Modelling Ridesharing in a Large Network with Dynamic Congestion

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Outline

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1. Introduction
2. Methodology
3. Application to Île-de-France
4. Conclusion

Motivations

- **Low vehicle occupancy**, especially for commuting trips (1.05 persons per vehicle on average for commuting trips in Île-de-France, EGT, 2010)
- Increasing vehicle occupancy would decrease **congestion** and **pollution**
- The Île-de-France government proposes **subsidies to ridesharing drivers** (1.50 euros per passenger + 0.10 euro per kilometers)
- What would be the impact of a large-scale development of ridesharing?

Ridesharing

- **Ridesharing:** service by which a car **driver** shares his/her vehicle with another person (a **rider**), for a similar trip
- Different from **ride-hailing** services (like Uber or Lyft), where the driver's only purpose is to propose lifts

Ridesharing

Individual **benefits** of ridesharing:

- The trip costs (fuel, car maintenance, tolls) can be shared between the driver and the rider
- The rider does not have to drive
- The trip is more pleasant when shared?

Ridesharing

Drawbacks to the large adoption of ridesharing:

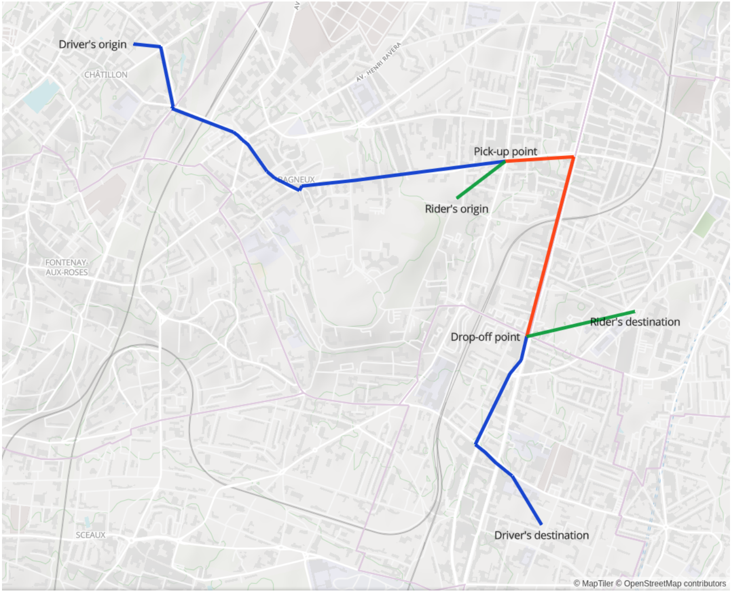
- The driver might have to make a **detour** or to **wait** for the rider
- The rider might need to **walk** to meet with the driver
- The driver's **schedule preferences** might not match the rider's schedule preferences
- Finding a **matching** driver / rider can be difficult

Ridesharing Scheme

We propose the following ridesharing scheme:

- Drivers keep their chosen route and departure time (**no detour** and **same schedule**)
- Drivers can be compensated by **state subsidies** for the (small) inconvenience cost of having someone in their car
- Riders **walk** from origin to a **pick-up point** and from a **drop-off point** to destination
- The trip is **free-of-charge** for the riders
- The **matching** between drivers and riders is centralized

Example



Driver's origin
CHÂTILLON
AV. HENRI RAVERA
Pick-up point
BAGNEUX
Rider's origin
FONTENAY-AUX-ROSES
Rider's destination
Drop-off point
SCEAUX
Driver's destination
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Results

We propose a methodology to evaluate the impact of such a ridesharing scheme, with an application to the **Île-de-France** region using the traffic simulator **METROPOLIS**.

Results with 30 % of people willing to participate in the scheme:

- **Ridesharing share:** 3.3 %
- Average **walking time** (for riders): 4 minutes and 53 seconds
- Variation of **mileage:** decrease of 204 000 vehicle-kilometers (2.2 %)

