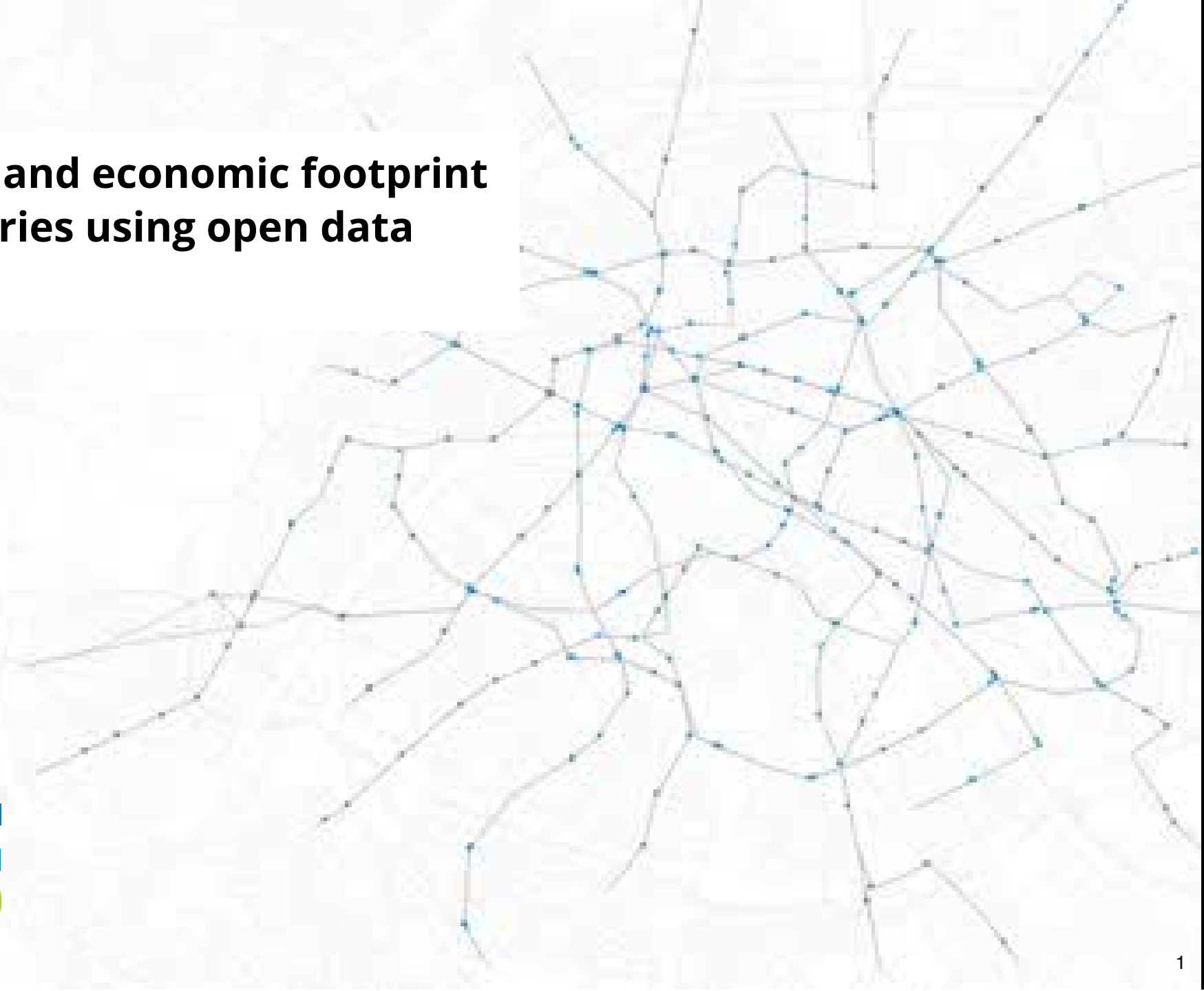
Modelling the ecological and economic footprint of last-mile parcel deliveries using open data

A case study for Lyon

Sebastian Hörl

6 December 2023

NSL Colloquium, Zurich



LEAD Project

***L**ow-**e**mission **A**daptive last-mile logistics supporting on-demand economy through **D**igital Twins*

- H2020 Project from 2020 to 2023
- Six living labs with different innovative logistics concepts
  - Lyon, The Hague, Madrid, Budapest, Porto, Oslo
  - One partner for implementation and one for research each
- Development of a generic modeling library for last-mile logistics scenario simulation and analysis

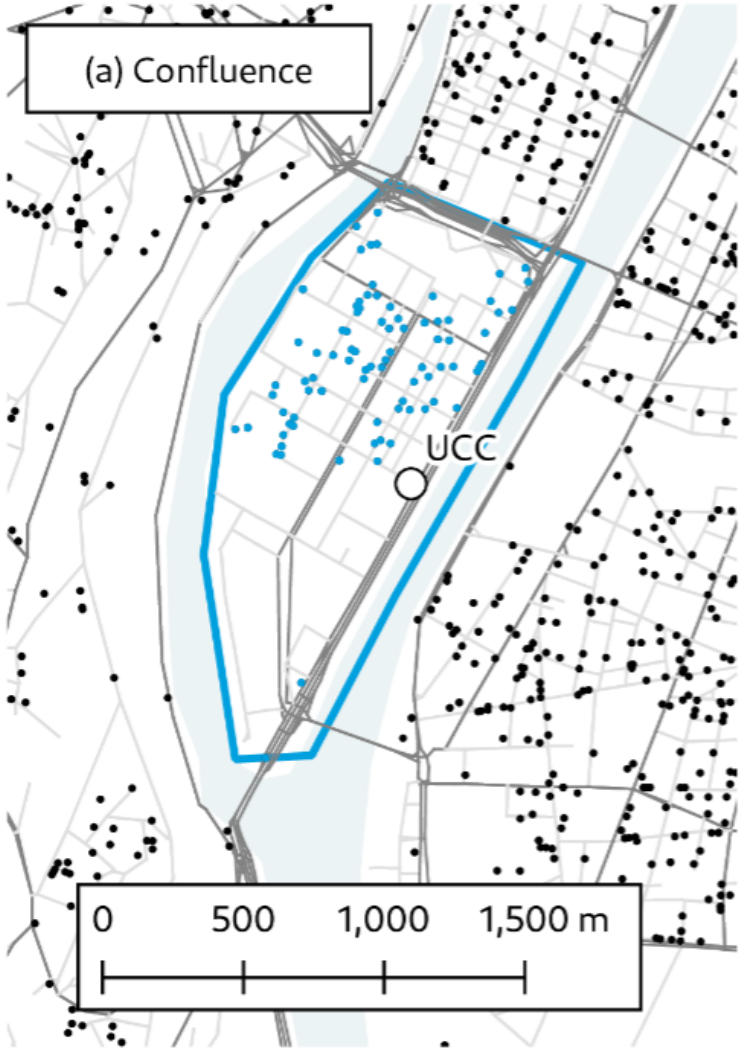
https://www.leadproject.eu/

Lyon Living Lab

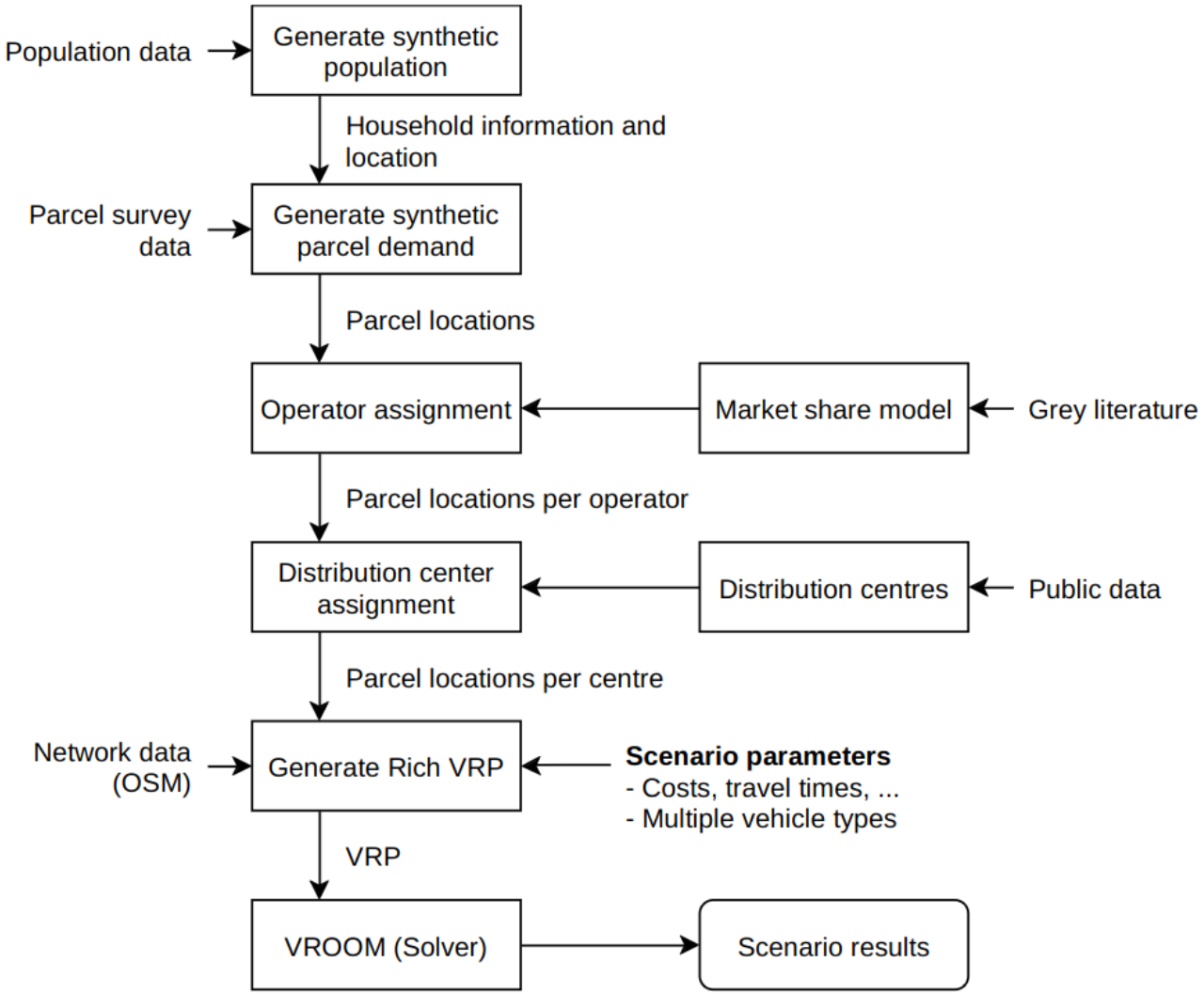
- Implementation of an urban consolidation centre (UCC) to collect the flow of goods and organize last-mile distribution

- Due to data availability
  - Focus on large-scale analysis
  - Focus on B2C parcel deliveries

- Research questions
  - What is the (approximate) impact of daily parcel deliveries in a Metropolitan area like Lyon in terms of emissions and energy consumption?
  - Which effects do specific interventions have?



