Hyperconnected Urban Parcel Network Design with Tight Delivery Service Requirements

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Joint work with

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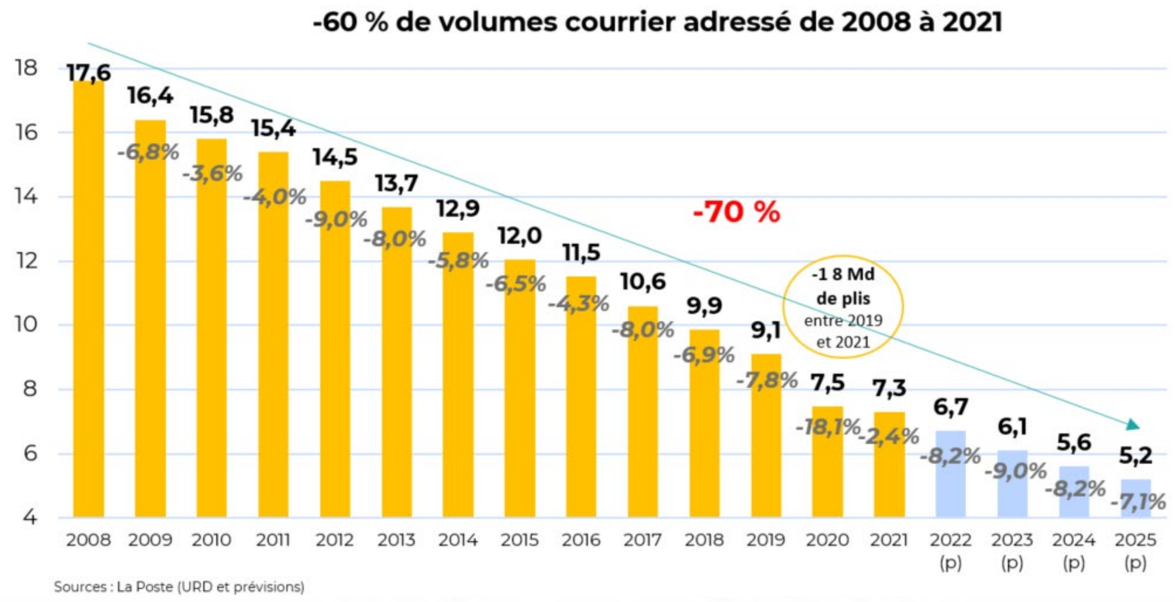
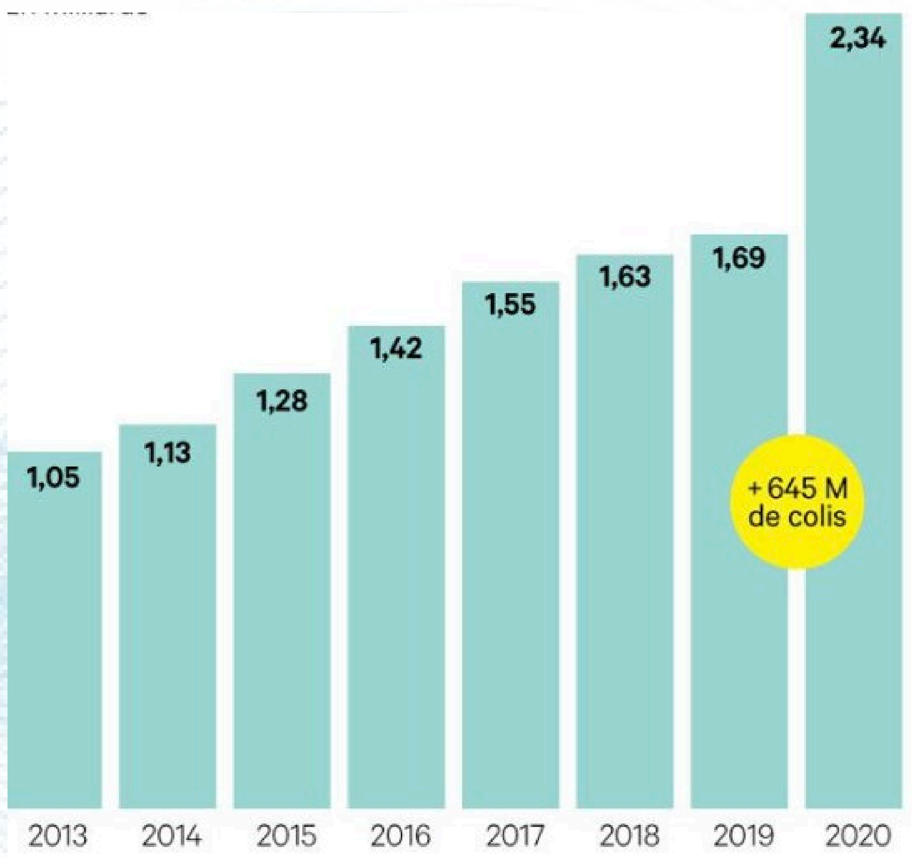
La Poste Group

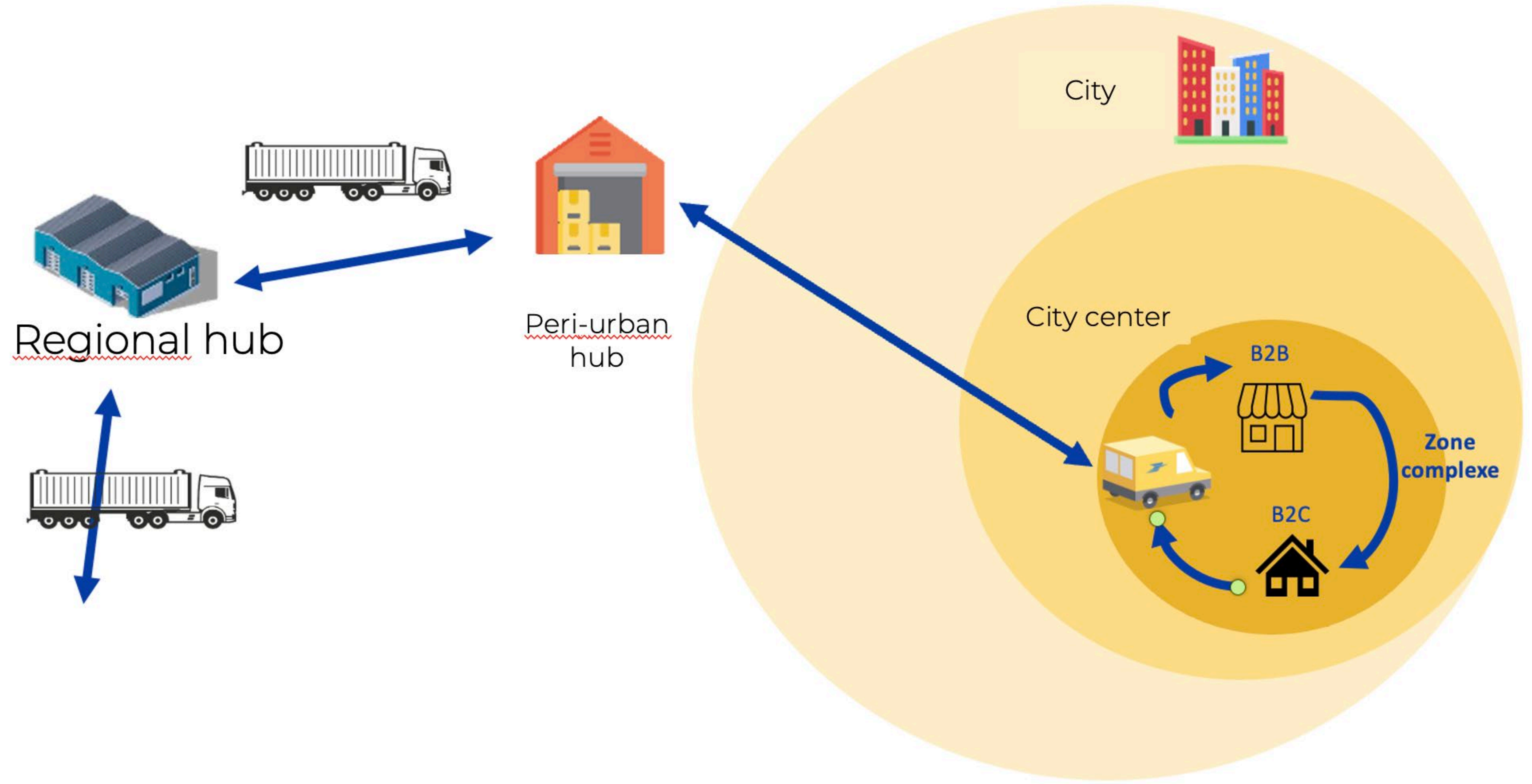
Context

La Poste’s network is in deep transformation.

