Let $v_r(D)$ be the served demand, as approximated through CA
Let a_{rd} be the demand in region r assigned to depot d, as approximated through CA

Fixed depot cost

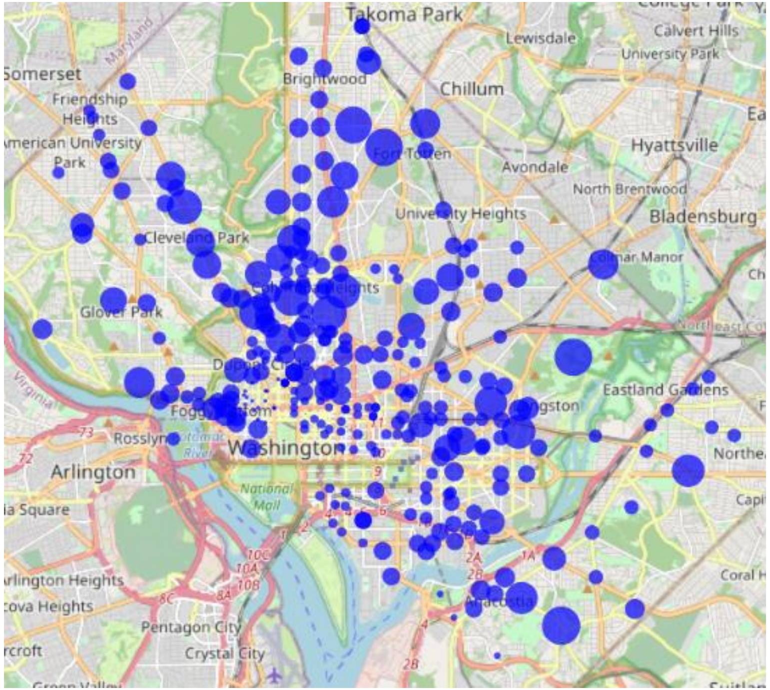
Outsourcing penalty

$$\mathcal{C}(D) = \underbrace{\phi^{\text{depot}}|D|}_{\text{Fixed depot cost}} + \sum_{r \in R} \left[\sum_{d \in D} \phi^{\text{cs}}_{dr} \frac{a_{rd}}{\sum_{d \in D} a_{rd}} \right] v_r(D) + \phi^{\text{reg}} \sum_{r \in R} (\hat{\mu}_r - v_r(D))$$

Distance-based crowd-shipper compensation

Case study

- Case study analysis based on Washington DC
- Demand is proportional to population
  - More demand in the suburbs, less in the city center
- Potential crowd-shippers are generated based on historical data from the Capital Bikesharing system
  - More users in the city center, less in the suburbs
- Our case study captures the asymmetry between supply and demand in realistic networks



Crowd-shipping

Results

- The best location is a trade-off between:
  - Geographically central locations
  - Locations that are on frequently used paths by crowd-shippers
- Usually, the second component is the dominant one!

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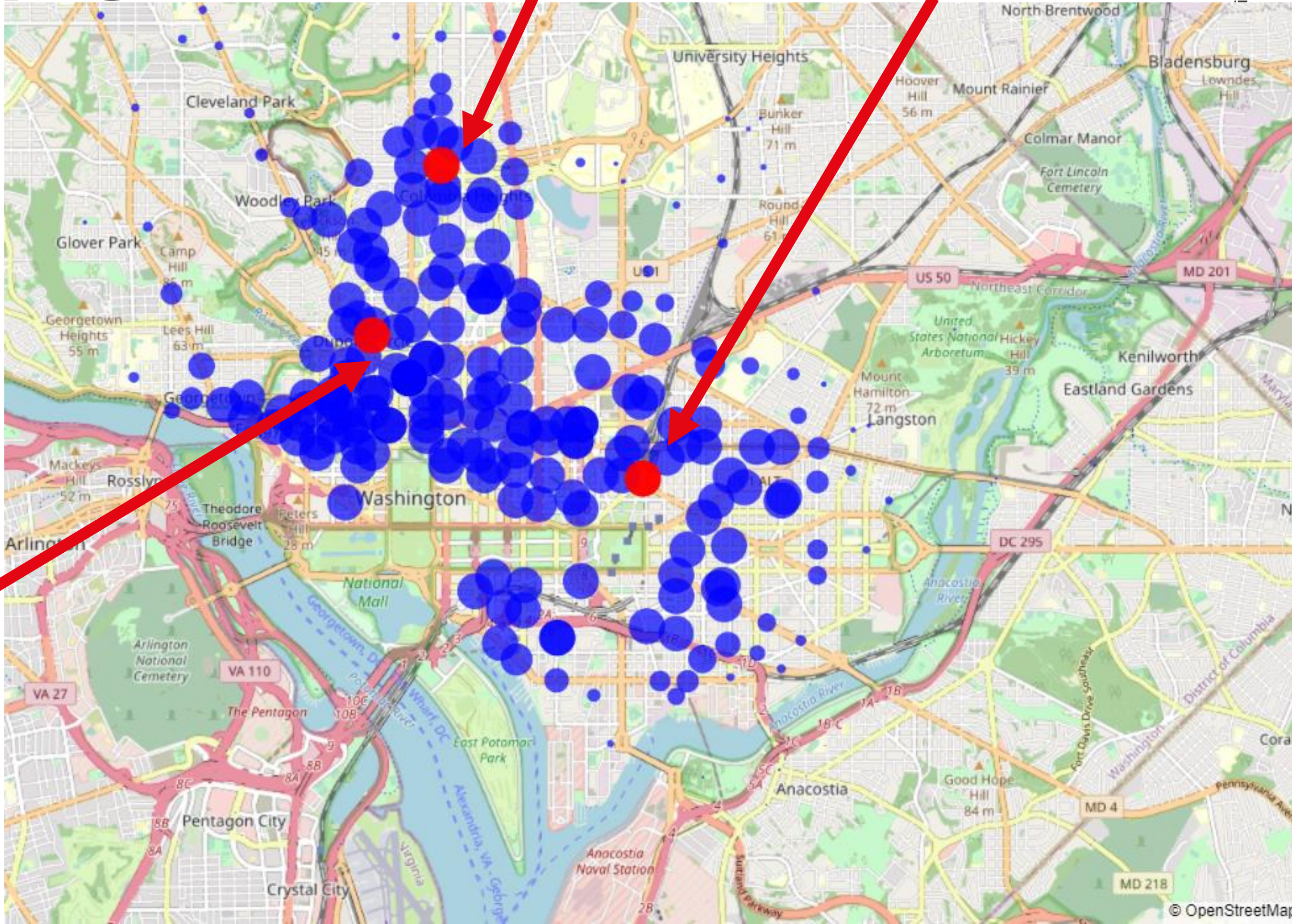
Crowd-shipping