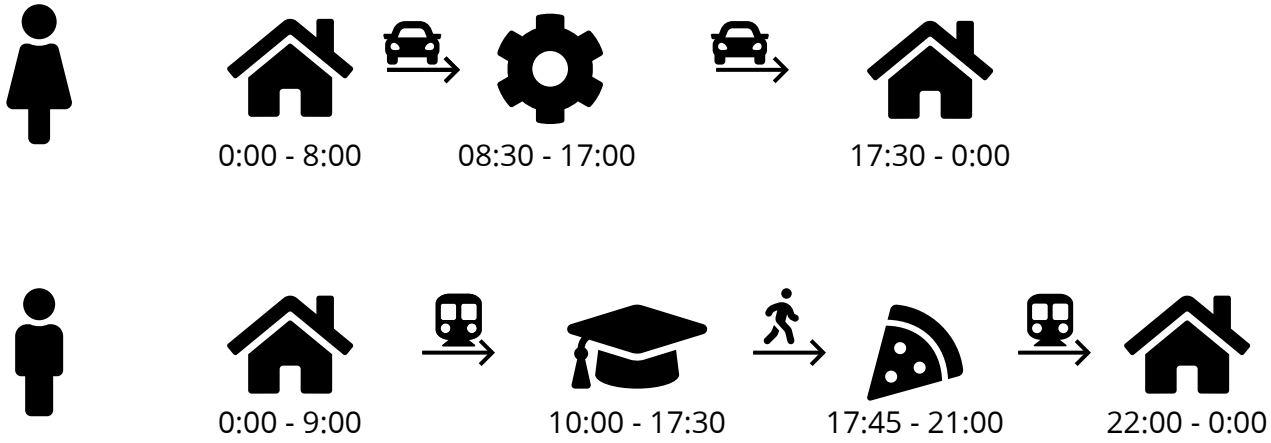
Methodology: Overview



Methodology: Synthetic travel demand

Synthetic travel demand has been generated for Lyon in order to perform agent-based mobility simulation of all residents' movements.

- Population census (RP)
- Income data (FiLoSoFi)
- Commuting data (RP-MOB)
- EDGT
- National HTS (ENTD)
- Enterprise census (SIRENE)
- Address database (BD-TOPO)
- OpenStreetMap
- GTFS (SYTRAL / SNCF)



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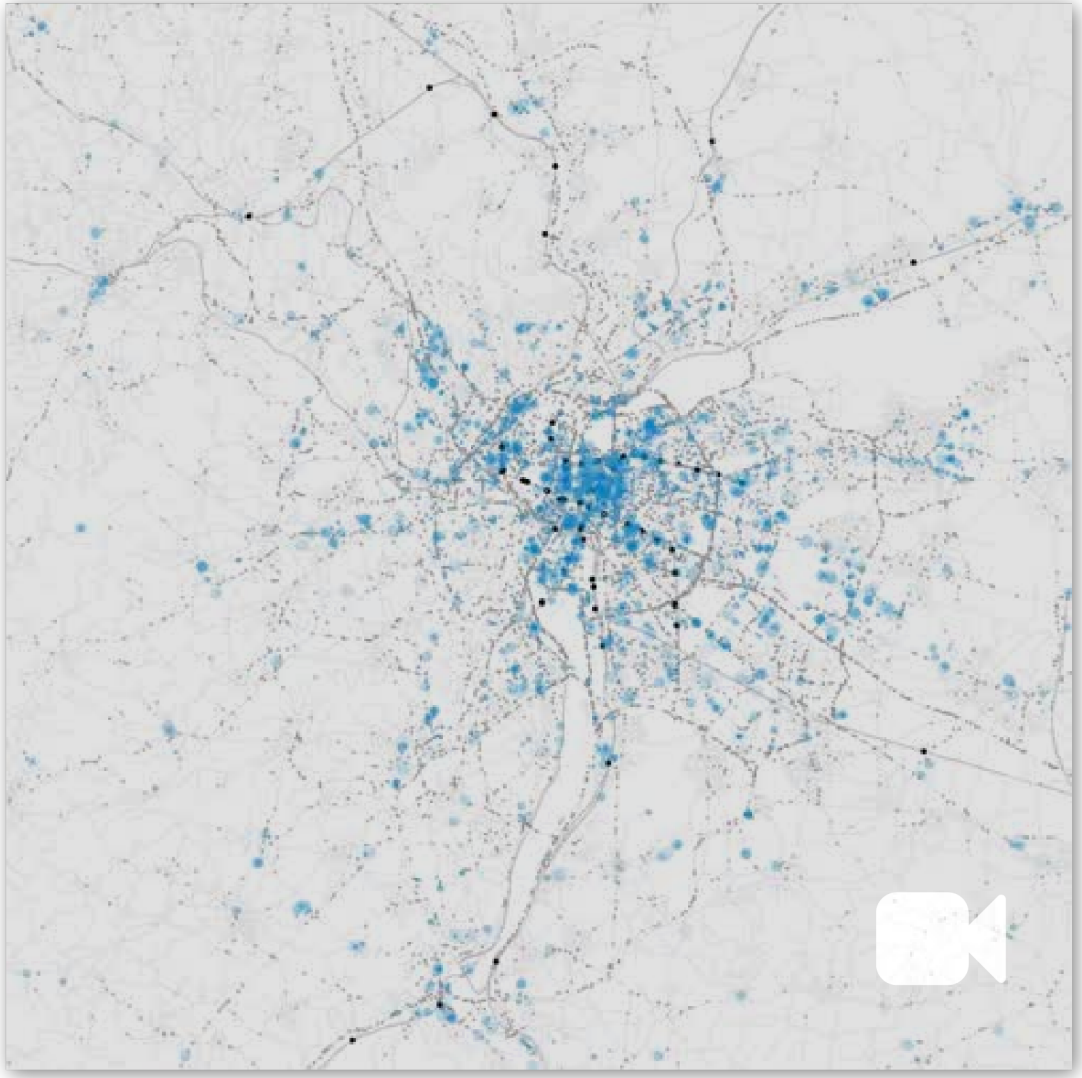

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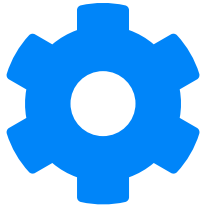
Open Data

+



Open Software

=

Reproducible research

Integrated testing

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Open Data

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Synthetic population and travel demand for Paris and Île-de-France based on open and publicly available data

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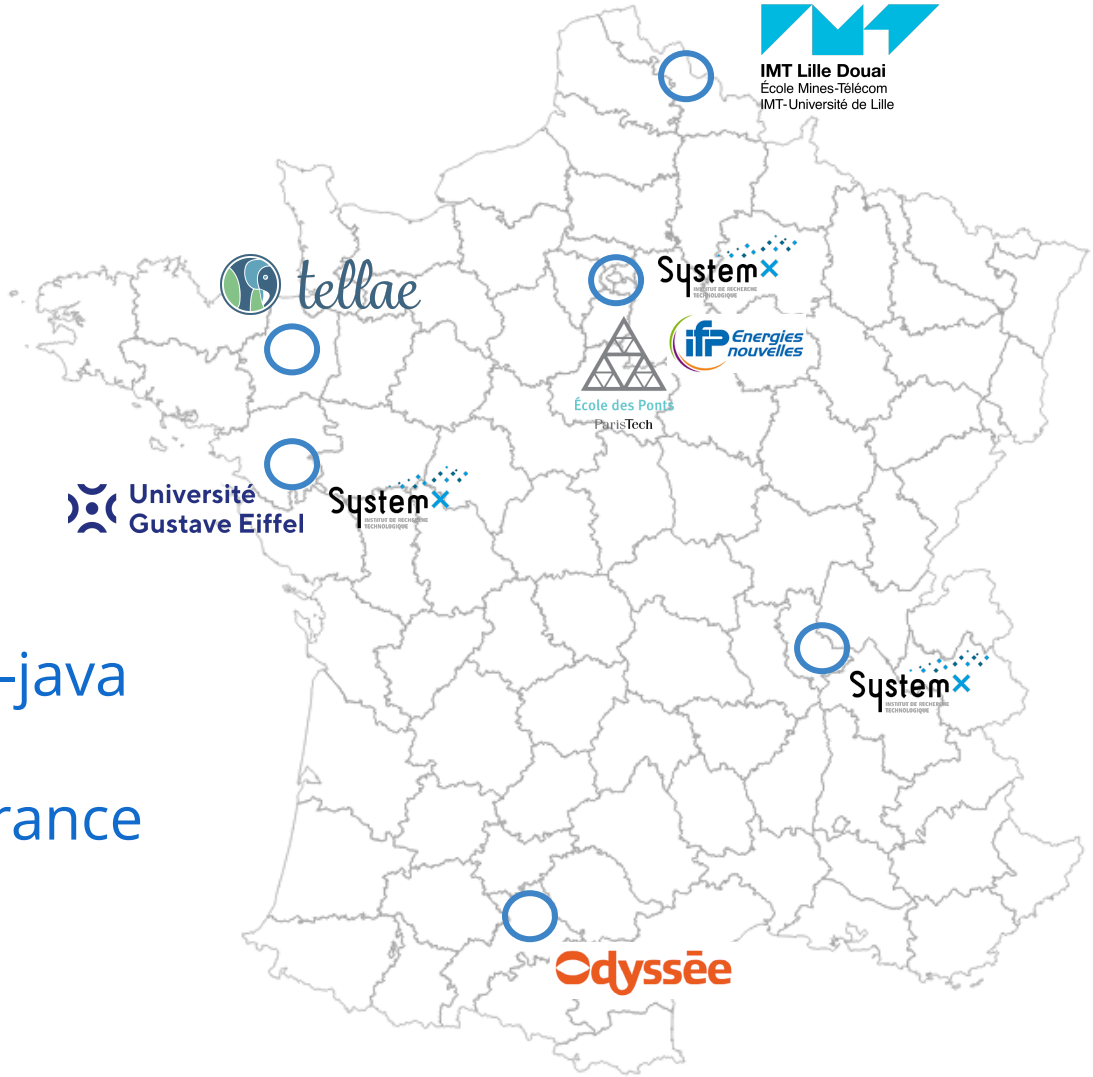
ABSTRACT

Synthetic populations of travelers and their detailed mobility behavior are an important basis for agent-based transport simulations, which are increasingly used in transport planning and research today. To date, research based on such simulations is rarely replicable as it is based on proprietary data and tools. To foster the discussion and steer research towards reproducible transport simulations, this paper introduces a process for generating a synthetic travel demand

Methodology: Synthetic travel demand



eqasim-org/eqasim-java

eqasim-org/ile-de-france

Methodology: Parcel demand

Based on sociodemographic attributes of the households, parcels are generated for the city on an average day.