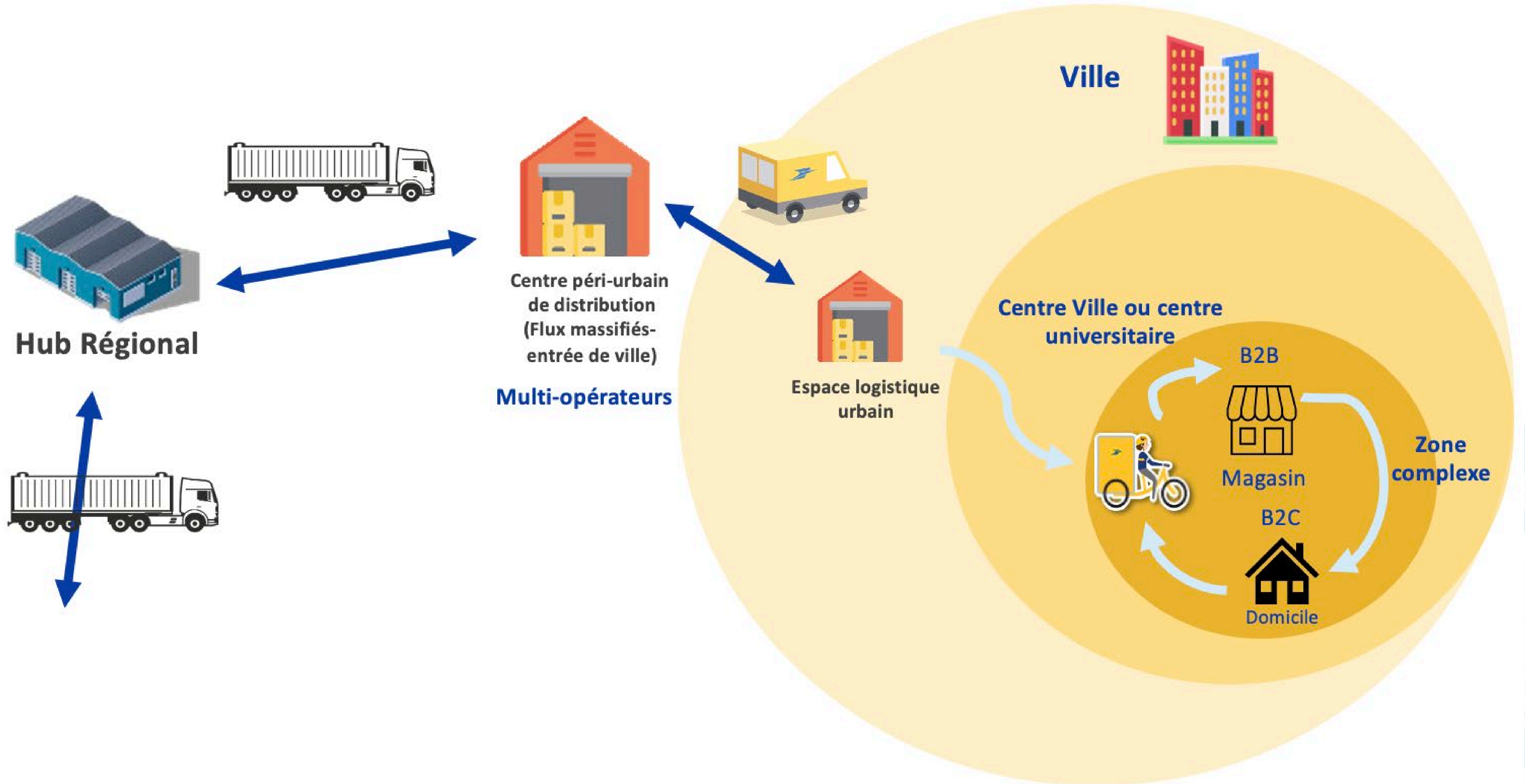




Historical delivery network



Current delivery network



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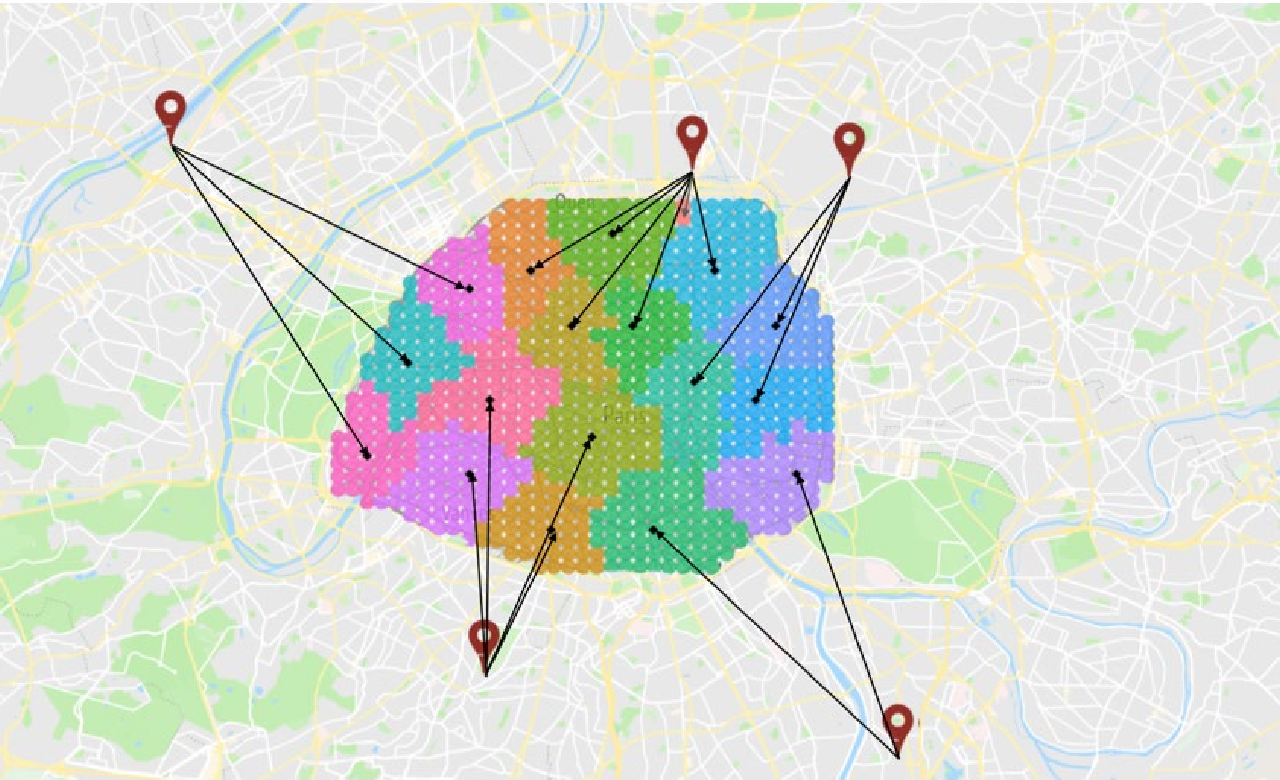
Emerging quick markets



BFMTV

L'hypercroissance du E-commerce : un challenge pour les ...

Le développement du « Ship from store » complexifie les plans de transport avec l'utilisation de plusieurs prestataires du dernier kilomètre. La ...

Il y a 1 jour

PR Newswire

Same Day Delivery Market Size to hit $ 16739 Million by 2027 ...

The same day delivery is very fast process so to avoid mix-ups if product ordered before noon are delivered on same day otherwise next morning ...

Il y a 3 semaines

E-marketing

Ship-from-store : ba&sh multiplie ses ventes en ligne par 3,5 ...

Ship-from-store : ba&sh multiplie ses ventes en ligne par 3,5 le premier jour des soldes. Publié par Clément Fages le 1 mars 2021 I Mis à jour le 5 mars 2021 à ...