Highly populated area

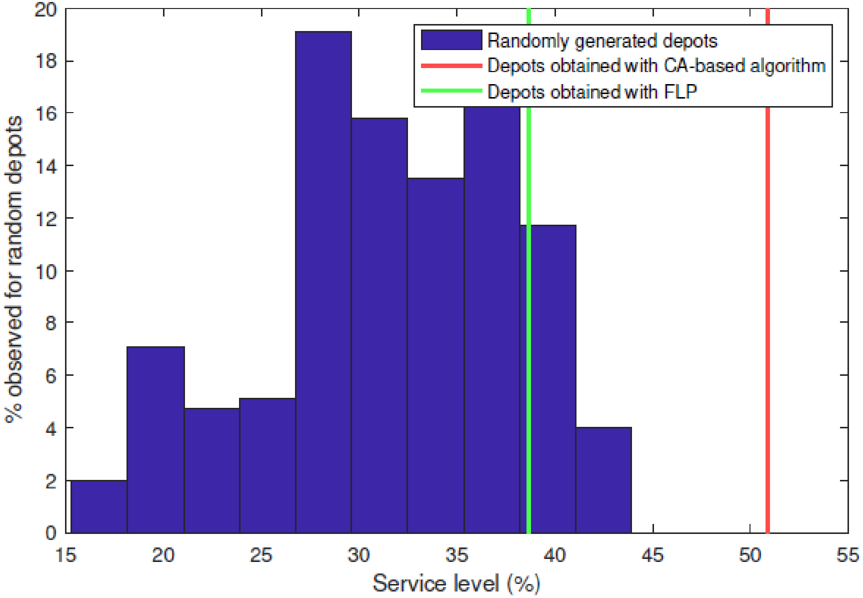
Train station
(high supply)

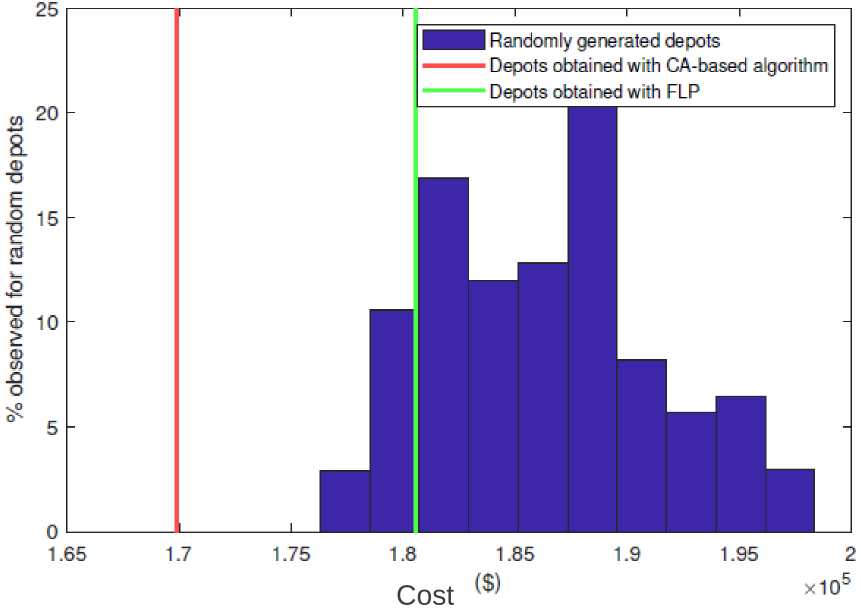


City center
(high supply)

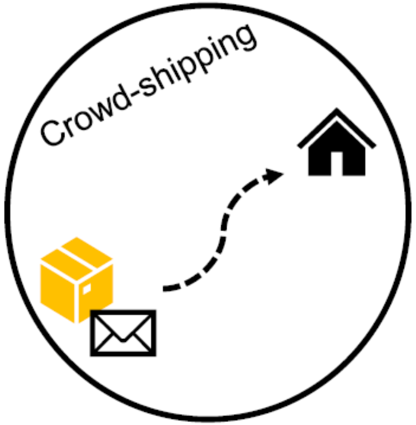
Crowd-shipping

- What if we ignore the knowledge we have on crowd-shipper movement?
- FLP: Facility Location Problem