Synthetic population

+

Out-of-home purchase survey

Achats découplés des ménages

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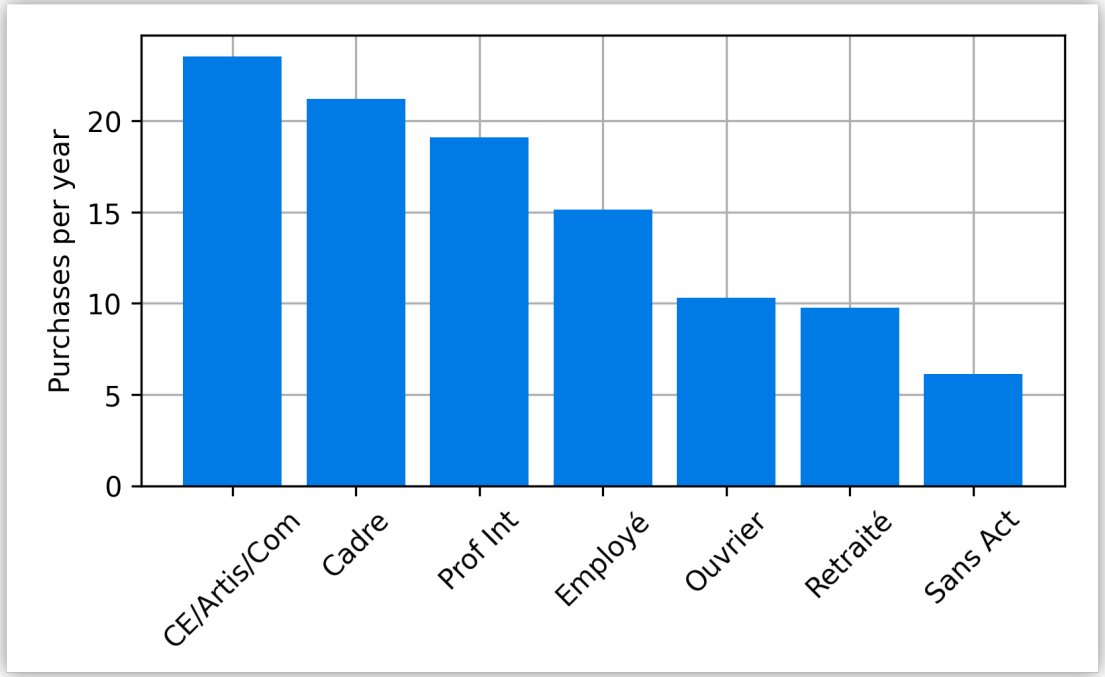

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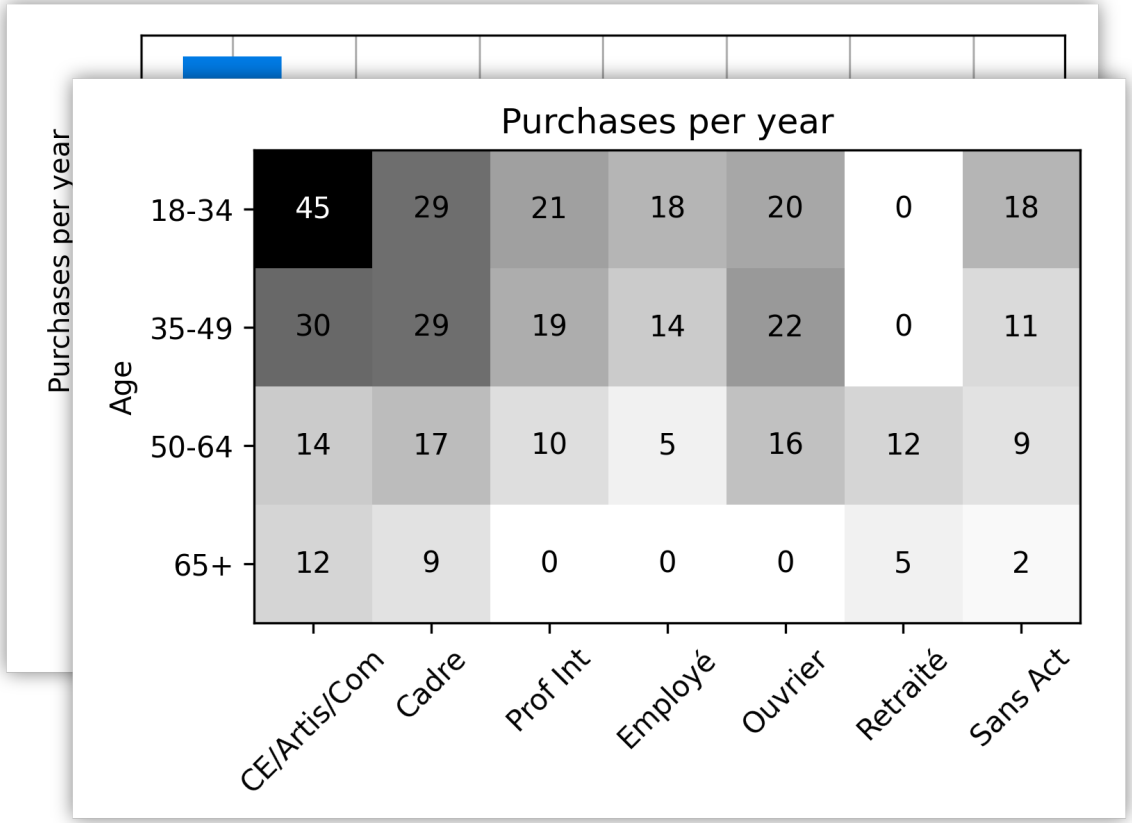

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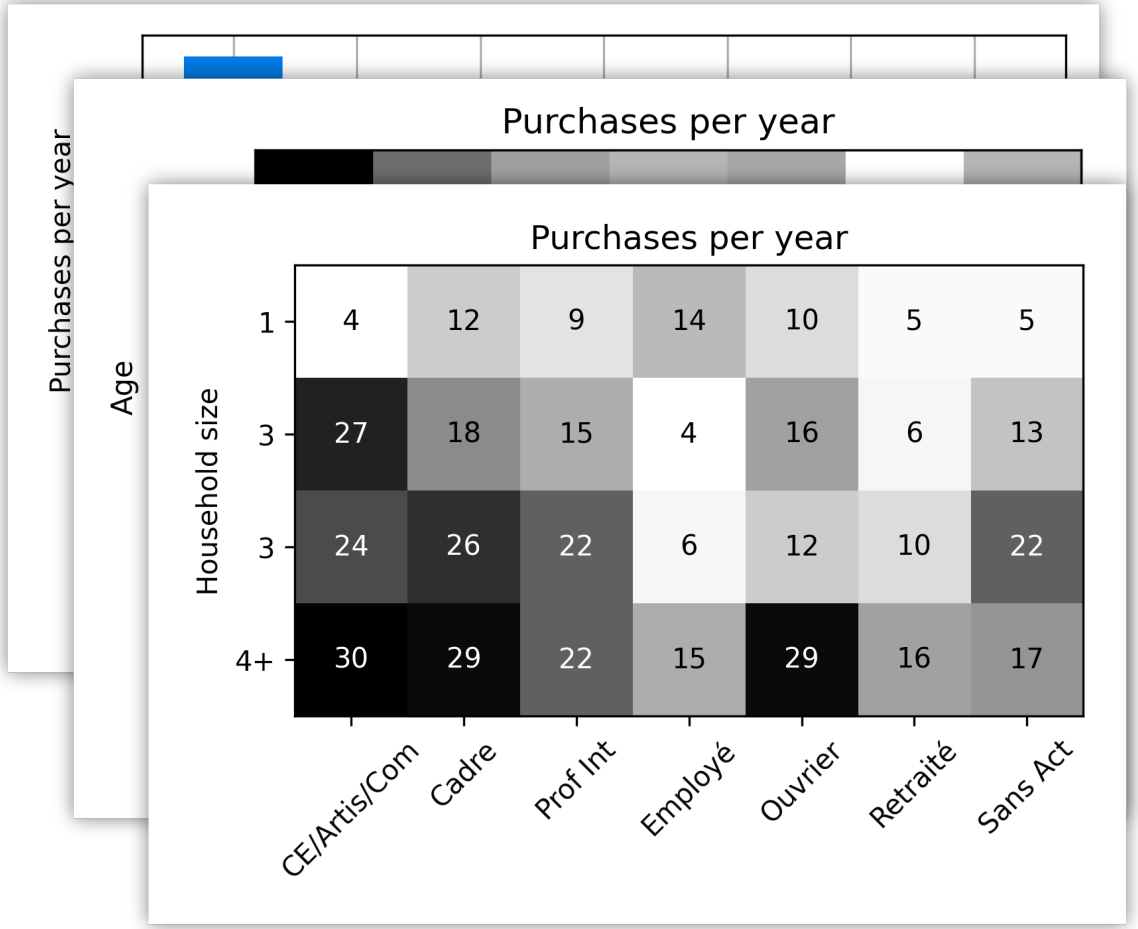