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Electro Dépôt déploie le ship-from-store avec Woop

Depuis la mi-novembre, l'enseigne de multimédia et d'électroménager a pu déployer une solution de livraison ship-from-store depuis ses 81 ...

20 janv. 2021

X

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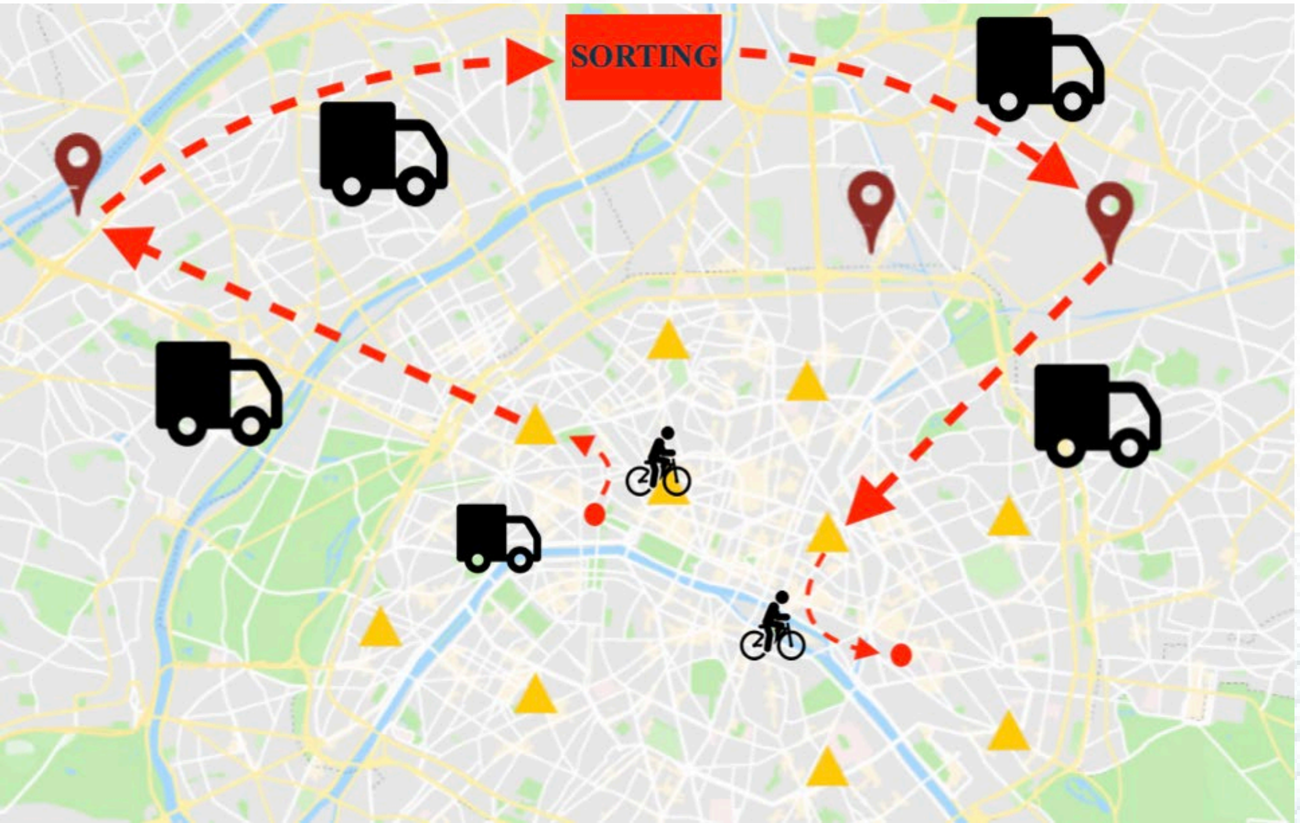

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20 janv. 2021

X

La Poste’s Group organization

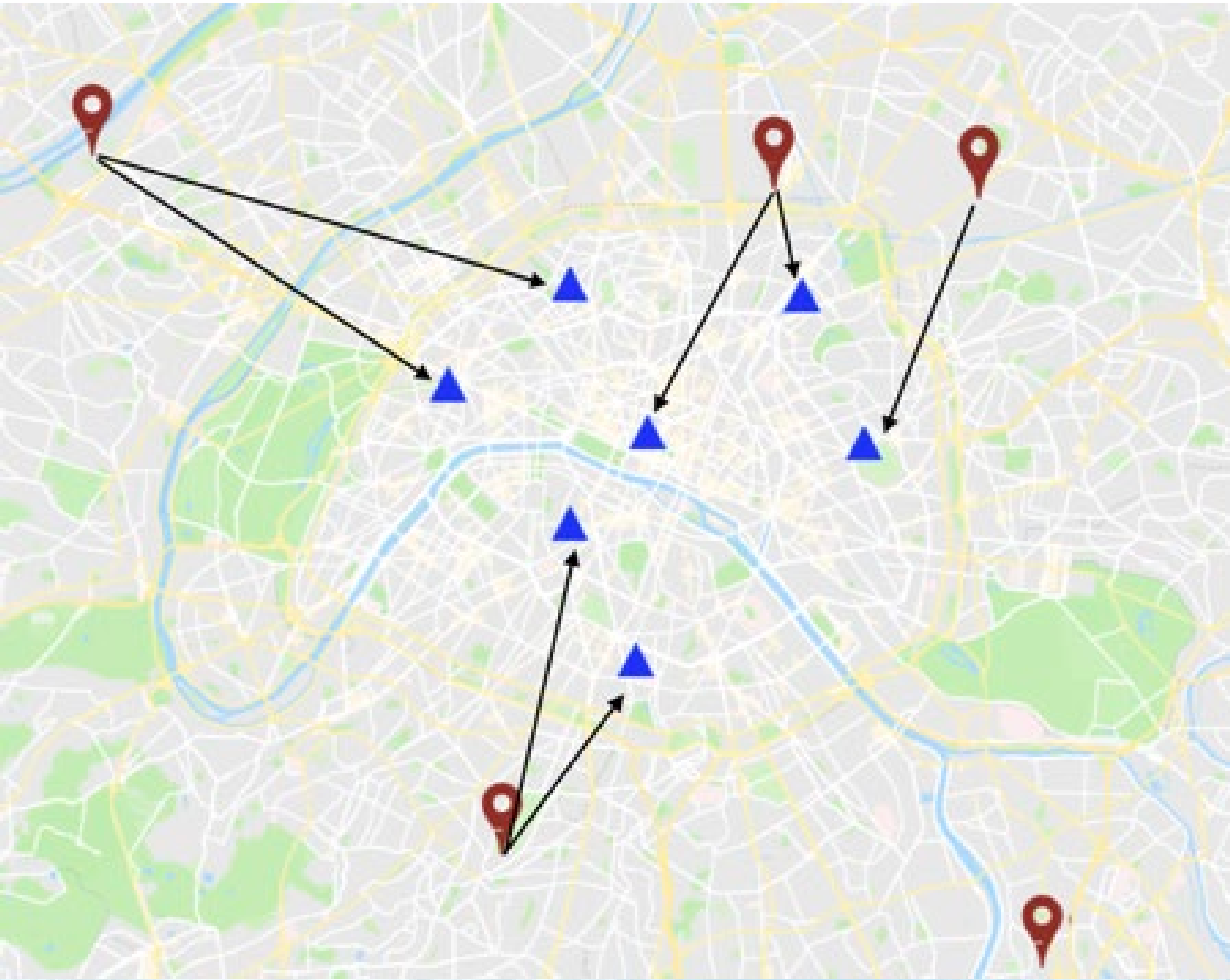
Historical role

colissimo	Parcel delivery historical French main actor
chronopost	International parcel express delivery
dpdgroup	International oversize parcel delivery

They all have an already established network, why not sharing it ?