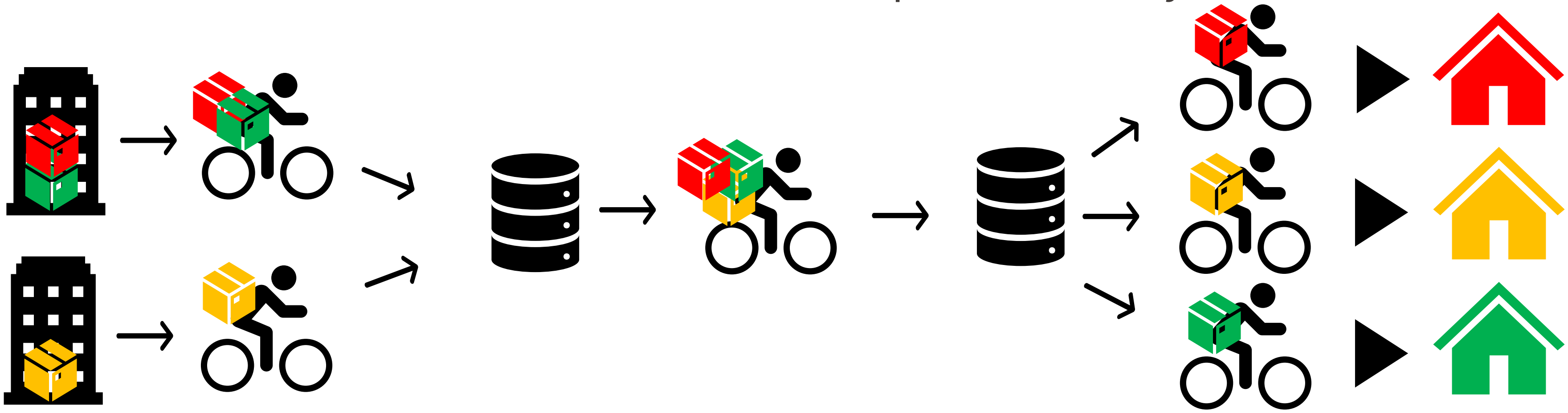


Operational decisions in a crowd-shipping system



Crowd-shipping with transfers

- We consider *bike-based crowd-shipping* in an *urban area*
- Bike trips are usually relatively *short distance*, and cannot go directly from origin to destination
- Various trips can be connected through *transfers* from one crowd-shipper to another
- This can increase the *service level* and improve *efficiency*



Crowd-shipping with transfers

- Highly similar to ride-sharing with transfers
- Can we use the same approach?
- If we allow for more than one transfer, the number of paths grows exponentially

→ We resort to column generation

Definition 2: Parcel Path
A parcel path is the *trajectory that a parcel traverses* to get from its origin to its destination. A parcel path is made up of one or more segments that a parcel travels with a crowd-shipper. Between segments, a parcel can be stored at a transfer point.

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Crowd-shipping with transfers

$$\text{maximize} \sum_{p \in P} \sum_{k \in K_p} \pi_k x_k$$

Maximize profit

$$\text{subject to}$$

$$\sum_{k \in K_p} x_k \leq 1 \qquad \forall p \in P$$

A parcel is delivered at most once

$$\sum_{k \in K} a_{ck} x_k \boxed{\leq 1} \qquad \forall c \in C$$

A crowd-shipper is used at most once

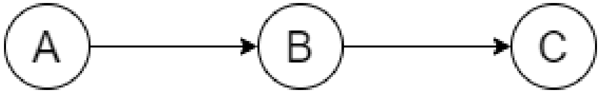
$$x_k \in \mathbb{B} \qquad \forall k \in K$$

This can be relaxed, but is outside the scope of this lecture

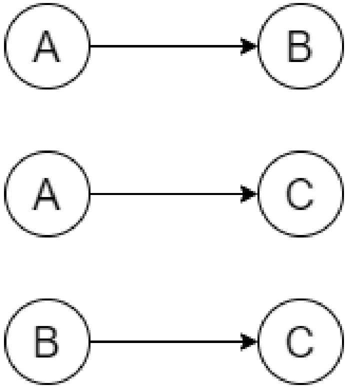
Problem description

Definition 1: Segment
A segment is *a part of a crowd-shippers itinerary* during which they can carry a parcel. A segment has a fixed start time, origin and destination and may incur a small detour on the crowd-shipper, relative to his/her original itinerary.

→ Multiple segments together constitute to a parcel path



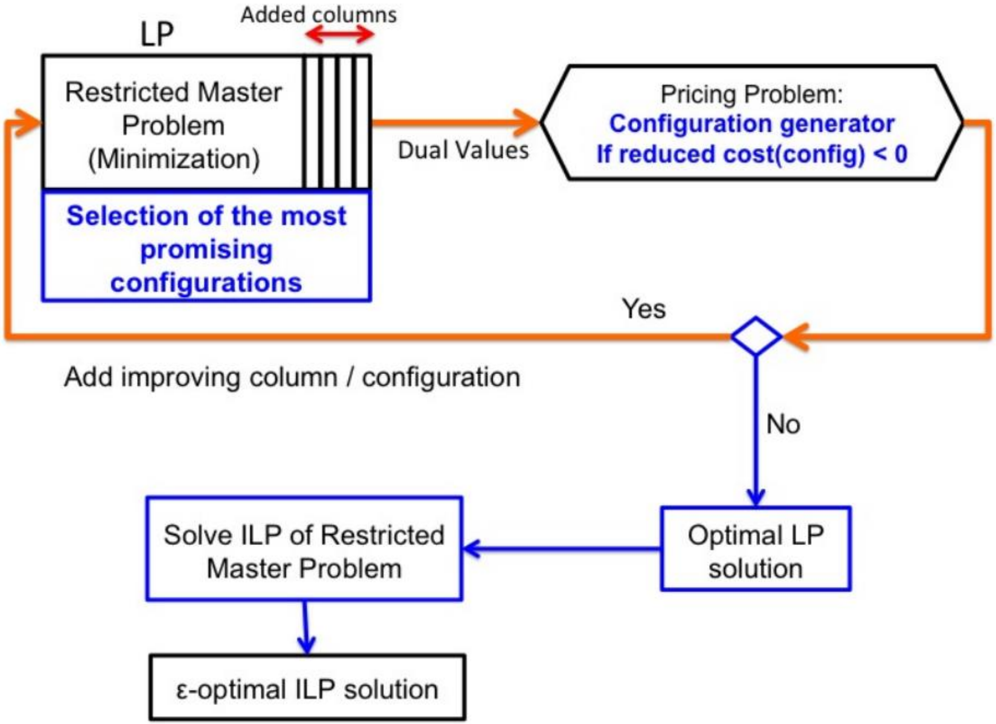
Crowd-shipper route



Segments

Crowd-shipping with transfers

- The details of the column generation approach is outside the scope of the lecture, but the intuition is as follows.