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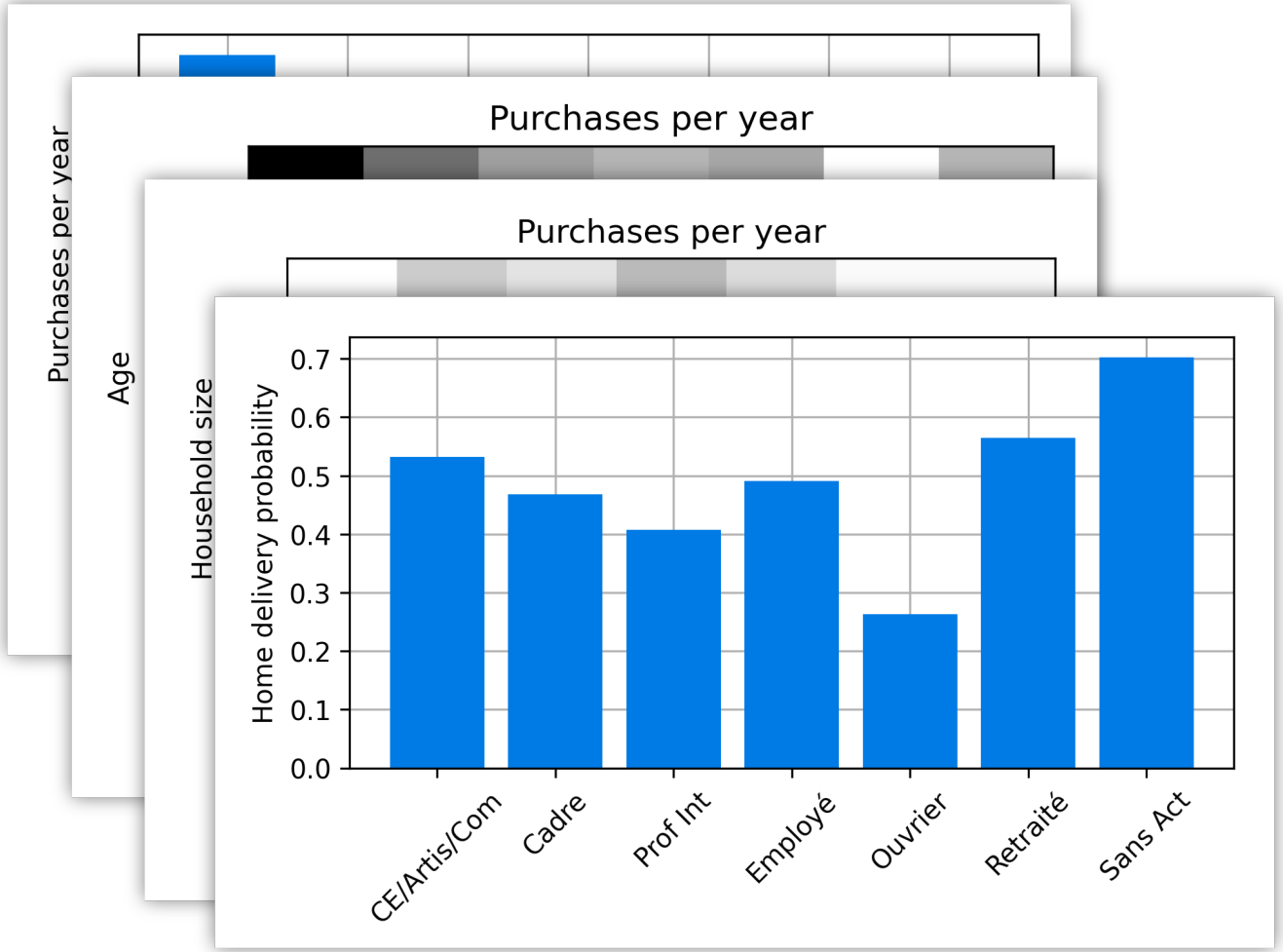

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Iterative proportional fitting (IFP)

- Based on synthetic population, find average number of purchases delivered to a household defined by *socioprofesional class*, *age of the reference person* and *household size* per day.

$$\sum_{a \in \mathcal{A}} n_{a,h,s} \cdot w_{a,h,s} = C_{h,s} \quad \forall s \in \mathcal{S},\ h \in \mathcal{H}$$

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$$\sum_{a \in \mathcal{A}} \sum_{h \in \mathcal{H}} \sum_{s \in \mathcal{S}} n_{a,h,s} \cdot w_{a,h,s} = C \longrightarrow \mu_{a,h,s} = d_s \cdot \frac{w_{a,h,s}}{365}$$

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Maximum entropy approach

- We now the average number of parcels, but we do *not* now the distribution of the *number of parcels* for a household on an average day.
- We know it must be non-negative, and we know the mean.
- Without additional data, we assume maximum entropy distribution, which is Exponential in this case.

$$F(N \leq n) = \text{Pois}(\mu)$$

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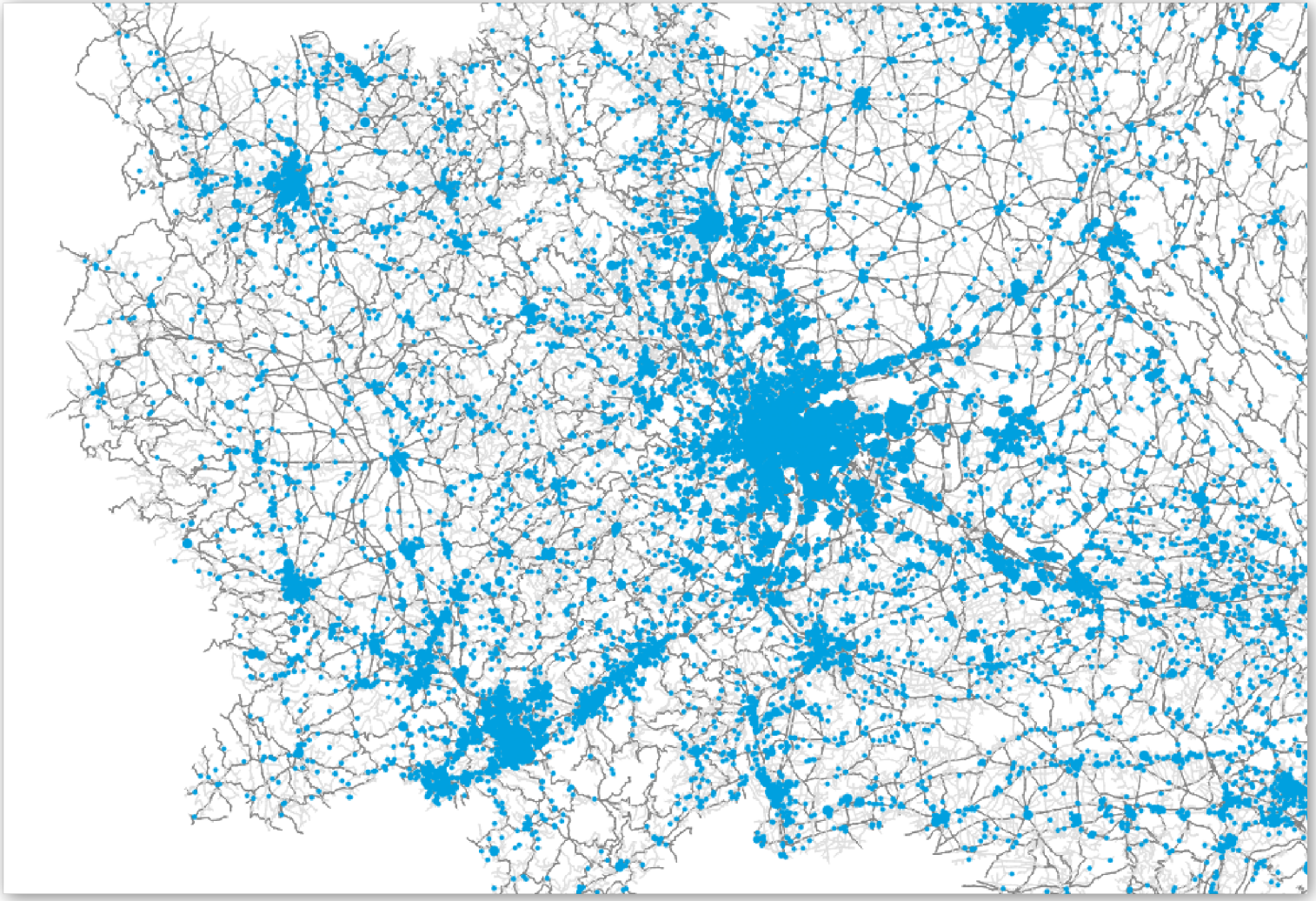