La Poste’s Group organization

La Poste has several twin companies, with their own already established networks



chronopost

colissimo

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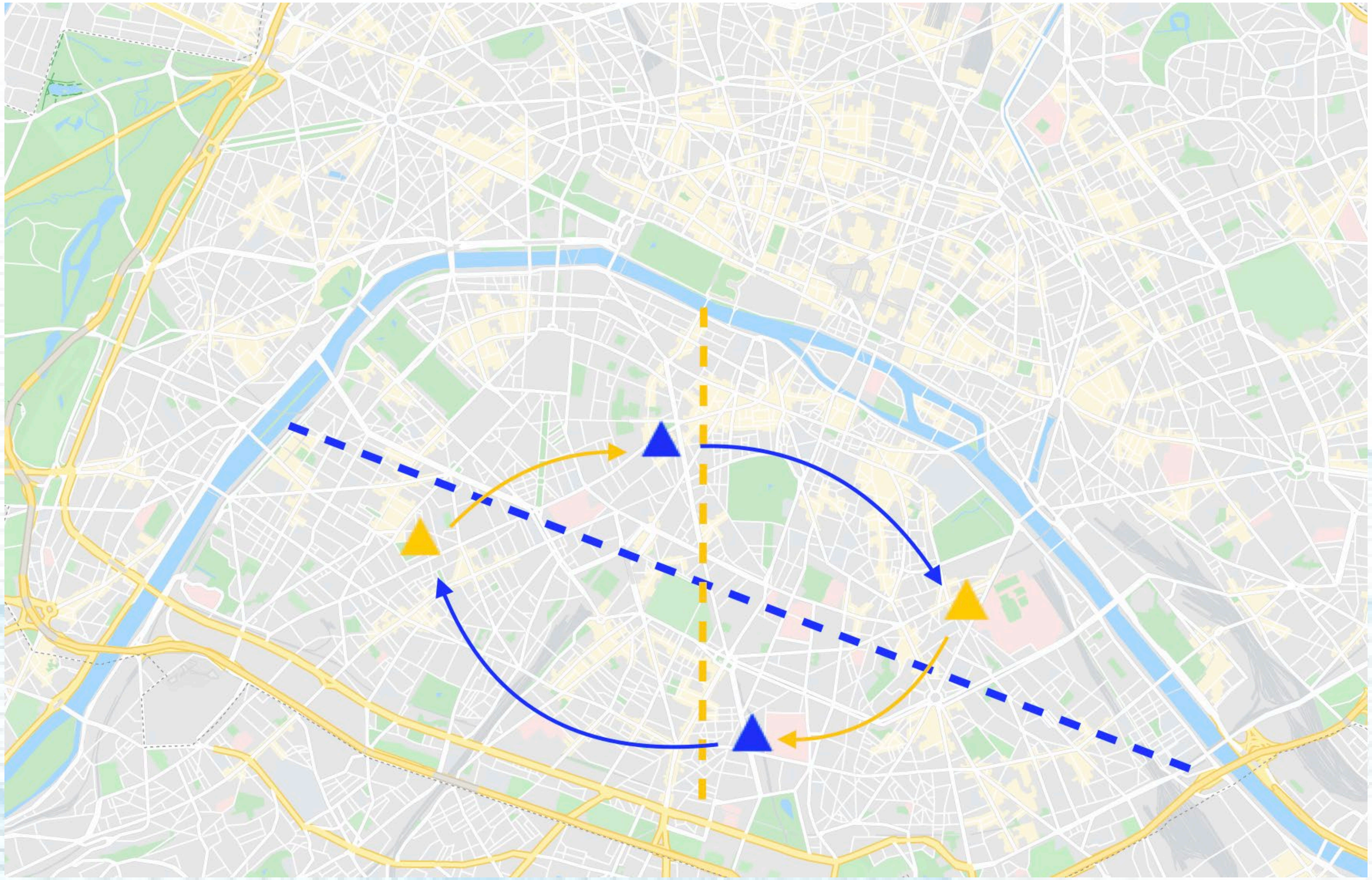
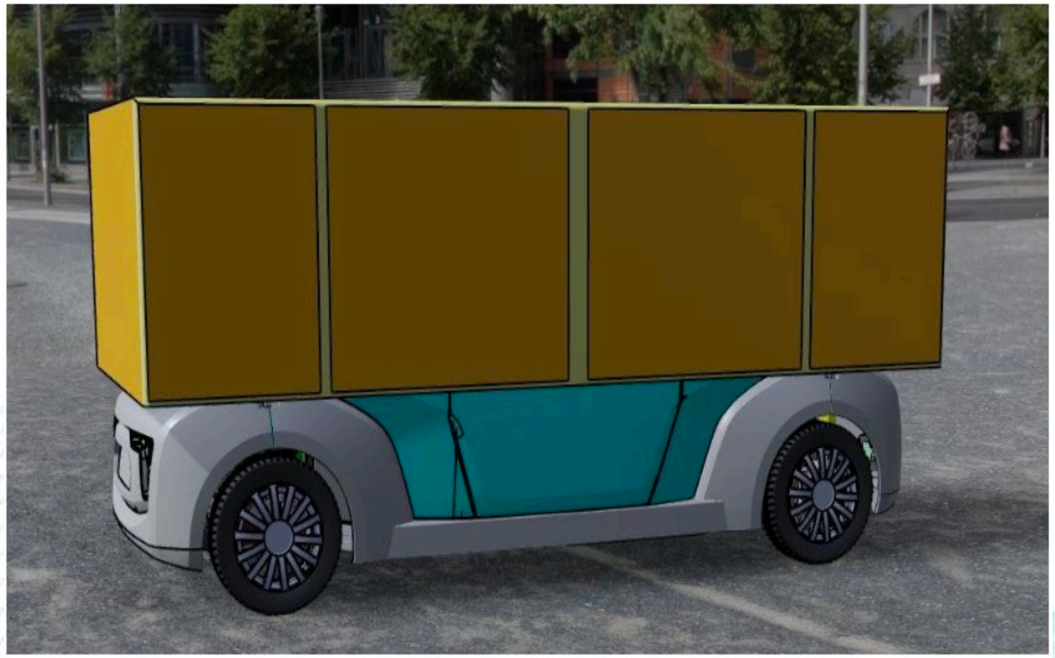
Natural overlapping



chronopost

colissimo

The introduction of new delivery methods allows a higher agility



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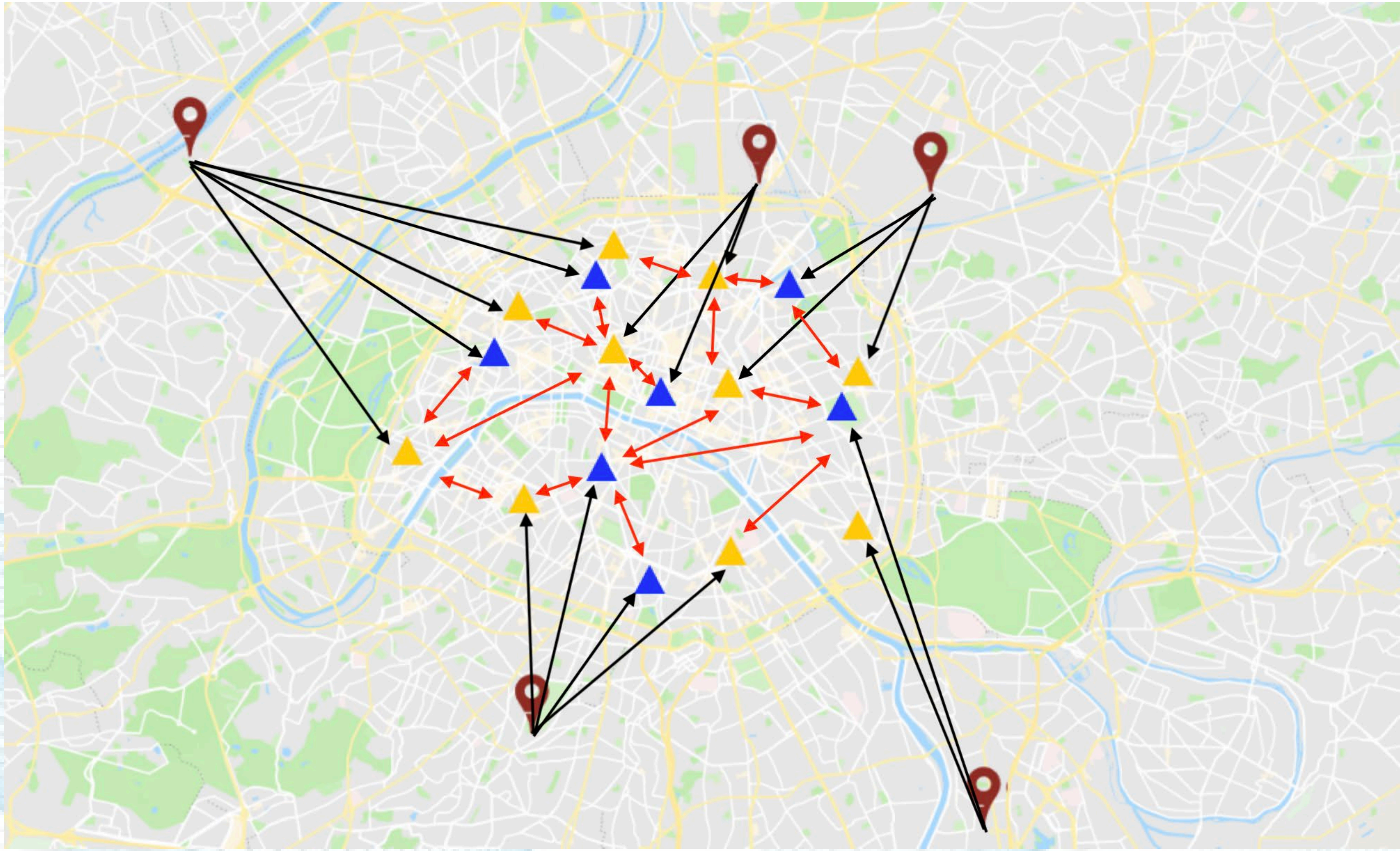
Introduction of interconnected networks