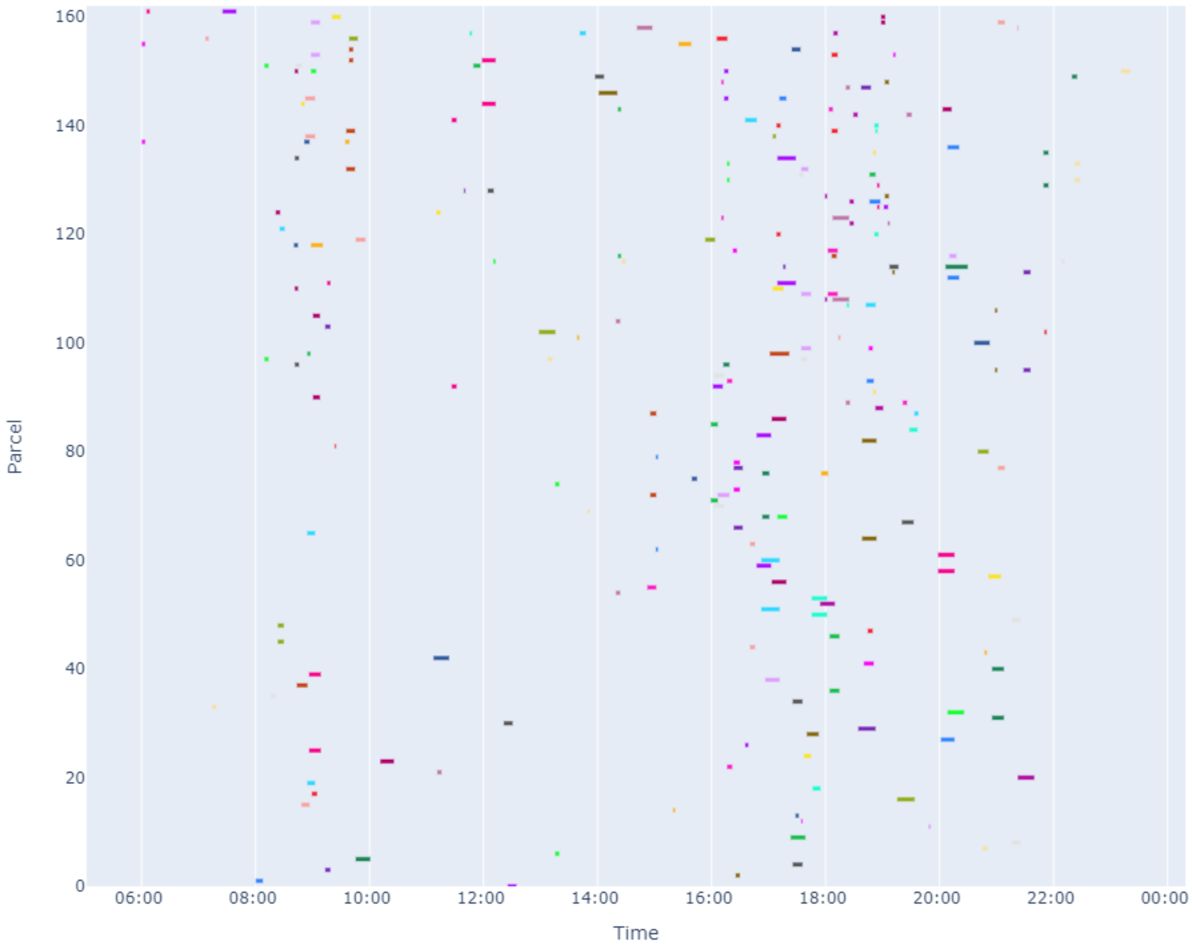


Crowd-shipping with transfers

- The details of the column generation approach is outside the scope of the lecture, but the intuition is as follows.

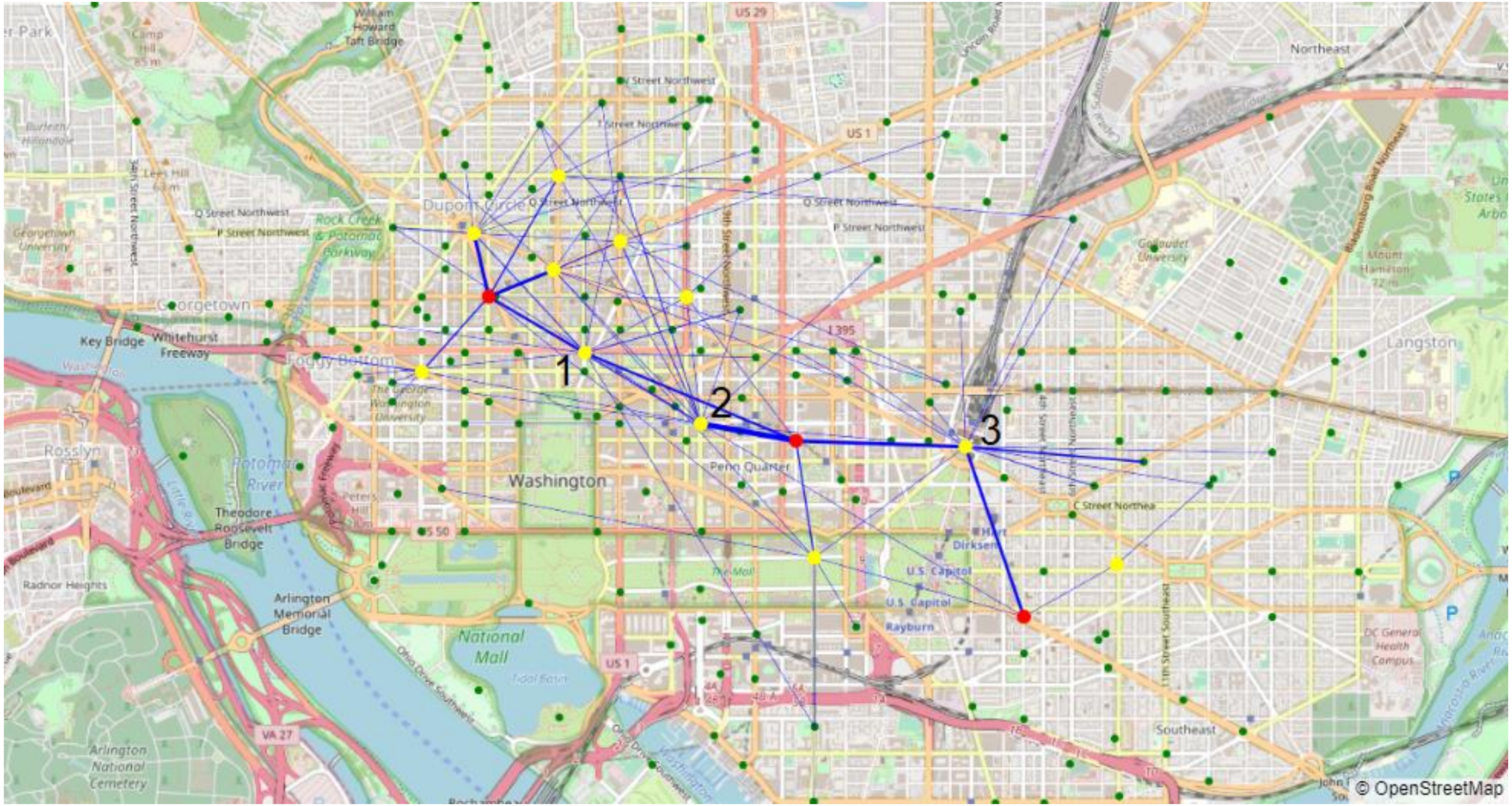
- **Master problem**: Selecting the best parcel paths that satisfy the constraints
- **Pricing problem**: Generating a new parcel path that improves the current solution
  - The pricing problem is equivalent to a shortest path problem on a graph $G = (V, A)$
  - The segments make up the vertices in V
  - If one segment can be executed after the other (in space and time) they are connected by an arc in A