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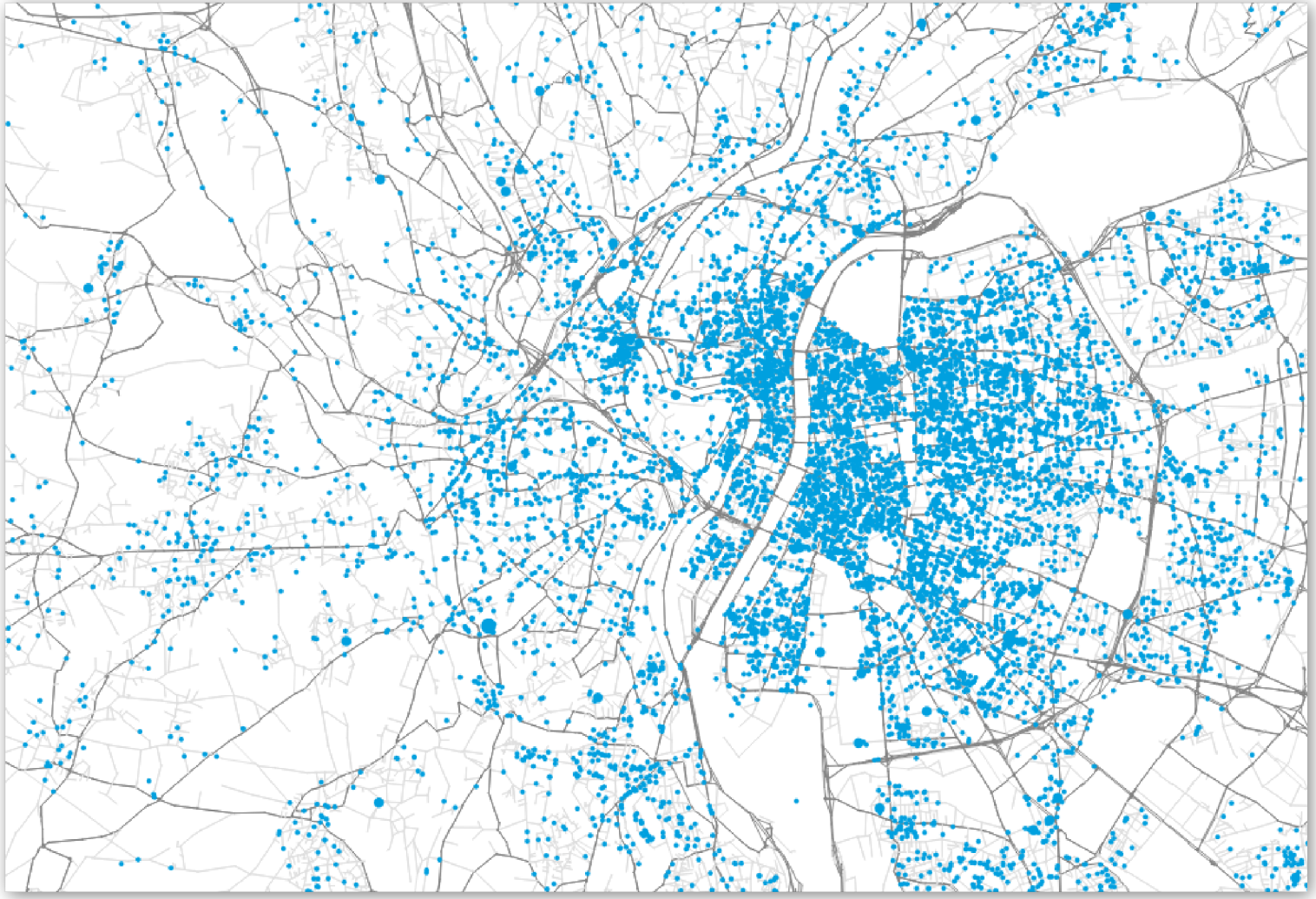

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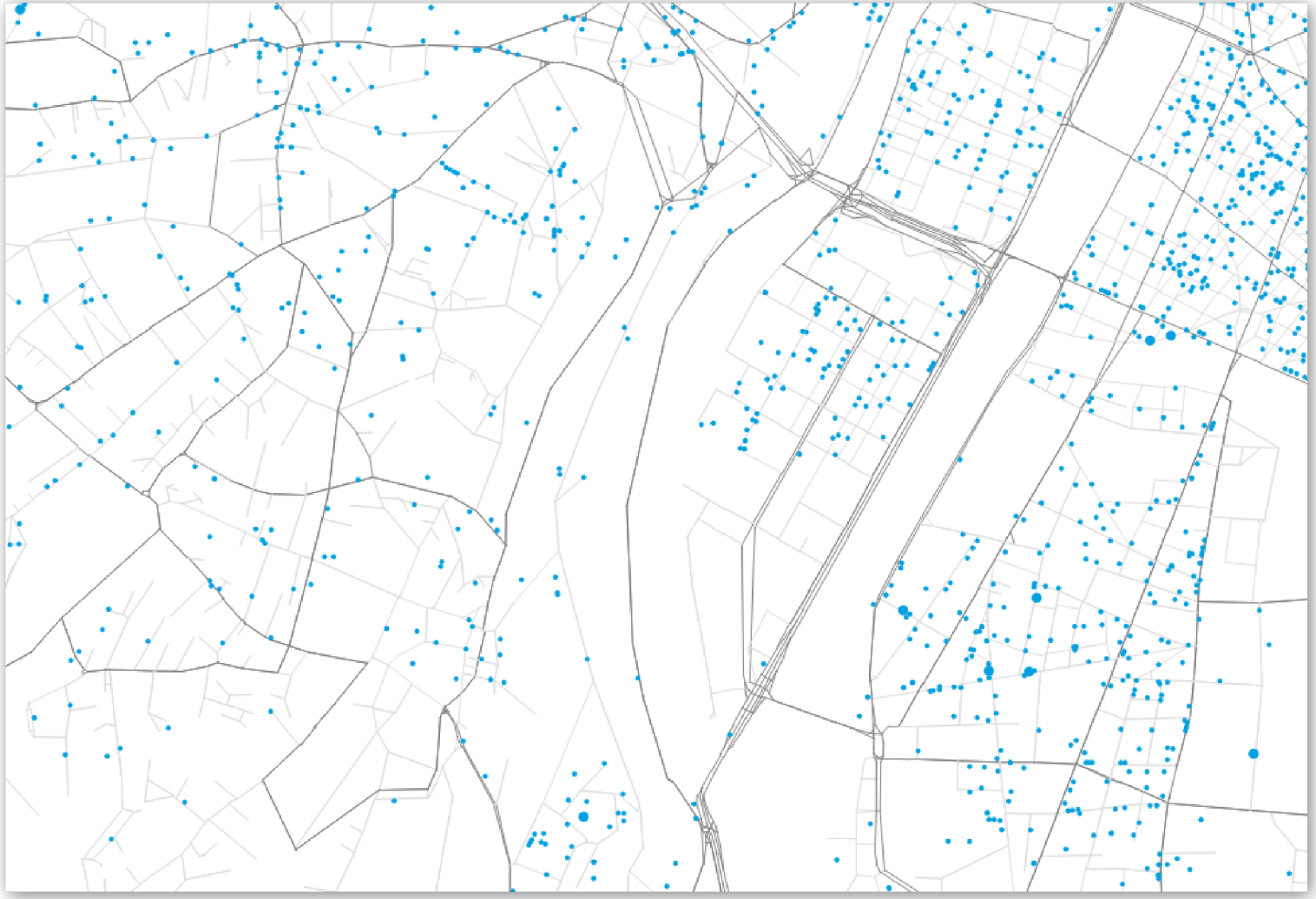

Methodology: Study area

How many parcels need to be delivered on one day?

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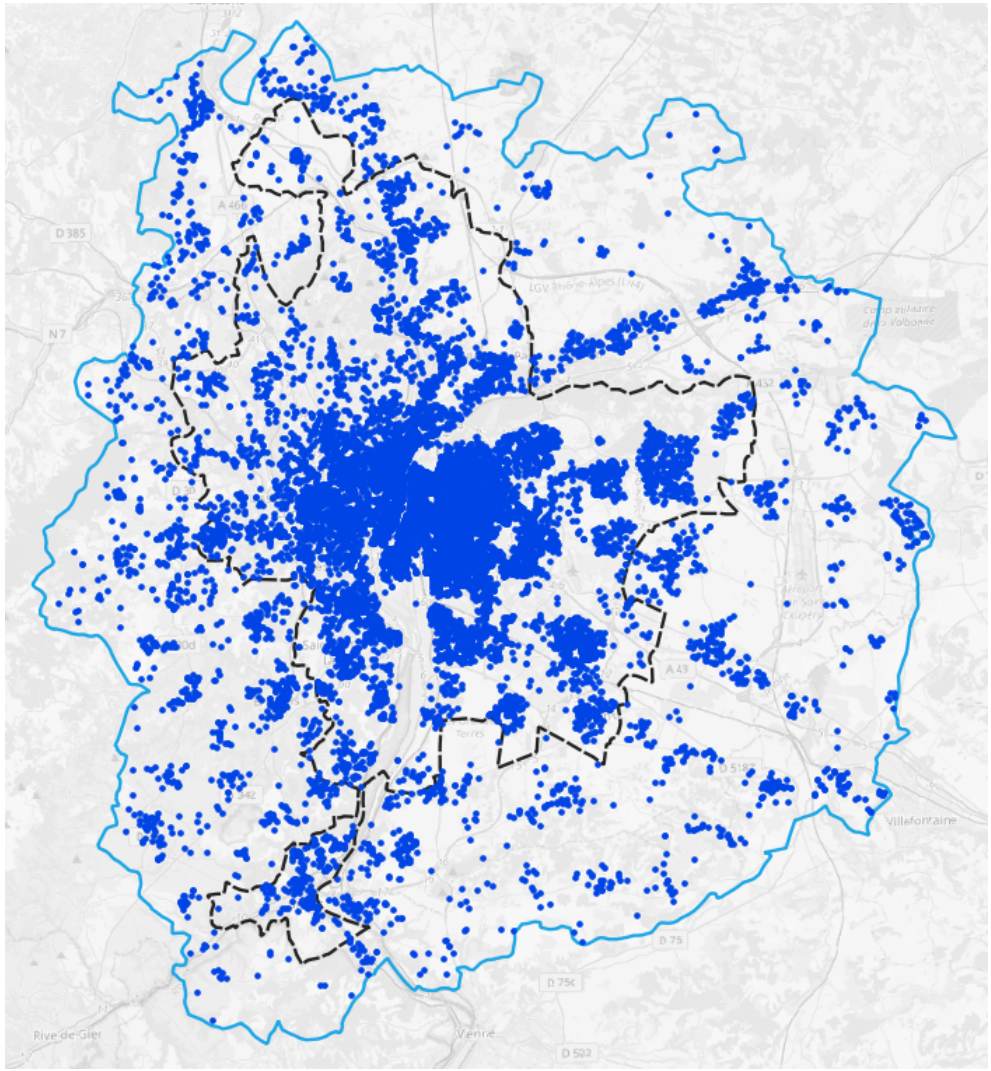

Perimeter

- City of Lyon
- Grand Lyon metropolitan region (dashed)
- Bordering municipalities including relevant logistics infrastructure

Demand

- 1.6M persons
- 790k households
- **16,252 parcels**

Methodology: Distribution centers

From where do operators delivery the parcels?