Literature Review

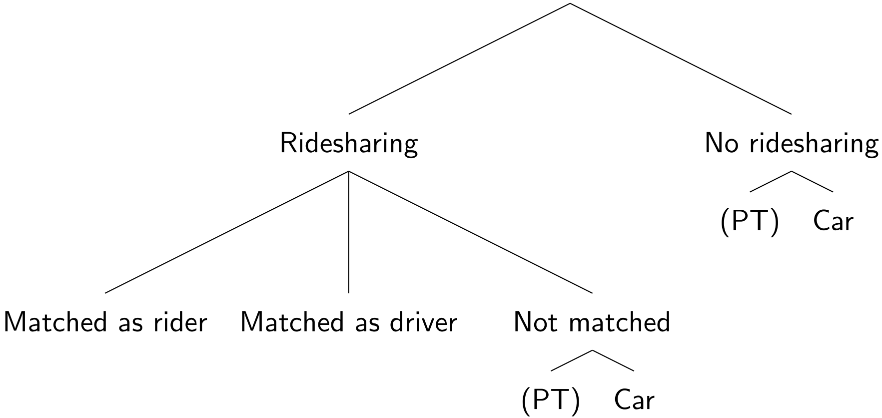
- Ridesharing **matching problem:** static (Yan and Chen, 2011; Herbawi and Weber, 2012; Liu et al., 2020) and dynamic (Agatz et al., 2011; Di Febbraro et al., 2013)
- **Benefits** of ridesharing: decreases traffic congestion (Xu et al., 2015; Cici et al., 2014), decreases CO2 emissions (Bruck et al., 2017; Chan and Shaheen, 2012)
- Study of ridesharing under **dynamic congestion:** simple bottleneck models (Qian and Zhan, 2011; Yu et al., 2019, de Palma et al., 2020), large networks (Galland et al., 2014)

Outline

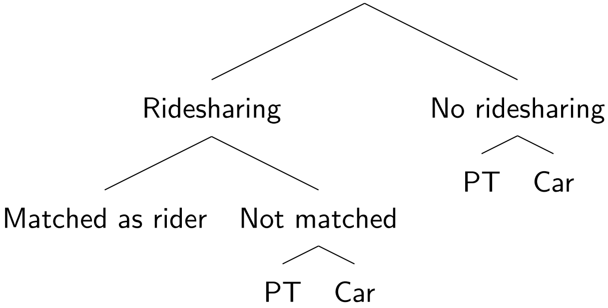
Four-Step Procedure

1. We run a simulation of **METROPOLIS without ridesharing** to identify the routes and departure times chosen
2. We compute the **ridesharing costs** for any pair of people participating in the ridesharing scheme
3. We find the **optimum matching**
4. We run a new simulation of **METROPOLIS, excluding the riders**, to get aggregate results (e.g., congestion level, mileage, mode shares)

Choices for former car drivers



Choices for former public-transit users



METROPOLIS

- **Mesoscopic dynamic traffic simulator**
- **Mode choice** between car and public transit (nested Logit model)
- **Departure-time choice** (continuous Logit model)
- **Route choice** (deterministic, minimum travel time)
- Choices are based on the **generalized travel cost**
- Congestion is modeled using **bottleneck models**

Generalized Travel Cost

The generalized travel cost by car includes **in-vehicle cost** and **schedule-delay cost** (α-β-γ model):

$$Cost_{\text{car}} = \underbrace{\alpha_{\text{car}} \cdot tt_{\text{iv}}}_{\text{In-vehicle cost}} + \underbrace{\beta \cdot [t^* - t_a]^+ + \gamma \cdot [t_a - t^*]^+}_{\text{Schedule-delay cost}}$$

- tt_{iv}: travel time (in-vehicle)
- t_a: arrival time
- t^*: desired arrival time
- α_{car}: value of time in the car
- β: penalty for early arrivals
- γ: penalty for late arrivals
- $[x]^+ = \max(0, x)$

Ridesharing Cost

The generalized travel cost for riders also includes **walking cost**:

$$Cost_{\text{RS}} = \underbrace{\alpha_{\text{car}} \cdot tt_{\text{iv}}}_{\text{In-vehicle cost}} + \underbrace{\alpha_{\text{walk}} \cdot tt_{\text{walk}}}_{\text{Walking cost}} + \underbrace{\beta \cdot [t^* - t_a]^+ + \gamma \cdot [t_a - t^*]^+}_{\text{Schedule-delay cost}}$$

- tt_{walk}: walking time (from origin to pick-up and from drop-off to destination)
- α_{walk}: walking value of time

Optimal Matching

The optimal matching is obtained by solving the following **linear programming problem:**

$$
\begin{cases}
\min\limits_{x_i, x_{i,j}} & \sum_i \left[x_i \cdot Cost_{NoRider}(i) + \sum_j x_{j,i} \cdot Cost_{Rider}(i,j) \right] \\
\text{s.t.} & x_i + \sum_j x_{j,i} = 1, \quad \forall i \\
& \sum_j x_{i,j} \leq x_i, \quad \forall i \\
& x_i \in \{0,1\}, \quad \forall i \\
& x_{j,i} \in \{0,1\}, \quad \forall (i,j)
\end{cases}
$$