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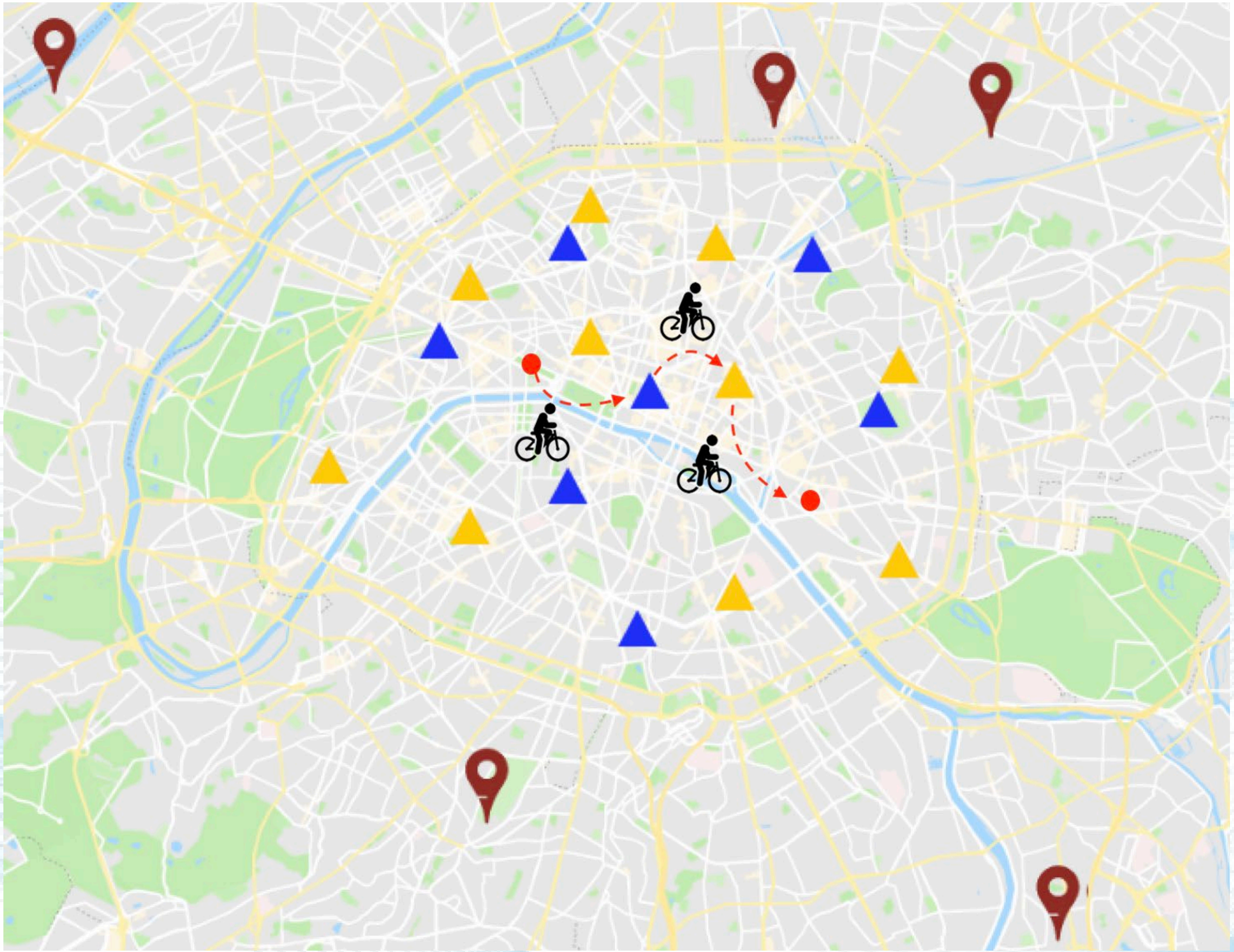

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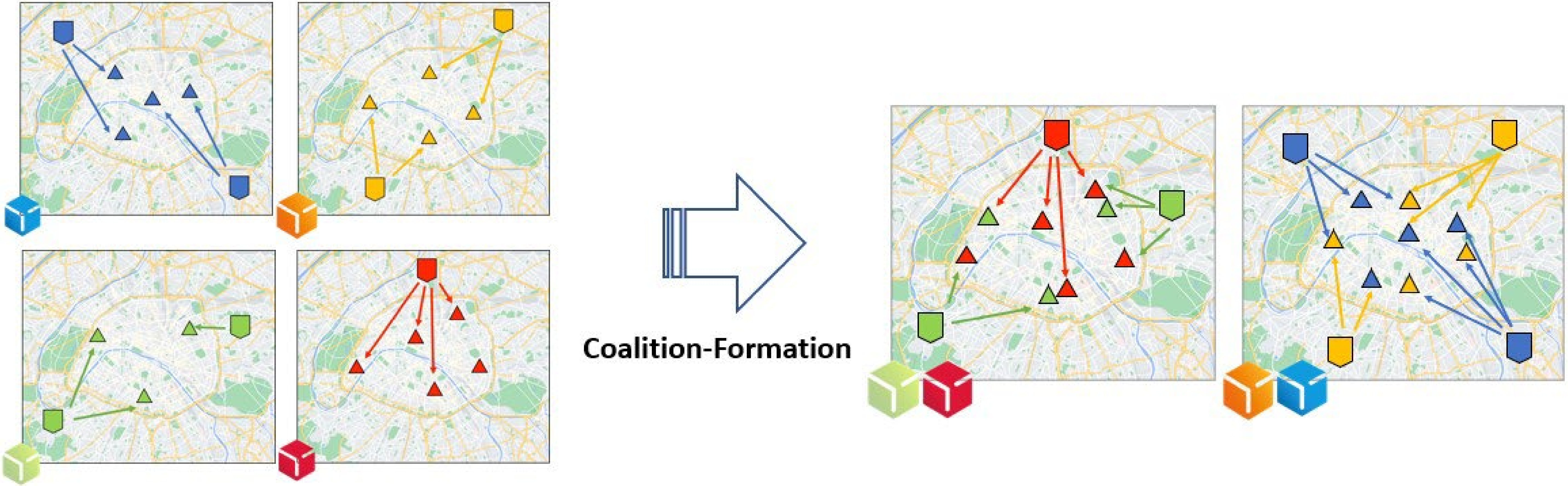
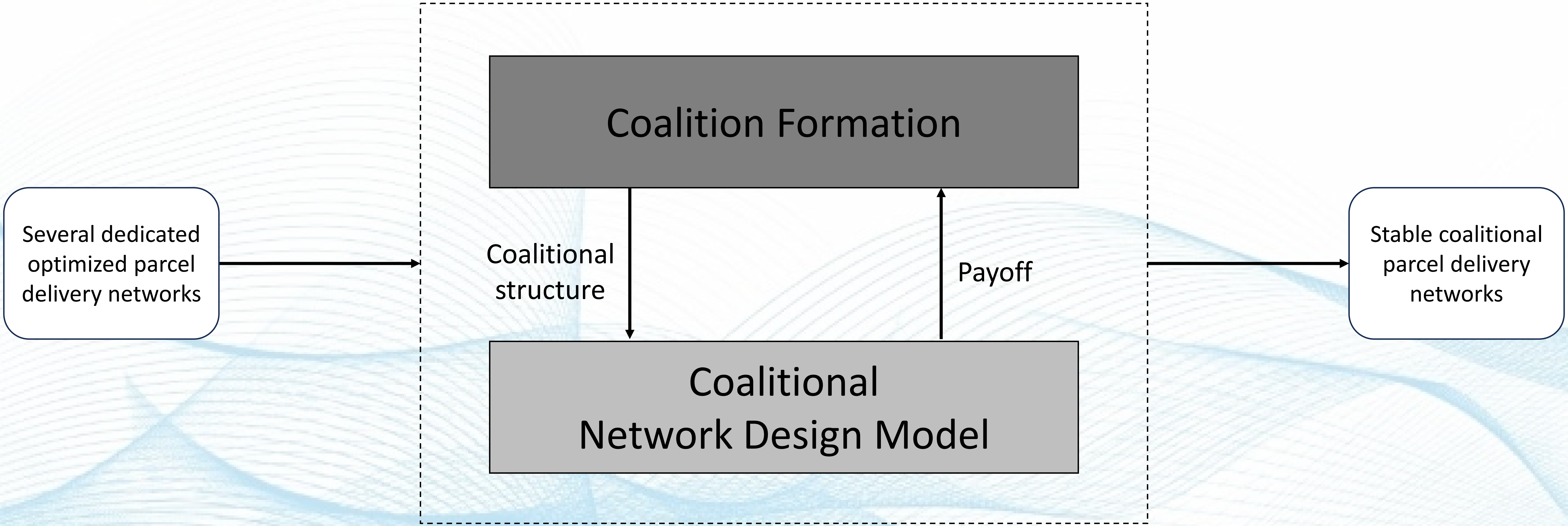
Idea of coalition formation