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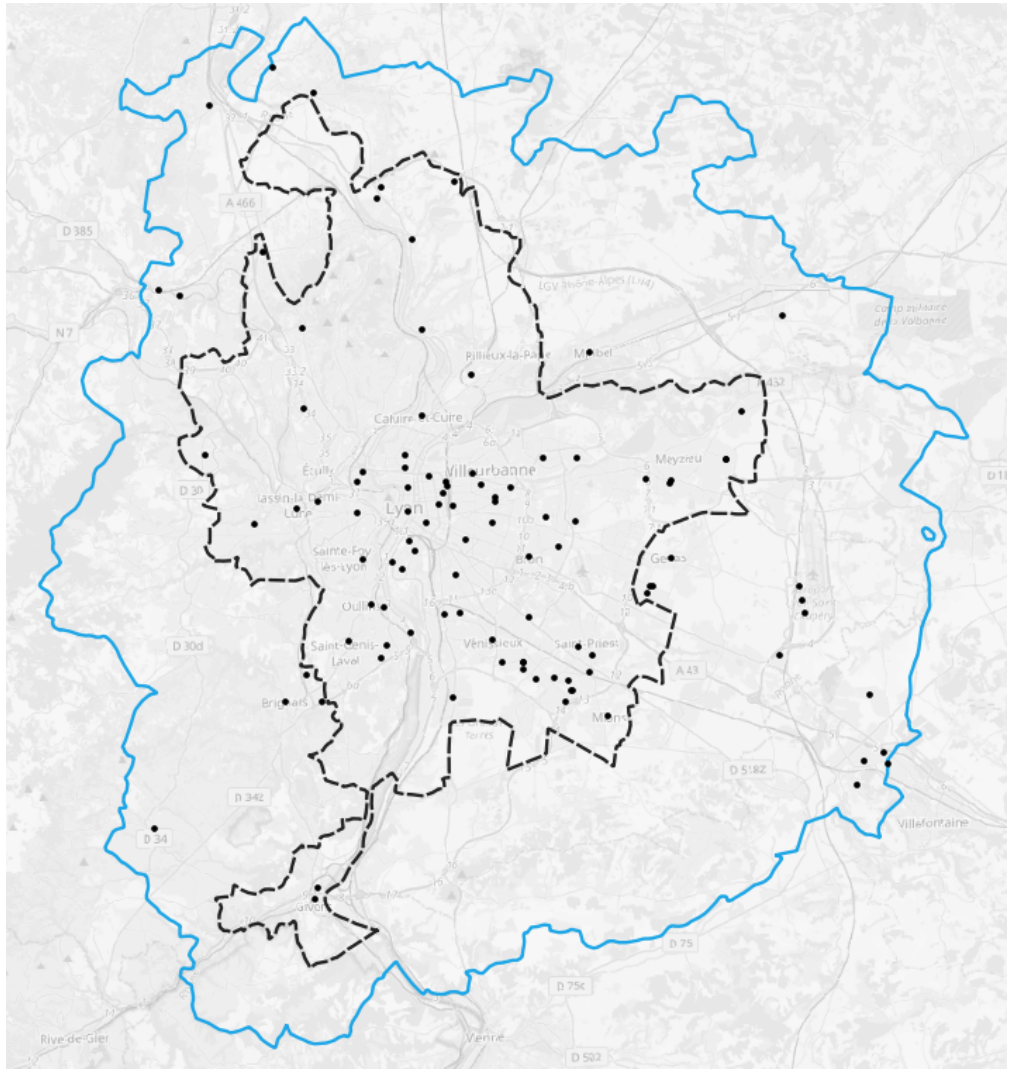
From where do operators delivery the parcels?



Approach

- Facilities per operator extracted from SIRENE
- Geolocated using public BAN API
- La Poste: Facilities with 20+ employees

Operator	Distribution centers
La Poste (Colissimo)	72
Chronopost	6
UPS	2
DPD	3
DHL	8
GLS	2
Colis privé	2
Fedex	9
Total	**104**

Methodology: Market shares

How many parcels are delivered by each operator?

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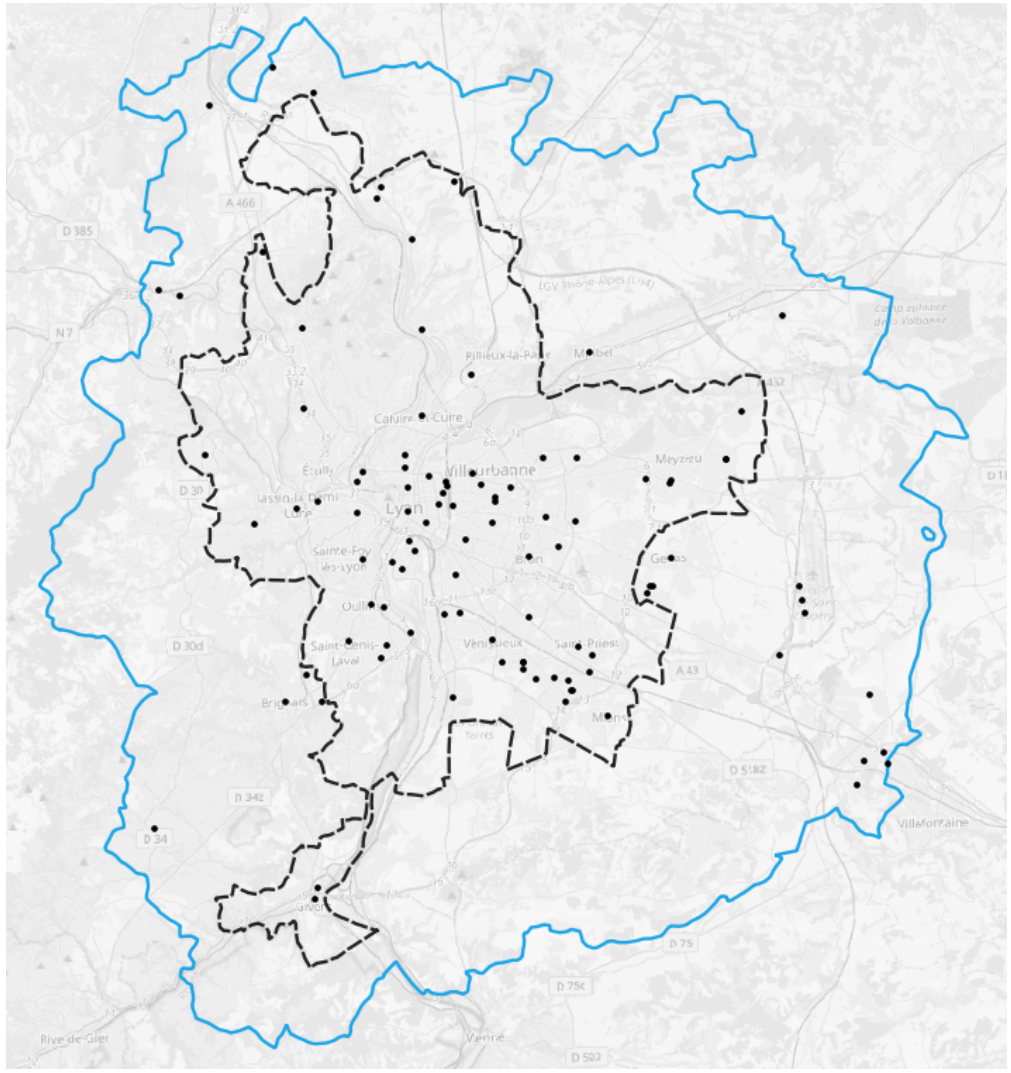

Approach

- For some operators, we know the **annual national volumes** from gray literature
- We know that La Poste (Colissimo + DPD + Chronopost) add up to about **65%** of all parcels in France
- For the rest, we approximate their market share using their annual **turnover values**

Methodology: Market shares

How many parcels are delivered by each operator?

Known parcels in France [Mio]	
Colissimo	471
Chronopost	176
Colis prive	63
DPD	117
	827

Parcels worldwide [Mio]		
GLS	840	10,02%
DHL	1 600	19,08%
Fedex	447	5,33%
UPS	5 500	65,58%
	8 387	**100,00%**

Turnover [M EUR]	
422	23,38%
545	30,19%
13	0,72%
825	45,71%
1 805	**100,00%**

Share	65,00%
gives total	**1 175**
Remaining	348
	29,64%

Final Parcels [Mio]			
Colissimo	471,00	40,08%	
Chronopost	176,00	14,98%	
Colis prive	63,00	5,36%	
DPD	116,80	9,94%	
GLS	81,43	6,93%	
DHL	105,16	8,95%	
Fedex	2,51	0,21%	
UPS	159,18	13,55%	
	1175,076923	**100,00%**	**65,00%**

Methodology: Assignment

How many parcels are delivered by each distribution center?

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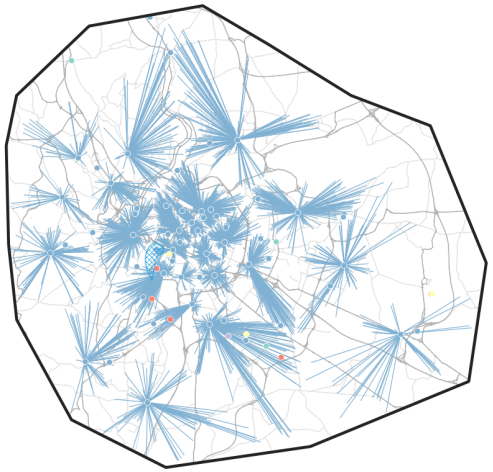
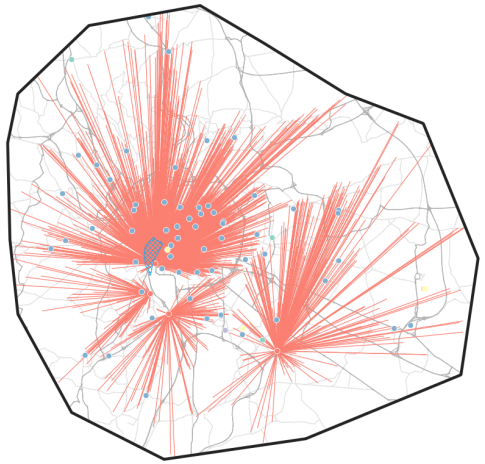