- $Cost_{NoRider}(i)$: travel cost of i when not a rider (car or public transit)
- $Cost_{Rider}(i,j)$: ridesharing cost of i when matched with driver j
- $x_i = 1$ if i travels by car or public transit (0 otherwise)
- $x_{j,i} = 1$ if j is a driver for i (0 otherwise)

Optimal Matching

- The optimal matching is optimal in the sense that it **minimizes the sum of the generalized travel cost**
- The program does not maximizes the number of matches or CO2 emissions reduction
- The matching cost of riders is always smaller than their cost as non-rider
- Riders are not matched with the best driver for them if he/she is not available
- The minimization program can be modified to allow **more than one driver per car** / **incentives to riders**

Outline

Data

- **Morning peak-period**
- Network: 43 857 links, 18 584 intersections and 1360 OD zones
- Demand: 934 042 trips by car or public-transit (commute and non-commute)
- Calibration of METROPOLIS from Saifuzzaman et al., 2012 (EGT 2001)

Assumptions

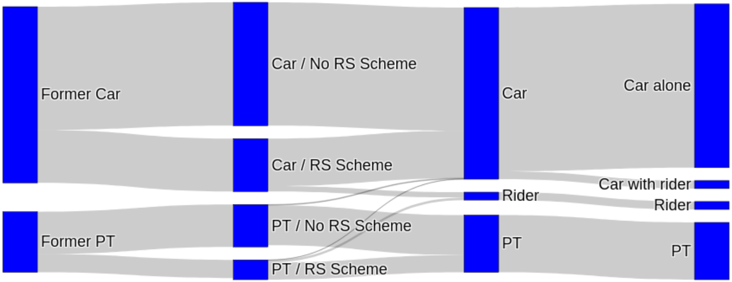
- The walking distance between an origin / destination and an intersection is the **euclidian distance**
- Walking speed is set to **4 km/h**
- $\alpha_{\text{car}} = 12.96$, $\alpha_{\text{PT}} = 13.24$, $\alpha_{\text{walk}} = 14.96$

Ridesharing Participation

- Assumption: A **fixed share of people are willing to participate in the ridesharing scheme** (as either a driver or a rider)
- Interpretation: Some people **cannot** do ridesharing for specific reasons (e.g., drive their children to school, have stuff in their trunk)
- Interpretation 2: For **x** % of the people, being with someone else in the car is better than being alone
- We will test different values: 10 %, 20 %, 30 %, 40 %

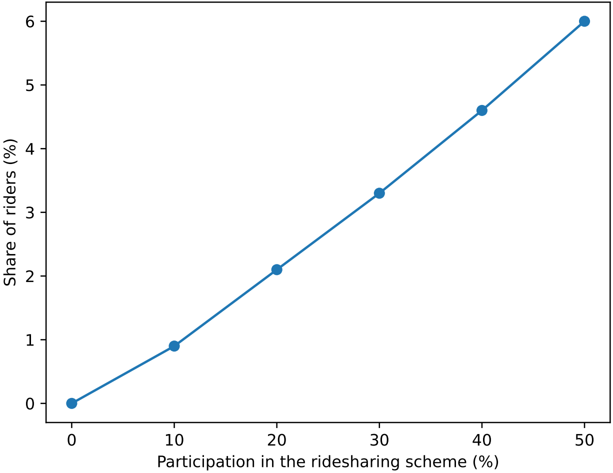
Mode Shifts

Mode shifts in the 30 % scenario:



Detailed results

Ridesharing share



Aggregate Results

Scenario	Ref.	10 %	20 %	30 %	40 %
Shares					
Transit modal share	25.5 %	25.3 %	24.8 %	24.3 %	23.9 %
Car modal share	74.5 %	73.9 %	73.2 %	72.4 %	71.5 %
Ridesharing modal share	0.0 %	0.9 %	2.1 %	3.3 %	4.6 %
Surplus					
Individual surplus variation (euros)	—	+72 763	+187 686	+305 683	+427 401
CO_2 emissions reduction (tons of CO_2)	—	11.387	21.809	39.372	57.900
Road network					
Congestion	22.1 %	21.7 %	21.4 %	20.6 %	19.8 %
Car VKT (10^3 km)	10 799	10 740	10 686	10 595	10 499

Drivers' Results

Scenario	Ref.	10 %	20 %	30 %	40 %
Mean travel time	15' 32"	15' 31"	15' 32"	15' 27"	15' 22"
Mean schedule-delay cost (euros)	2.67	2.67	2.67	2.67	2.65
Mean travel cost (euros)	6.03	6.02	6.02	6.00	5.97
Share of time spent with a passenger (for ridesharing drivers only)	—	51.5 %	56.1 %	58.0 %	59.8 %