Set of delivery actors with their own dedicated parcel delivery networks

Set of coalitions of actors with shared parcel delivery networks

Coalitional Decision-Making Framework



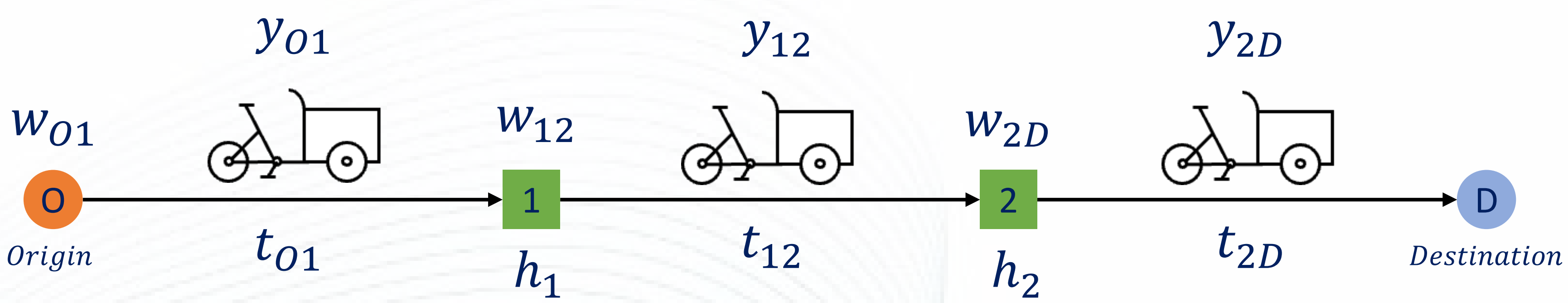
(1) Which profitable coalitions?
(2) How to design the coalitional network of each coalition
(3) How to allocate the joint costs of the coalitional network between actors

Coalitional Network Design

- **Aim:**
  - Design a coalitional urban parcel delivery network for a given coalition to enable tight delivery service requirements in a cost minimization manner

- **Model and Decisions:**
  - Path-based IP and frequency-based model on a flat network
  - Decisions
    - Which hubs to activate → micro-hub network decisions
    - How many vehicle dispatches along each arc per unit time → vehicle frequency decisions

Modelling Delivery Service Requirements



- τ_k: Service requirements of O-D commodity k
- t_a: Travel time on arc a
- h_i: Hub processing time at micro hub i
- y_a: # of cargo bikes over arc a per time unit
- w_a: Dwell time before traversing arc a

Assumptions (Dayarian et al., (2022) , Greening et al., (2022))

- Each O-D commodity arrives at its origin according to a uniform distribution
- Cargo bikes are dispatched between locations according to a uniform distribution

⇒ Dwell time before traversing arc a is $w_a \sim$ Uniform $(0, \frac{1}{y_a})$ with avg. of $\frac{1}{2} \cdot \frac{1}{y_a}$

$$\sum_{a \in p} t_a + \sum_{i \in p} h_i + \sum_{a \in p} \mathbb{E}[w_a] \leq \tau_k \quad \Rightarrow \sum_{a \in p} \frac{1}{2} \cdot \frac{1}{y_a} \leq \widehat{\omega}_{kp} = \tau_k - \left(\sum_{a \in p} t_a + \sum_{i \in p} h_i \right)$$

Total allowable dwell time along path p for commodity k

Coalitional Network Design Model with TDSR

- Data:
  - $\mathcal{S}$: Set of coalitions
  - $\mathcal{N}^s$: Set of hubs for coalition $s \in \mathcal{S}$
  - $\mathcal{A}^s$: Set of arcs for coalition $s \in \mathcal{S}$
  - $\mathcal{K}^s$: Set of commodities (O-D pairs) for coalition $s \in \mathcal{S}$
  - $\mathcal{P}_k^s$: Set of pregenerated paths for commodity $k \in \mathcal{K}$ for coalition $s \in \mathcal{S}$

- Decisions for coalition $s \in \mathcal{S}$:
  - $x_h^s \in \{0,1\}$: Hub selection
  - $y_a^s \in \mathbb{Z}_{\geq 0}$: # of CBs over arc a
  - $z_{kp}^s \in \{0,1\}$: Path selection of commodity k

$$\min \quad \sum_{h \in \mathcal{N}^s} f_h \cdot x_h^s + \sum_{a \in \mathcal{A}^s} g_a \cdot y_a^s$$

$$\text{s.t} \quad \sum_{p \in \mathcal{P}_k^s} z_{kp}^s = 1, \qquad \forall k \in \mathcal{K}^s$$

$$\sum_{k \in \mathcal{K}^s} \sum_{p \in \{p \in \mathcal{P}_k^s : a \in p\}} q_k \cdot z_{kp}^s \leq v \cdot y_a^s, \qquad \forall a \in \mathcal{A}^s$$

$$\sum_{a \in p} \frac{1}{2} \cdot \frac{1}{y_a^s} \leq \hat{\omega}_{kp} + M \cdot \left(1 - z_{kp}^s\right), \qquad \forall k \in \mathcal{K}^s, p \in \mathcal{P}_k^s$$

$$Q_i^{min} \cdot x_i^s \leq \sum_{a \in \delta^+(i)} y_a^s \leq Q_i^{max} \cdot x_i^s, \qquad \forall i \in \mathcal{N}^s$$

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Case Study

Table 1: Summary of parcel delivery actors

Delivery actor	# of Micro-hubs	Market Share	# of OD Commodities
1	19	60%	35591
2	3	10%	6162
3	8	30%	18105

- French urban megacity (Paris)
  - 412 demand zones
  - Order of 1.6 million parcels weekly across 52k origin-destination (O-D) pairs
- French parcel/postal company
  - 3 subsidiaries of parcel delivery actors
  - Each actor offers tight delivery service requirements
    - 6,12,24,48-hour delivery
- 3 Cost-sharing methods to compute marginal cost
  - Shapley cost allocation
    - Weighted average of all marginal cost to all possible coalitions
  - Proportional fairness allocation
    - Allocation proportional to total commodity volume
  - Egalitarian allocation
    - Equal Allocation

Case Study: Cost-Sharing Methods

Input:

S: Set of coalitions

I: Set of actors

I^s: Set of actors in coalition $s \in S$

M: Set of cost-sharing methods

$= \{\text{Shapley, PF, Eg}\}$

K_i: Set of commodities for actor i

q_{ik}: Volume of commodity k of actor i

$C_{i,s}^m$: Marginal cost of actor i in coalition s for allocation method $m \in M$