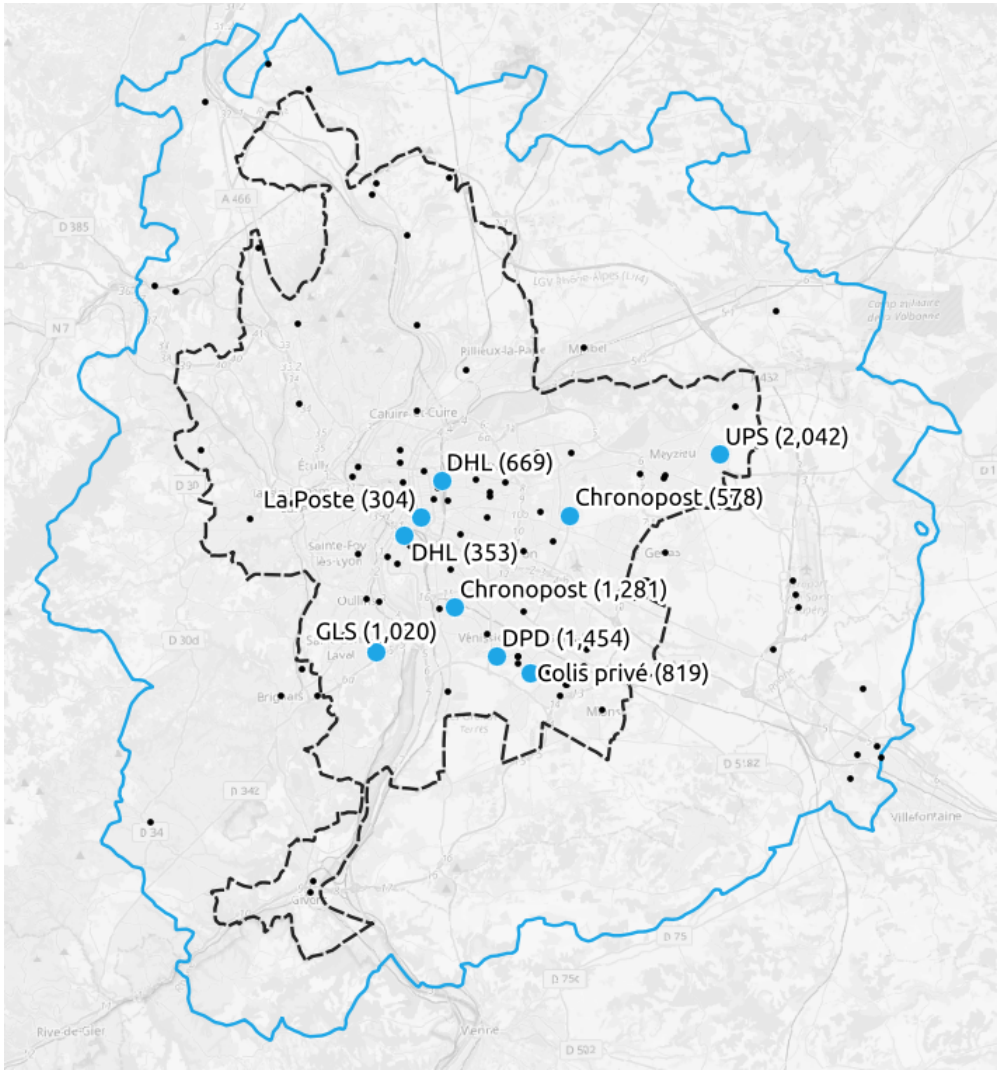
Approach

- For each parcel, sample an operator
- Find the operator's distribution center that is closest (shortest distance) to the parcel

Operator	Distribution centers	Market share [%]	Parcels
La Poste (Colissimo)	72	40.08	6,384
Chronopost	6	14.98	2,430
UPS	2	13.55	2,210
DPD	3	9.94	1,632
DHL	8	8.95	1,477
GLS	2	6.93	1,169
Colis privé	2	5.36	917
Fedex	9	0.21	33
Total	**104**	**100**	**16,252**

Methodology: Assignment

How many parcels are delivered by each distribution center?



Approach

- For each parcel, sample an operator
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Outcome

- Nine centers with 300+ parcels
- Remaining centers with less than 300

Methodology: Cost structures

What influences operators decisions?

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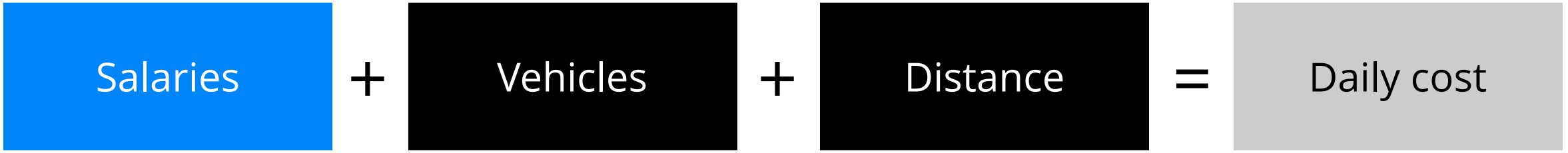
What influences operators decisions?

Salaries + Vehicles + Distance = Daily cost

Methodology: Cost structures

What influences operators decisions?



Assumption (from grey literature)

- 1,300 EUR net per month
- 1,700 EUR gross per month
- 2,550 EUR staff cost per month

- 25 active days per month
- **102 EUR per day**

Methodology: Cost structures

What influences operators decisions?

Salaries + Vehicles + Distance = Daily cost

- We examined **long-duration rental offers** (LLD) of French vehicle manufacturers

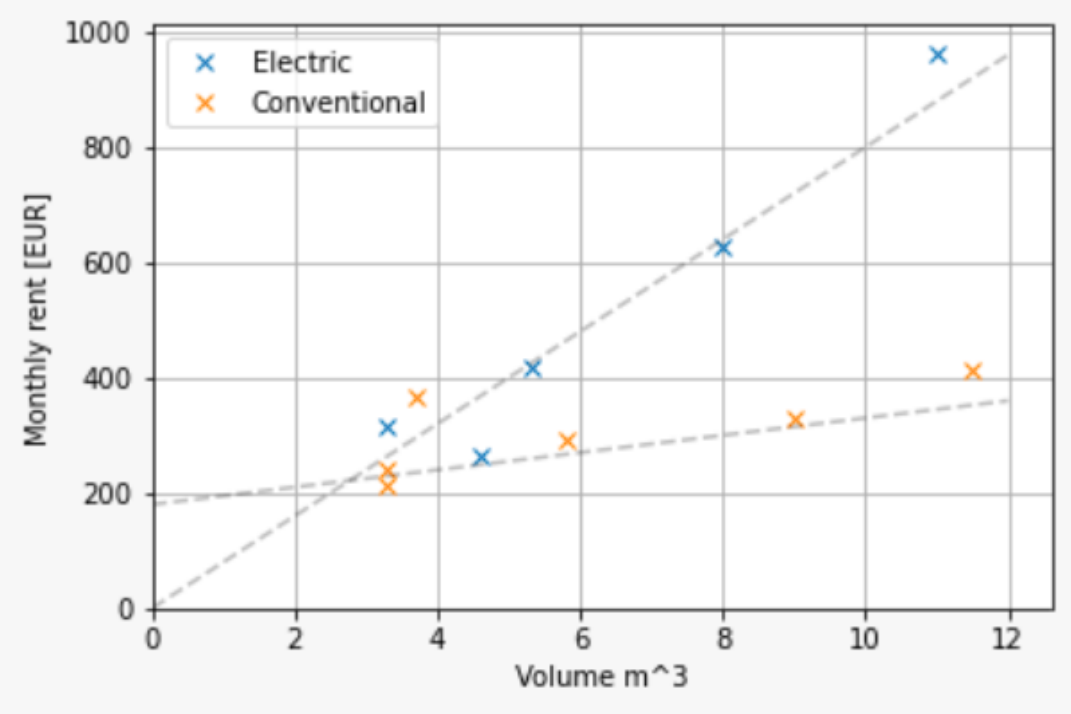
		Rent	First Rent	Months	Total	Volume	Type	Gazole	CO2	Wh/km	Batterie kWh	Autonomie
Citroen	Jumpy	366	466	48	368,08	3,7	G	6,2	162			
							E					
Citroen	E-Berlingo	301	1036	48	316,31	3,3	E			187		274
Citroen	Jumper	412	512	48	414,08	11,5	G	7,8	206			
Peugeot	Boxer	899	4005	48	963,71	*11*	*E*			361		117
Peugeot	E-Expert	329	4510	48	416,1	5,3	E			230		238
Renault	Expres Van	139	4471	60	211,2	3,3	G	5,1	134			
Renault	Kangoo Van	159	5063	60	240,73	3,3	G	5,4	143			
Renault	Trafic	189	6483	60	293,9	5,8	G	6,7	176			
Renault	Master Fourgo	209	7388	60	328,65	9	G	8,4	221			
Renault	Kangoo E-Tech	259	499	60	263	4,6	E			152	33	270
Renault	Master E-Tech	629	553	60	627,73	8	E			*275*	33	120

Methodology: Cost structures

What influences operators decisions?

Salaries + Vehicles + Distance = Daily cost

- **Insight:** Rental costs depend linearly on the transport volume



Methodology: Cost structures

What influences operators decisions?

Salaries + Vehicles + Distance = Daily cost

- **Seven prototypical vehicle types:** 3 sizes thermal or electric plus cargo-bike

Vehicle type	St	Mt	Lt	Se	Me	Le	Be
Size	S	M	L	S	M	L	S
Propulsion	T	T	T	E	E	E	E
Capacity	33	50	100	33	50	100	14
Unit cost [EUR/d]	210	260	370	260	400	800	160

Methodology: Cost structures

What influences operators decisions?

Salaries + Vehicles + Distance = Daily cost

- Distance-costs depend on consumption of **fuel** and **electricity**
- Multiplied by fuel or electricity prices (example 1.45 EUR/L and 9ct/kWh)

Vehicle type	**St**	**Mt**	**Lt**	**Se**	**Me**	**Le**	**Be**
Size	S	M	L	S	M	L	S
Propulsion	T	T	T	E	E	E	E
Capacity	33	50	100	33	50	100	14
Fuel consumption [L/100km]	5	6	8	-	-	-	-
Electricity consumption [Wh/km]	-	-	-	160	200	300	42
Distance cost* [EUR/100km]	304.5.0	377.00	522.00	14.00	18.00	27.00	3.80

Methodology: Cost structures

What influences operators decisions?