Spatio-temporal analysis



Spatio-temporal analysis

Red = origin/depot/store
Yellow = transfer hub
Green = destination



Results

- Column (and row) generation allows to rapidly solves the problem close to optimality
- Transfers can gain 30% in revenue and service level, and increased capacity can increase it by another 40%

- Our global approach outperforms locally optimal assignment strategies by 25%.
  - Coordination between crowd-shippers is extremely important!

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Tactical decisions in a crowd-shipping system

Pricing of on-demand mobility

- Demand can be increased by positive rewards (incentives, subsidies) or decreased by negative rewards (taxes)
- How is this used in on-demand mobility:
  - Stimulate ride-hailing users to share a trip
  - Stimulate car users to ride-share
  - Stimulate commuters to participate as a crowd-shipper
  - Etc.
  - Can you think of something else?

Price & reward strategy in a crowd-shipping system

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Idea:

- A driver arrives
- A reward/price is offered to the driver in return for executing the job
- The driver can choose to accept or decline

What is the trade-off?

- If the reward is high, many people accept, but the costs are high
- If the reward is low, costs are low, but few people accept, some jobs remain unexecuted

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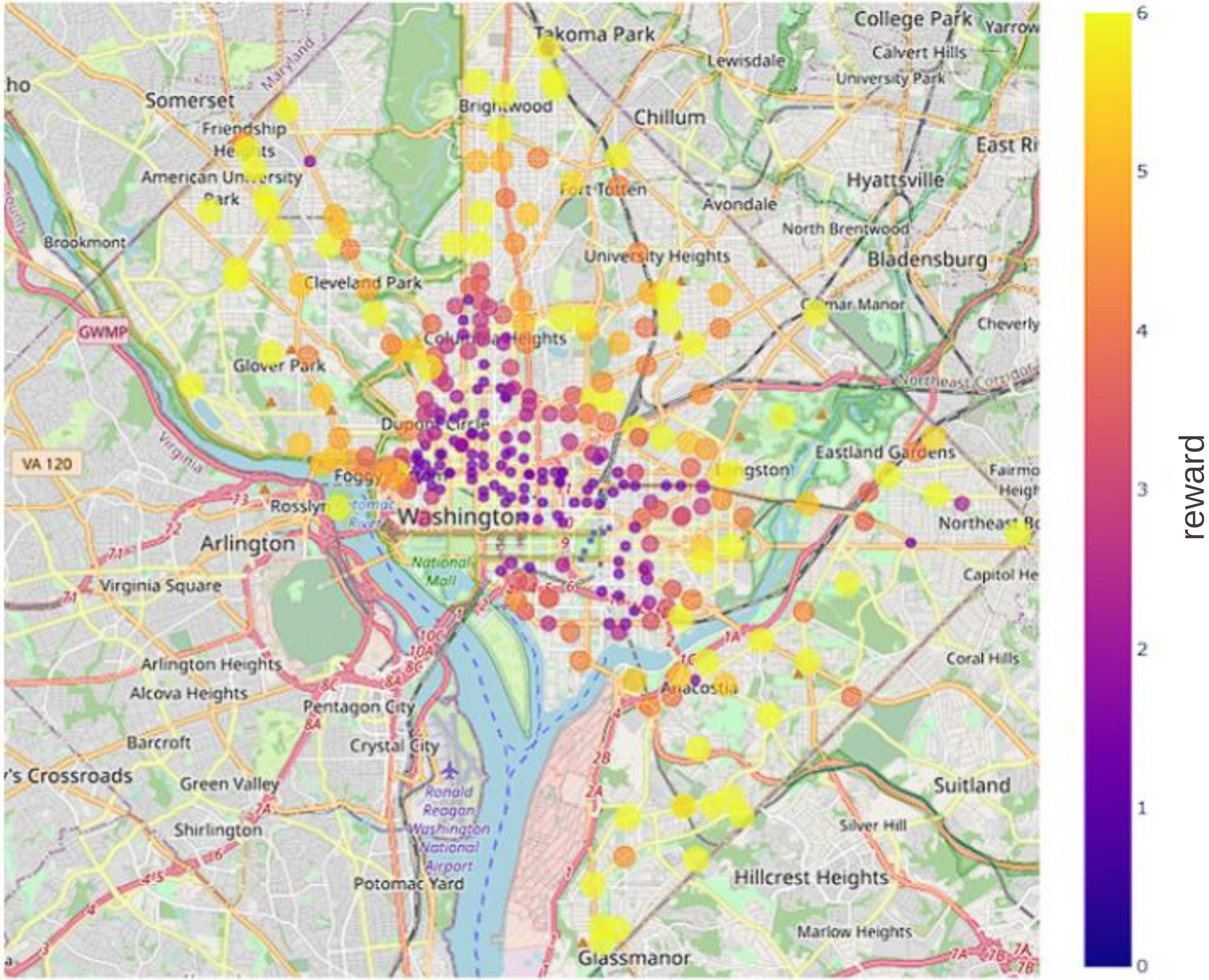
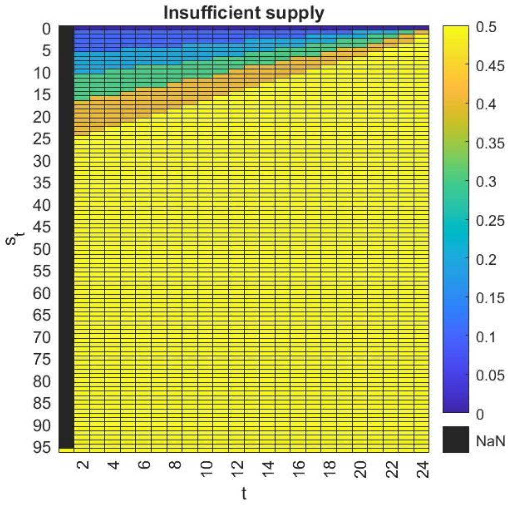
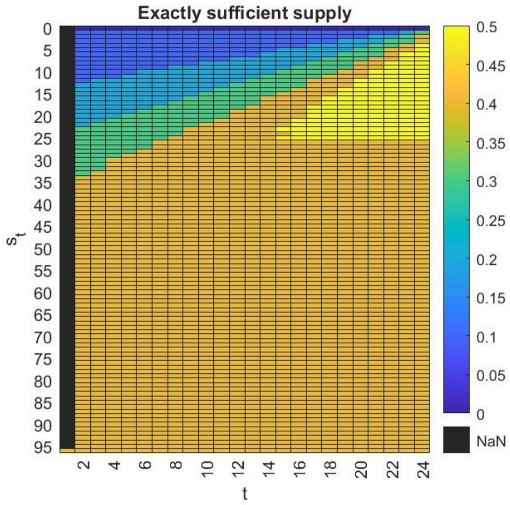
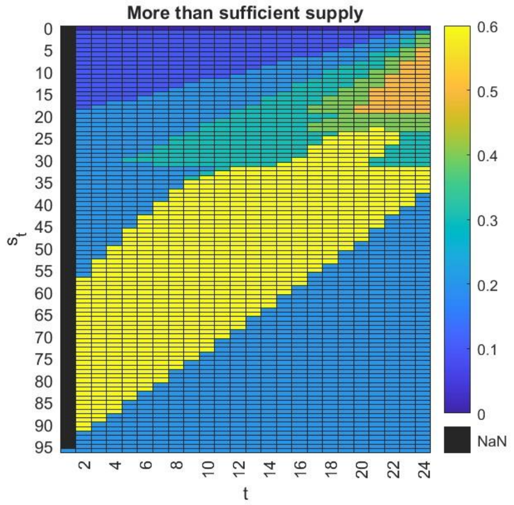
If we apply these tools to the Washington DC case study from before…



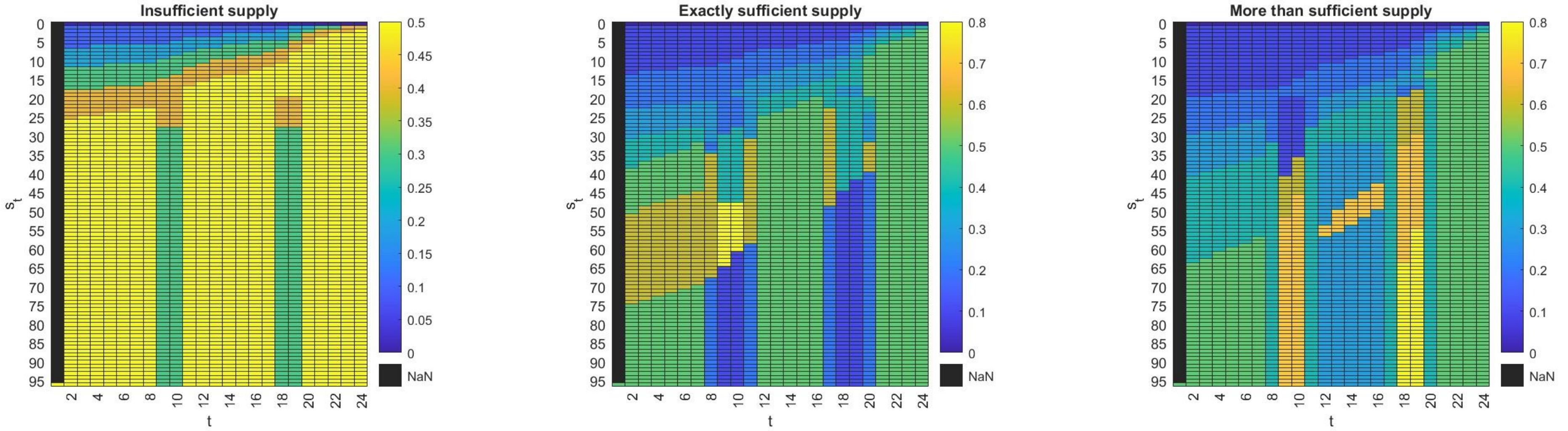
Rewards over time if number of crowd-shippers is constant