Riders' Results

Scenario	Ref.	10 %	20 %	30 %	40 %
Mean OD distance (meters)	—	5491	5972	6205	6425
Mean walking distance (meters)	—	383	347	325	310
Mean car travel time	—	7' 21"	8' 00"	8' 20"	8' 38"
Mean travel time	—	13' 06"	13' 12"	13' 13"	13' 17"
Mean travel cost (euros)	—	3.26	3.24	3.22	3.22
Riders at their best match	—	76.7 %	69.3 %	65.0 %	62.2 %

Multiple Passengers: Aggregate Results

Passengers per driver	1	2	3
Shares			
Transit modal share	24.3 %	24.1 %	24.0 %
Car modal share	72.4 %	71.9 %	71.8 %
Ridesharing modal share	3.3 %	4.0 %	4.2 %
Surplus			
Individual surplus variation (euros)	+305 683	+368 724	+393 185
CO2 emissions reduction (tons of CO2)	39.372	51.145	50.373
Road network			
Congestion	20.6 %	20.1 %	19.6 %
Car VKT (10^3 km)	10 595	10 534	10 538

Note: Assuming 30 % of participation in the ridesharing scheme

Multiple Passengers: Drivers' Results

Passengers per driver	1	2	3
Drivers			
Mean travel time	15' 27"	15' 22"	15' 20"
Mean schedule-delay cost (euros)	2.67	2.66	2.65
Mean travel cost (euros)	6.00	5.98	5.96
Ridesharing drivers			
Number of drivers with a passenger	31 168	24 764	22 695
Average number of passengers	1.0	1.5	1.7
Share of time spent with a passenger	58.0 %	59.4 %	59.7 %

Multiple Passengers: Riders' Results

Passengers per driver	1	2	3
Mean OD distance (meters)	6205	6174	6164
Mean walking distance (meters)	325	325	327
Mean car travel time	8' 20"	8' 23"	8' 23"
Mean travel time	13' 13"	13' 15"	13' 17"
Mean travel cost (euros)	3.22	3.26	3.27
Riders at their best match	65.0 %	72.7 %	76.0 %

Incentives to Riders: Aggregate Results

Incentive amount per rider	0 euro	0.5 euro	1 euro	1.5 euros
Shares				
Transit modal share	24.2 %	24.0 %	23.8 %	23.8 %
Car modal share	72.5 %	72.3 %	72.1 %	71.8 %
Ridesharing modal share	3.3 %	3.7 %	4.1 %	4.4 %
Road network				
Congestion	22.0 %	20.5 %	21.6 %	21.6 %
Car VKT (10^6 km)	10.61	10.58	10.57	10.58
Surplus				
Individual surplus variation (euros)	48 830	65 150	83 680	102 650
Expenses (euros)	0	17 420	38 130	61 000

Incentives to Riders: Drivers' Results

Incentive amount per rider	0 euro	0.5 euro	1 euro	1.5 euros
Mean travel time	15' 41"	15' 28"	15' 41"	15' 41"
Mean schedule-delay cost (euros)	2.67	2.66	2.67	2.67
Mean travel cost (euros)	6.06	6.00	6.06	6.06
Share of time spent with a passenger (for ridesharing drivers only)	58.0 %	55.1 %	52.9 %	51.1 %

Incentives to Riders: Riders' Results

Incentive amount per rider	0 euro	0.5 euro	1 euro	1.5 euros
Mean euclidian OD distance (meters)	6205	6077	6010	5970
Mean walking distance (meters)	325	366	406	449
Mean car travel time	8' 20"	8' 10"	8' 03"	7' 58"
Mean travel time	13' 13"	13' 39"	14' 9"	14' 41"
Mean travel cost (euros)	3.22	3.34	3.48	3.63
Riders at their best match	65.0 %	60.7 %	56.2 %	52.9 %

Outline

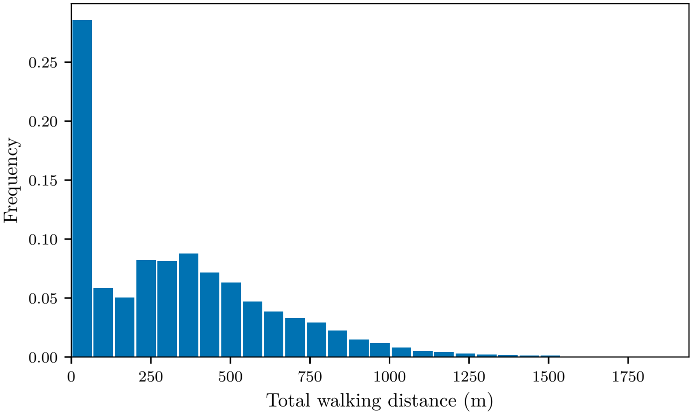
Concluding remarks:

- Ridesharing is an **effective tool to reduce congestion and CO2 emissions**
- Because of **network effects**, state intervention through **subsidies** might be needed to start-up a shift to ridesharing

Possible extensions:

- Allowing **multi-hopping** (two or more drivers for a single rider) and **intermodality** (e.g., ridesharing trip then public-transit)
- Considering **morning and evening commute** together

Walking Distance



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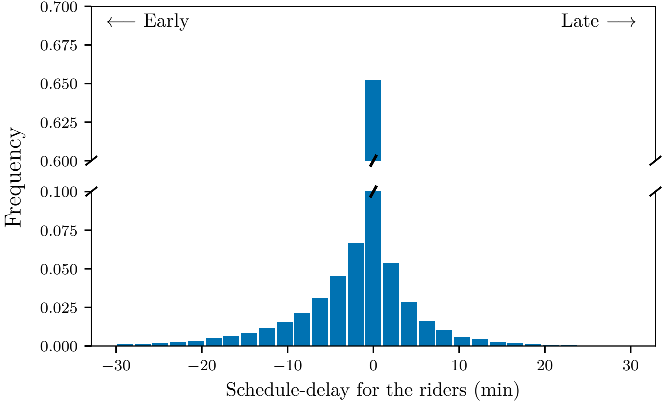
Riders' Schedule-Delay



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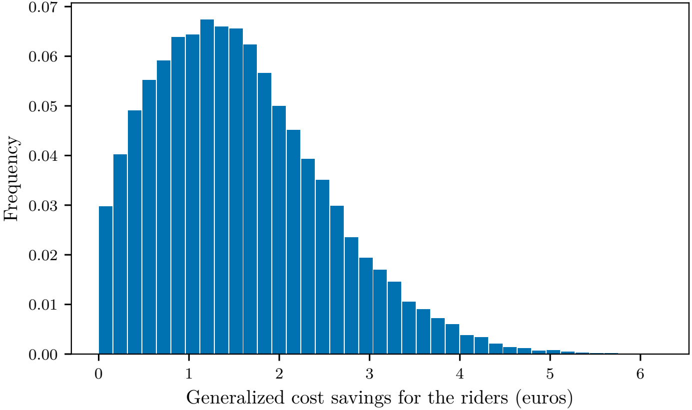
Generalized Cost Savings



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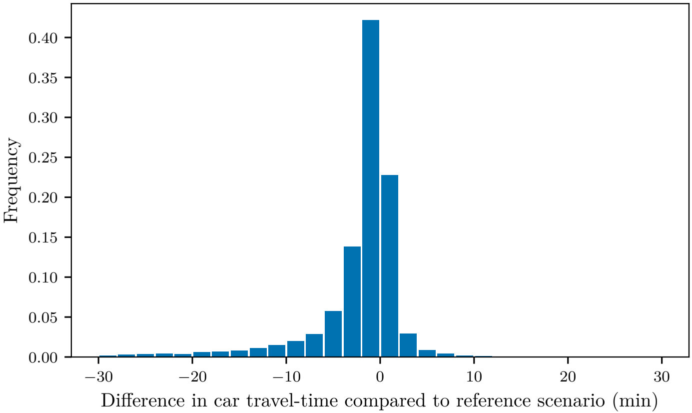
Car Travel-Time Variation



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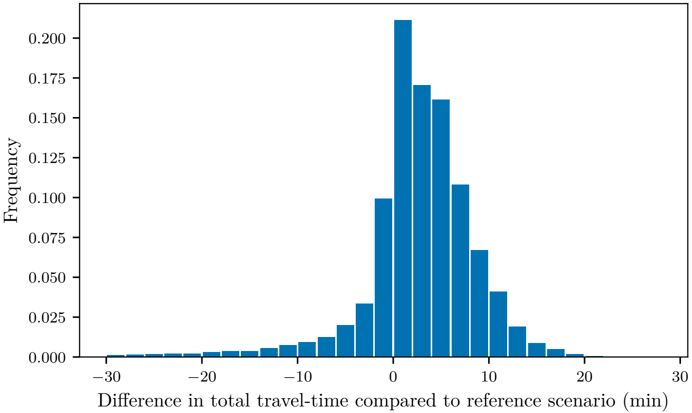
Total Travel-Time Variation



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