Cost-Sharing Methods:

- Shapley Cost Allocation: $C_{i,s}^{Shapley} = \sum_{\bar{I} \subseteq I^s : i \in \bar{I}} \frac{(|I^s| - |\bar{I}|)! \cdot (|\bar{I}| - 1)!}{|I^s|!} \cdot (C_{\bar{I}} - C_{\bar{I} \setminus \mathrm{i}})$
- Proportional Fairness Allocation: $C_{i,s}^{PF} = \frac{C_s \cdot \sum_{k \in K_i} q_{ik}}{\sum_{i' \in I^s} \sum_{k \in K_{i'}} q_{ik}}$
- Egalitarian Allocation: $C_{i,s}^{Eg} = \frac{C_s}{|I^s|}$

Case Study: Global Network Design Performance

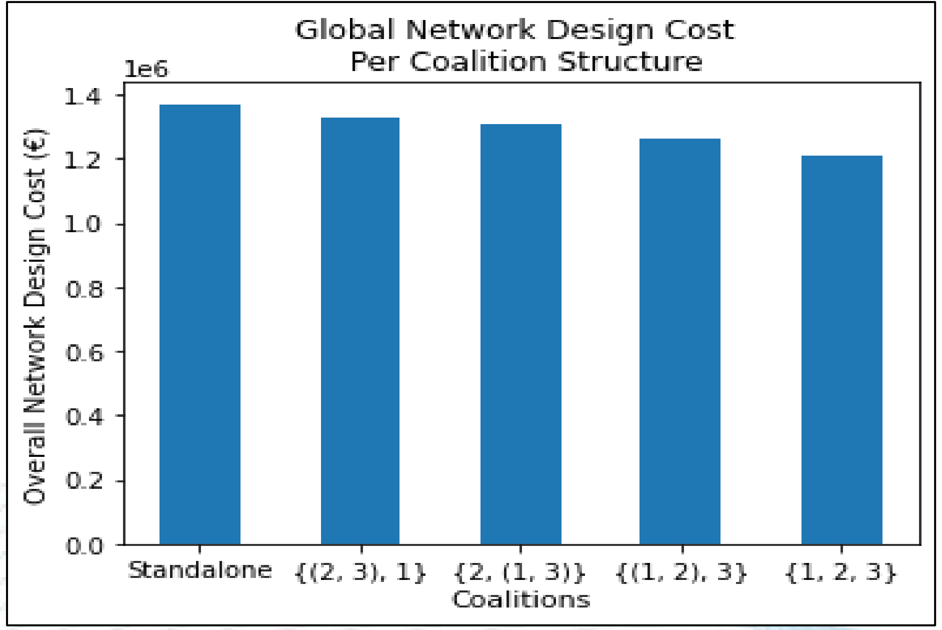
Table 1: Summary of Network Design of individual actors

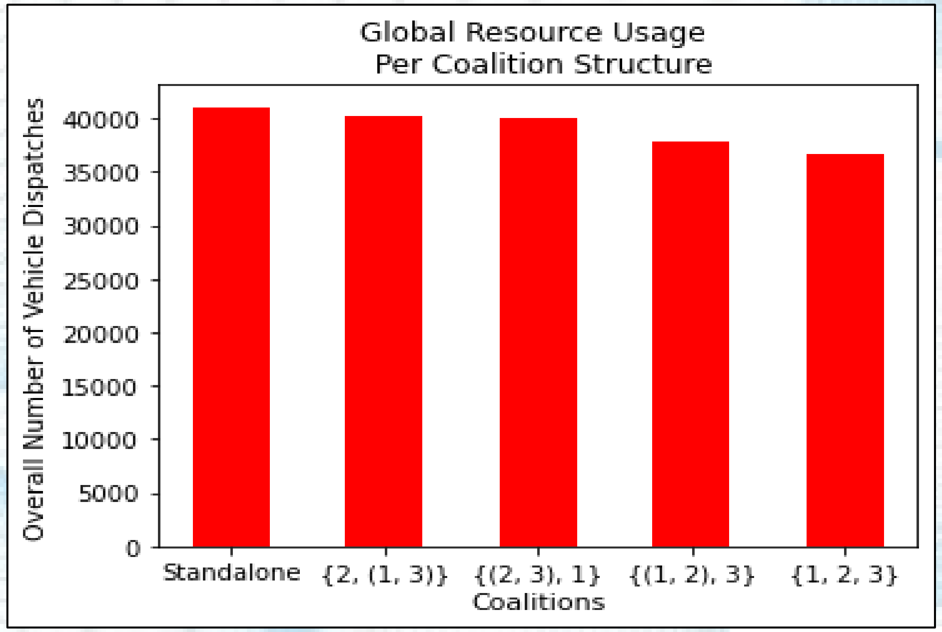
Actor	#. of open MHs	No. O-D Commodities	Cost (€)
1	19	35591	830692.29
2	3	6162	124791.77
3	8	18105	414332.01

Table 2: Summary of possible coalitions

Coalition	# of potential MHs	# of open MHs	# of O-D Commodities	Description
(1,2)	19	19	41301	Coalition of Actors 1 and 2
(1,3)	27	26	52472	Coalition of Actors 1 and 3
(2,3)	11	11	24044	Coalition of Actors 2 and 3
(1,2,3)	30	28	57968	Grand Coalition