Rewards over time if number of crowd-shippers changes during the day



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Multi-modal transportation

Multi-modal transport

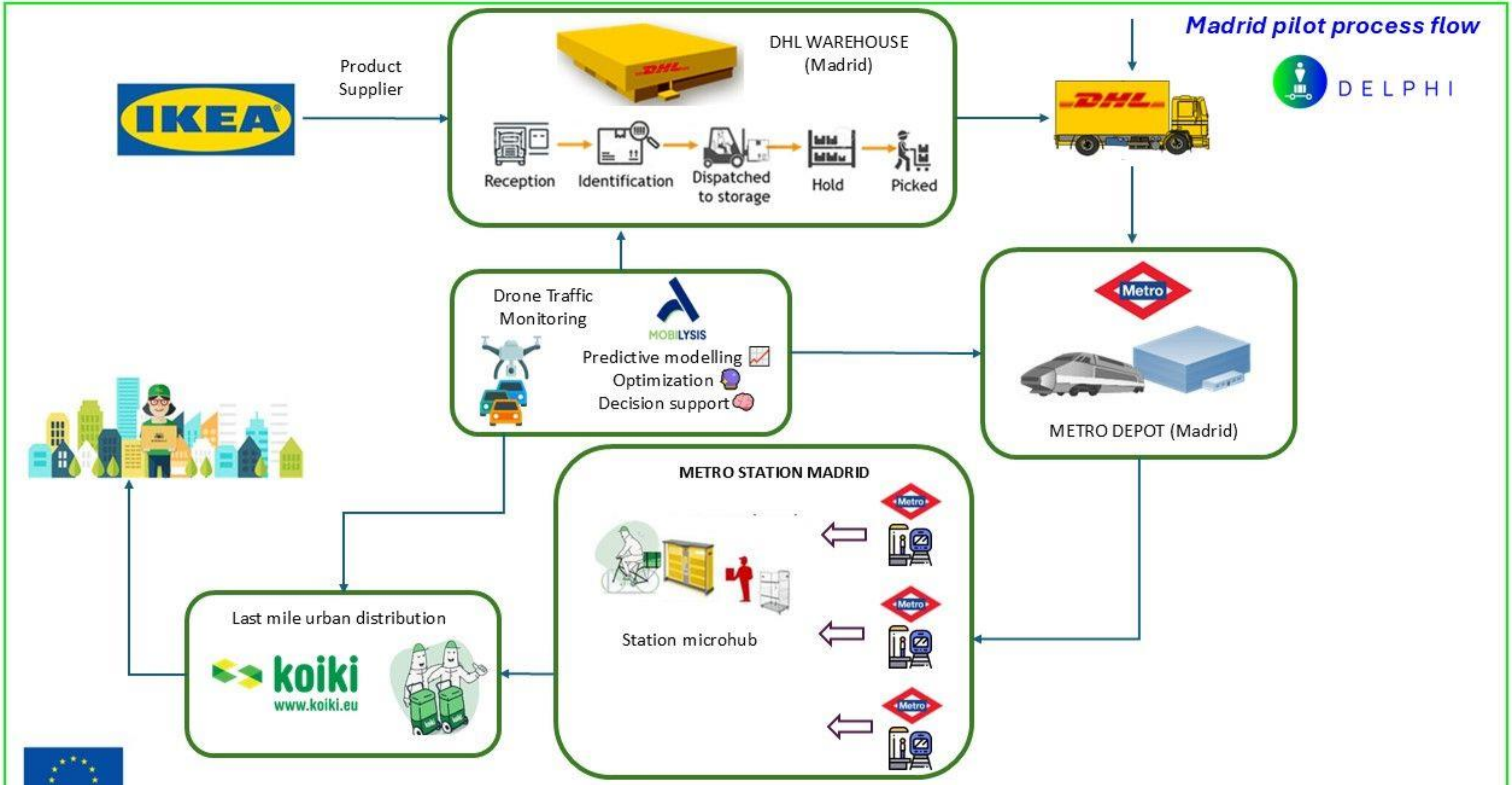
- **Definition:** Transportation of a single product by at least two modes of transportation

- Common for long-haul transportation, for example:
  - First ship, then truck
  - Firt plane, then truck
- Less common for short-haul (last-mile) transportation.
  - Traditionally: Trucks are used
    - Pro: Efficient
    - Con: Polluting and undesirable presence in cities
  - New alternative: Micro-delivery
    - Pro: Not polluting, more sustainable
    - Con: Less efficient

Multi-modal transport

- Multi-modal transport in last-mile delivery can use the benefits of both these options, while avoiding their downsides.