Salaries + Vehicles + Distance = Daily cost

- Additional information from our manufacturer analysis: **Emissions**
- Assuming 90 gCO2eq/kWh for electric vehicles

Vehicle type	**St**	**Mt**	**Lt**	**Se**	**Me**	**Le**	**Be**
Size	S	M	L	S	M	L	S
Propulsion	T	T	T	E	E	E	E
Capacity	33	50	100	33	50	100	14
Emissions** [g_{CO2eq}/km]	130	160	215	14.4	18	27	3.8

Methodology: Optimization

Minimize costs

Methodology: Optimization

Minimize costs

Heterogeneous Vehicle Routing Problem

- Minimize cost *per distribution center*
- Operator can choose vehicles (7 types) and routes

- Operator must deliver all assigned parcels
- Maximum active time per day 10h
- Active time is travel time + 120s delivery + 60s pick-up per parcel

- Vehicles can not exceed capacity (we assume **10 parcels per m3**)
- Multiple tours per vehicle are allowed

- Vehicles start and end the day at the distribution center

Methodology: Optimization

Minimize costs

Heterogeneous Vehicle Routing Problem

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Data

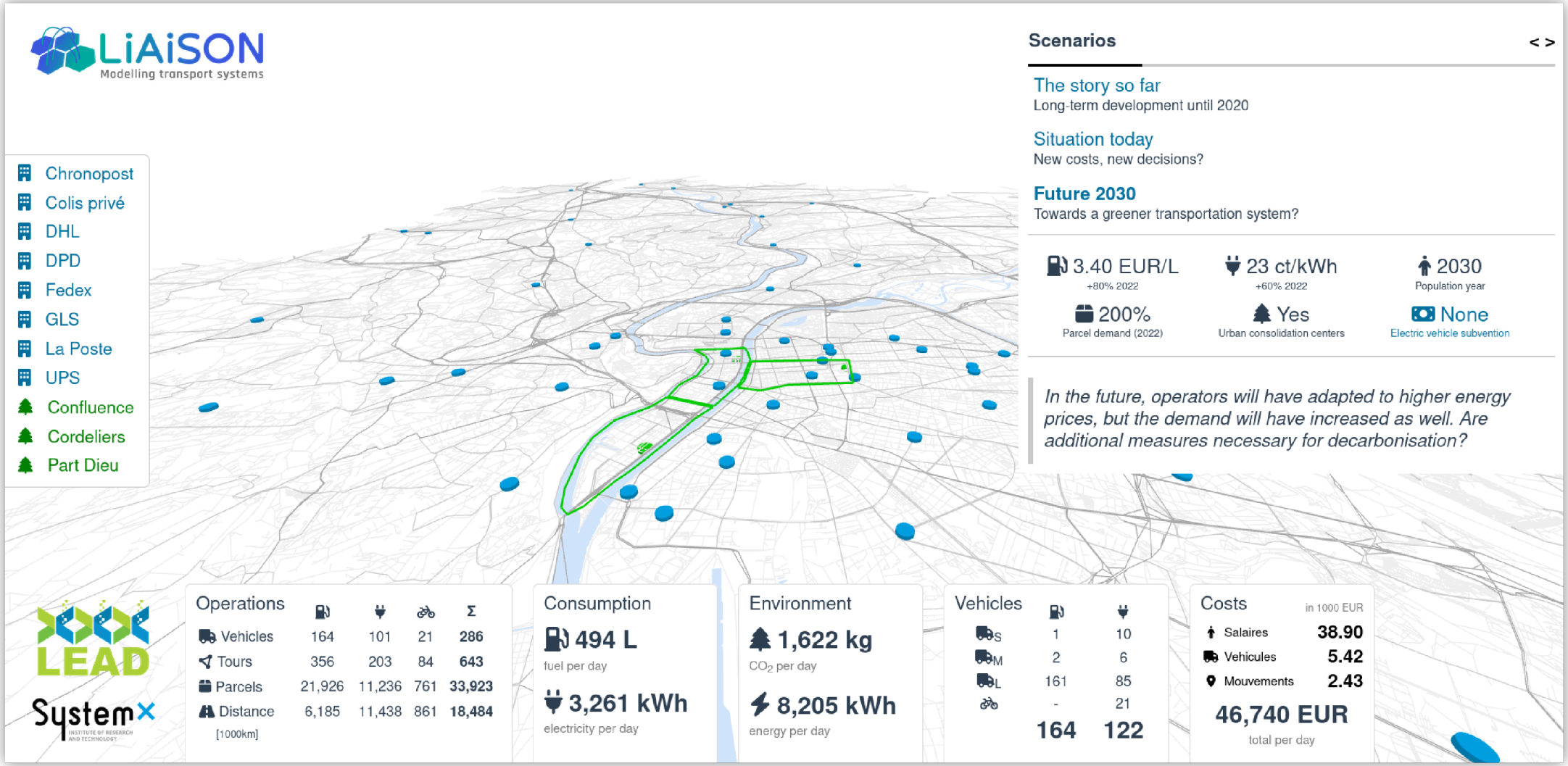
- OpenStreetMap network
- Extracted using osmnx

- Distance matrix between parcels and depot
- Travel time matrix using congestion factors

Solver

- Open-source
- VROOM

Visualisation platform



Scenarios and Results

- **Baseline 2022**: Estimate today's situation with today's price structure and demand
- **Baseline 2030**: Parcel delivery demand increased 100%
- **Quantitative** mitigation scenarios
  - Increasing the price of thermic vehicles
  - Implementing a substantial carbon tax
- **Qualitative** mitigation scenarios
  - Forbidding thermic vehicles in Lyon's LEZ
  - Forbidding thermic vehicles in the whole region

Scenarios and Results

Today vs. Future

	Today	Future 2030	Change [%]
Deliveries	**16252**	**33923**	**+108%**
Distance [km]	12451	18129	+45%
Energy [kWh]	6855	11925	+74%
CO2eq [kg]	1750	3115	+78%
Fuel [L]	635	1143	+80%
Electricity [kWh]	510	500	-2%
Cost per delivery [EUR]	2.09	1.77	-15%

Scenarios and Results

Today vs. Future

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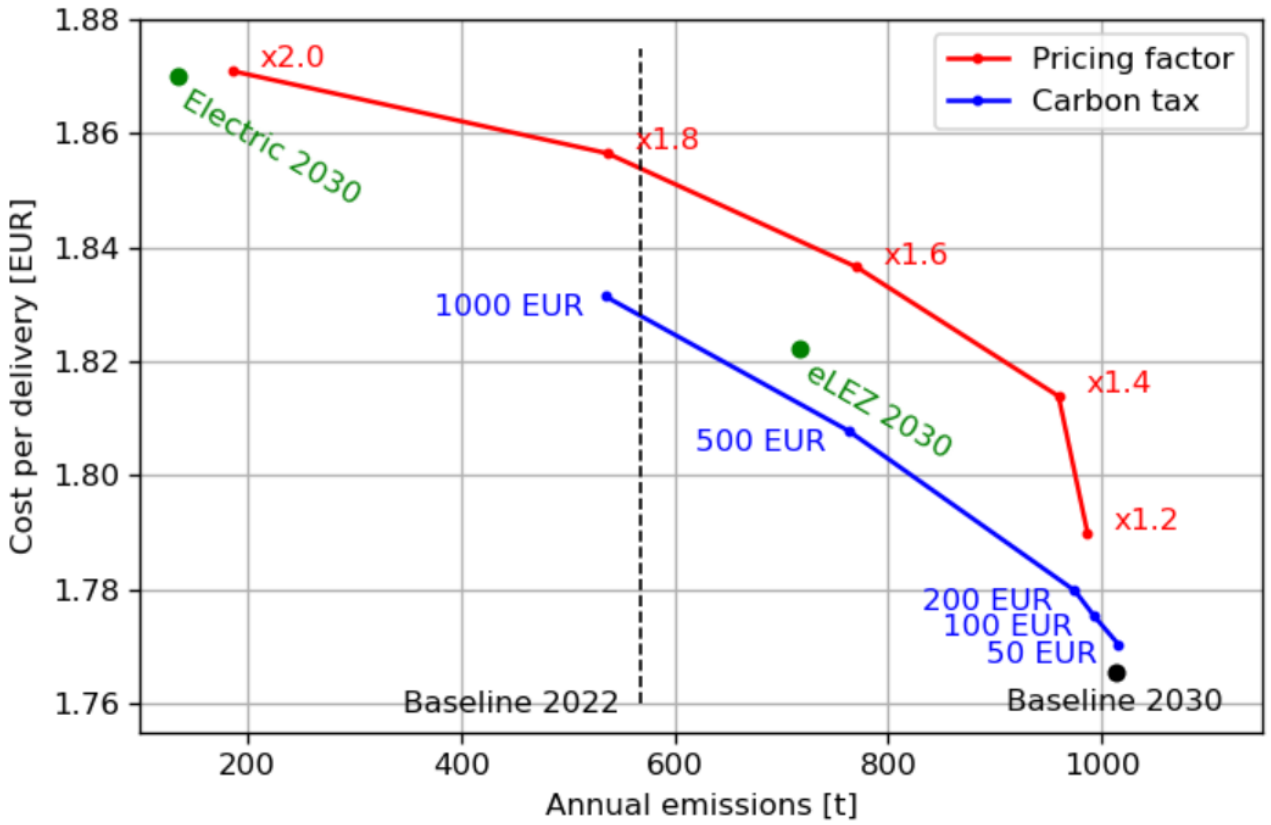
Scenarios and Results

Mitigation



Discussion & Open questions

- **Validation**
  - What data can we use to validate the model?
  - Validation of individual operators?

- **Coherence**
  - Are our cost structures coherent? Did we miss some aspects?

- **Replicability**
  - Data available anywhere in France (but ADM survey only for Lyon)
  - Theoretically applicable anywhere in France

Next steps

- **Integration of new components**
  - Integration of UCC
  - Pickup points
  - Parcel lockers
  - Automated deliveries

- **Extension to Copenhagen (and B2B)**
  - Part of the Horizon Europe project DISCO

Questions?

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https://slides.com/sebastianhorl/heart23