Figure 3: Global Network Design Performance





Case Study: Impact of Cost-Sharing Methods

Figure 4: Allocated cost to actors per cost-sharing method

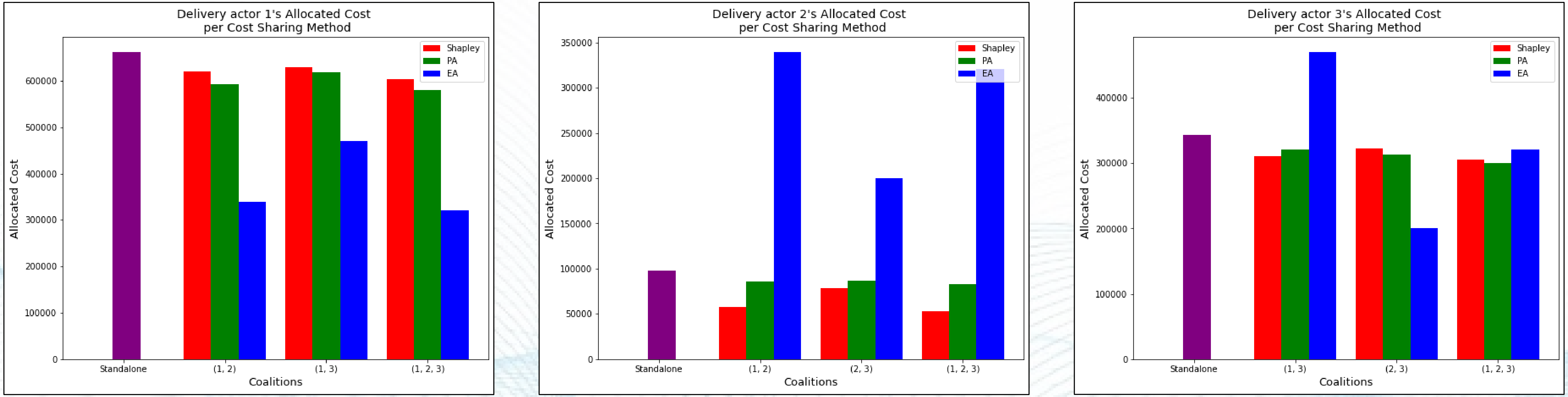
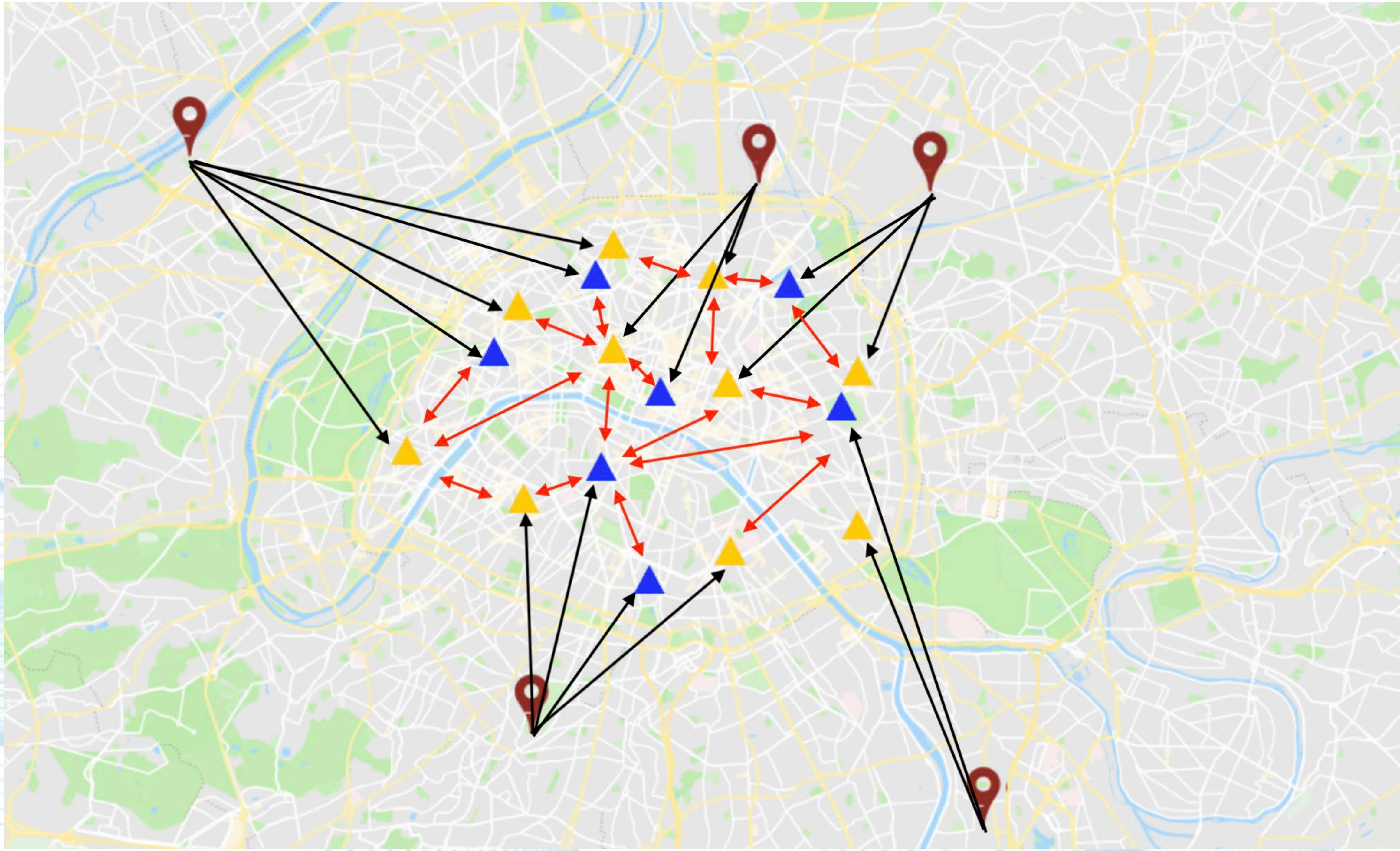


Table 3: Summary of coalitional decisions per cost-sharing method

Total No. Coalitions	**Shapley**			**Proportional (PA)**			**Egalitarian (EA)**		
	No. Cop. Actors	No. Prof. Coalitions	|Coal|	No. Cop. Actors	No. Prof. Coalitions	|Coal|	No. Cop. Actors	No. Prof. Coalitions	|Coal|
7	3	5	1	3	5	1	0	0	3

Type of connected networks



Simulation for Robust O-D Service Guarantees

: Starts every X minutes, either full or not.

Future work : introduction of robust policy for vehicle dispatch

Congestion created by a fixed number of vehicles and a rigid dispatch policy

Summary

Thank you!

Questions: johan.leveque@laposte.fr

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Robust O-D Service Guarantees

Assumptions (Dayarian et al., (2022) , Greening et al., (2022))

- Each O-D commodity arrives at its origin according to a uniform distribution
- Cargo bikes are dispatched between locations according to a uniform distribution

$\Rightarrow$ Dwell time before traversing arc a is $w_a \sim$ Uniform $(0, \frac{1}{y_a})$ with avg. of $\frac{1}{2} \cdot \frac{1}{y_a}$

$$\sum_{a \in p} t_a + \sum_{i \in p} h_i + \sum_{a \in p} \mathbb{E}[w_a] \leq \tau_k \quad \Rightarrow \sum_{a \in p} \frac{1}{2} \cdot \frac{1}{y_a} \leq \widehat{\omega}_{kp} = \tau_k - \left(\sum_{a \in p} t_a + \sum_{i \in p} h_i \right)$$

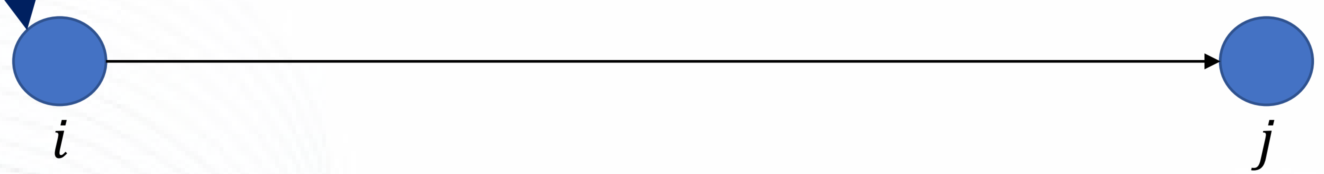
- Vehicle dispatches $\Rightarrow$ Uniform distribution
  - Restrictive
  - Over-optimistic (50%) $\Rightarrow$ not robust

- Q. Is there any other way to ensure robustness in O-D service guarantees with frequency variables?

Robust O-D Service Guarantees

n demand flows

- each with volume q_d $\forall d \in \{1,2,..n\}$
- Arriving on an interval $[0, T]$



k vehicles with capacity v such that $k * v \geq \sum_d q_d$

Policy:

- 1st vehicle must depart **either at the latest at $\frac{1}{k}$ time or when full**
  - τ_i: departure time of vehicle i
- i^{th} vehicle ($\forall i > 1$) must depart **either at the latest at $\tau_{i-1} + \frac{1}{k}$ or when full**

Robust O-D Service Guarantees

n demand flows

- each with volume q_d $\forall d \in \{1,2,..n\}$
- Arriving on an interval $[0, T]$

k vehicles with capacity v
such that $k * v \geq \sum_d q_d$

If 1[st] vehicle leaves at t
(leaving b/c it's full)

2[nd] vehicle must leave by
$t + \frac{1}{k}$

→ No flows wait more than $\frac{1}{k}$

→ We need at most 2k vehicles to ensure waiting time $\leq \frac{1}{k}$

- At most k vehicles for those leaving every $\frac{1}{k}$ time, not full
- At most k vehicles for those leaving when full

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Robust O-D Service Guarantees

➢ Theoretically, having twice more vehicles leads to 100% O-D service guarantees

- Too conservative?
- What would happen if we only increased # of vehicles by k times?
  - $k < 2$

➢ Experiments for robustness in O-D service guarantees through simulation

- Impact of different k (= 2, 1.9, 1.7, 1.5, ..) on robust O-D service guarantees

what if k < 2?

$$\min \sum_{h \in \mathcal{N}^s} f_h \cdot x_h^s + \sum_{a \in \mathcal{A}^s} 2 \cdot g_a \cdot y_a^s$$

$$\text{s.t} \quad \sum_{p \in \mathcal{P}_k^s} z_{kp}^s = 1, \qquad \forall k \in \mathcal{K}^s$$

$$\sum_{k \in \mathcal{K}^s} \sum_{p \in \{p \in \mathcal{P}_k^s : a \in p\}} q_k \cdot z_{kp}^s \leq v \cdot y_a^s, \qquad \forall a \in \mathcal{A}^s$$

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Simulation for Robust O-D Service Guarantees

: Starts every X minutes, either full or not.

Congestion created by a fixed number of vehicles and a rigid dispatch policy

Simulation for Robust O-D Service Guarantees

: Starts either when full or when it’s time → Suppose to have twice the number of trucks.
Is this really twice in practice ?

Adapted policy, delivery times are highly reduced due to an increased and flexible frequency