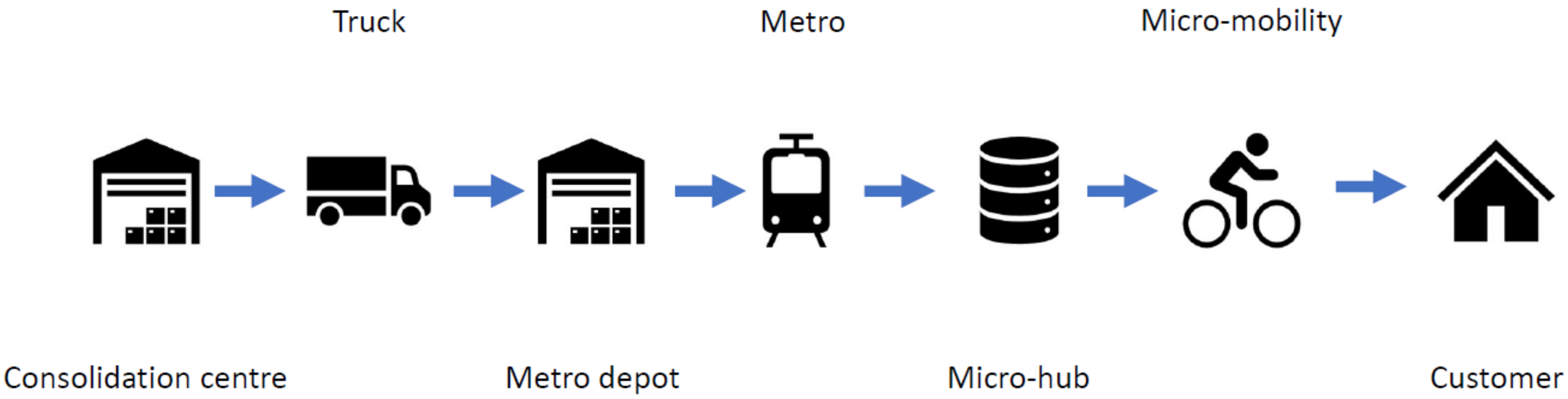
- One example: DELPHI EU project



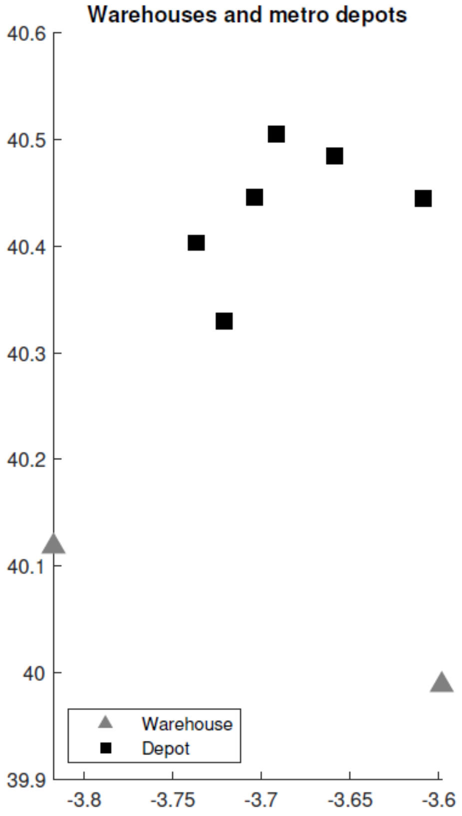
Funded by the European Union

DELPHI project has received funding under grant agreement No 101104263. It is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

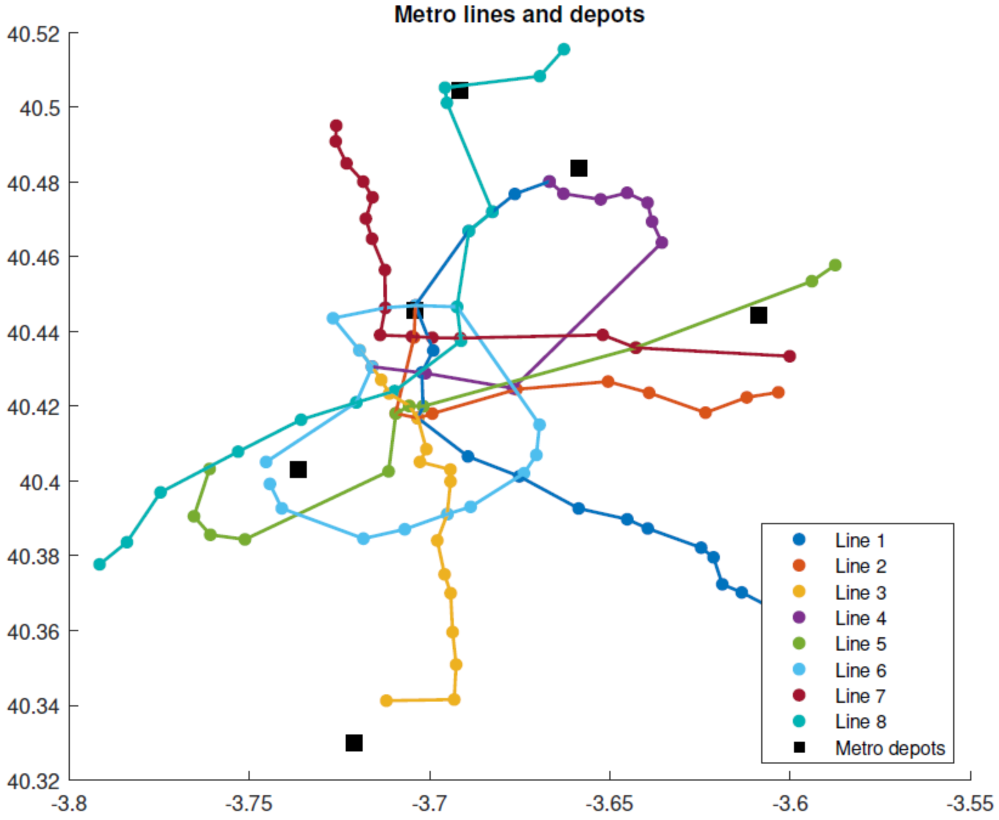
Strategic decision: Where to open micro-hubs



The network



Warehouses and metro depots
40.6
40.5
40.4
40.3
40.2
40.1
40
39.9
-3.8
-3.75
-3.7
-3.65
-3.6
Warehouse
Depot



Metro lines and depots
40.52
40.5
40.48
40.46
40.44
40.42
40.4
40.38
40.36
40.34
40.32
-3.8
-3.75
-3.7
-3.65
-3.6
-3.55
Line 1
Line 2
Line 3
Line 4
Line 5
Line 6
Line 7
Line 8
Metro depots

Simulated results

Table 1: Comparison of multi-modal to traditional delivery

Truck	MD	Truck cost (€)	MD cost (€)	Total cost (€)	Emissions (CO2 KG)	Staff	KM/Staff
Multi-modal							
small	foot	2017.25	6457.30	8474.55	430.83	154	20.97
small	bike	1861.32	2183.45	4044.77	397.52	52	63.62
large	foot	1942.36	6561.67	8504.03	323.73	153	21.44
large	bike	1904.54	2164.36	4068.90	317.42	54	60.73
Traditional							
small		4803.87		4803.87	1025.97		
large		5101.88		5101.88	850.31		

Exercises: Easy ways for location decisions

Simulated results

Table 1: Comparison of multi-modal to traditional delivery

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Traditional							
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large		5101.88		5101.88	850.31		

Thank you!

Now: Time for questions

Next hours: Exercises

For questions later, don't hesitate to email me
p.s.a.stokkink@tudelft.nl or the TA's

If this topic interested you and you want to know more or work on this yourself, contact me at:

p.s.a.stokkink@tudelft.nl