

Agent-based modeling of big cities in France: opportunities and challenges

The case study of Paris Greater Area and Rouen Normandie Metropolitan

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“Shared Autonomous Vehicle service design, modeling, and simulation”

Transport modeler with over 6 years of experience on Transportation Planning, Modeling and Simulation

Publications

Rouen Metropolitan Area

- Vosooghi, R., Puchinger, J., Jankovic, M., Vouillon, A., 2019. Robo-Taxi Service Design, Modeling and Simulation. In *Transportation Research Part C (2019)*.
- Vosooghi, R., Kamel, J., Puchinger, J., Leblond, V. and Jankovic, M., 2019 . Robo-Taxi Service Fleet Sizing: Assessing the Impact of User Trust and Willingness to Use. In *Transportation (2019)*.
- Vosooghi, R., Puchinger, J., Bischoff, J., Jankovic, M., Vouillon, A., 2019. Shared Autonomous Electric Vehicle Service Performance: Assessing the Impact of Charging Infrastructure and Battery Capacity. In *Transportation Research Part D (2019)*. Under revision.

Paris Greater Area

- Kamel, J., Vosooghi, R., Puchinger, J., Ksontini, F., Sirin, G., 2018. Exploring the Impact of User Preferences on Shared Autonomous Vehicle Modal Split: A Multi-Agent Simulation Approach. In *Transportation Research Procedia*, 37, (pp.115-122).

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Data preparation



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Case studies



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Limitations and issues

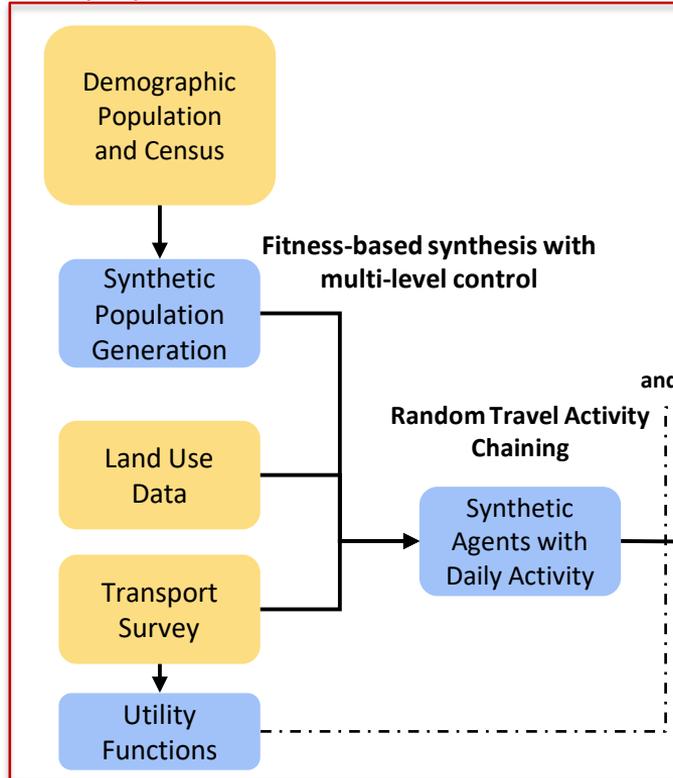


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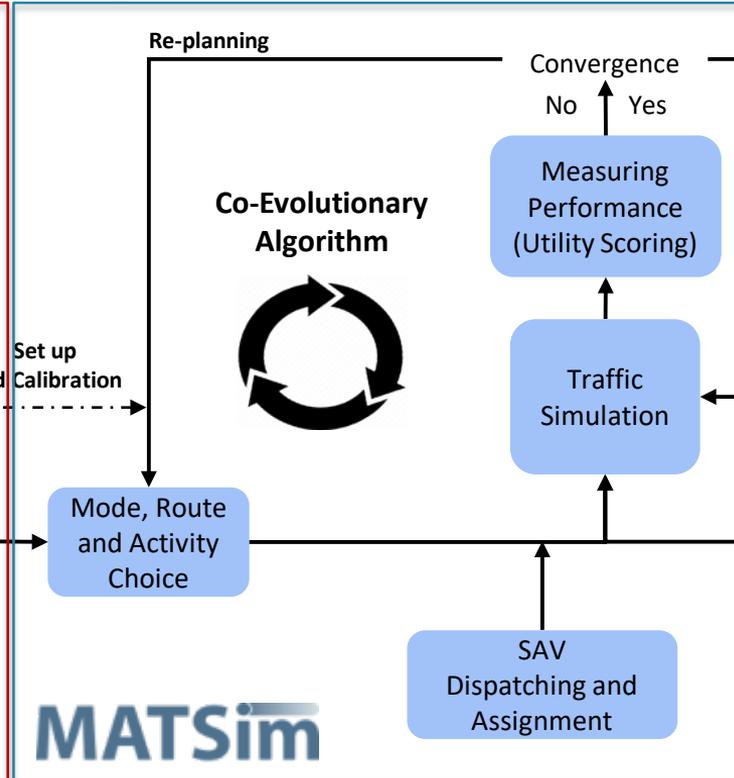
Conclusion



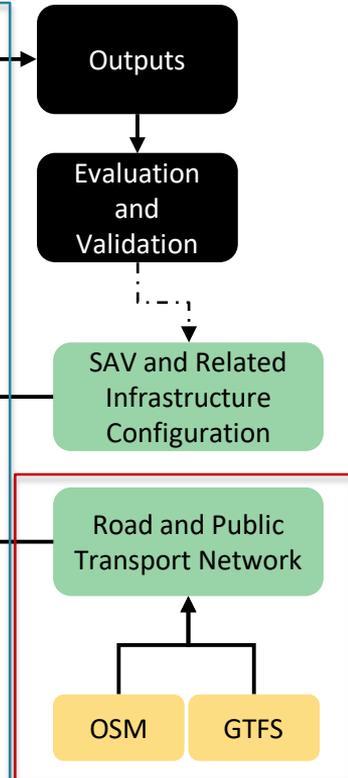
Data preparation



Multi-agent simulation



Simulation framework



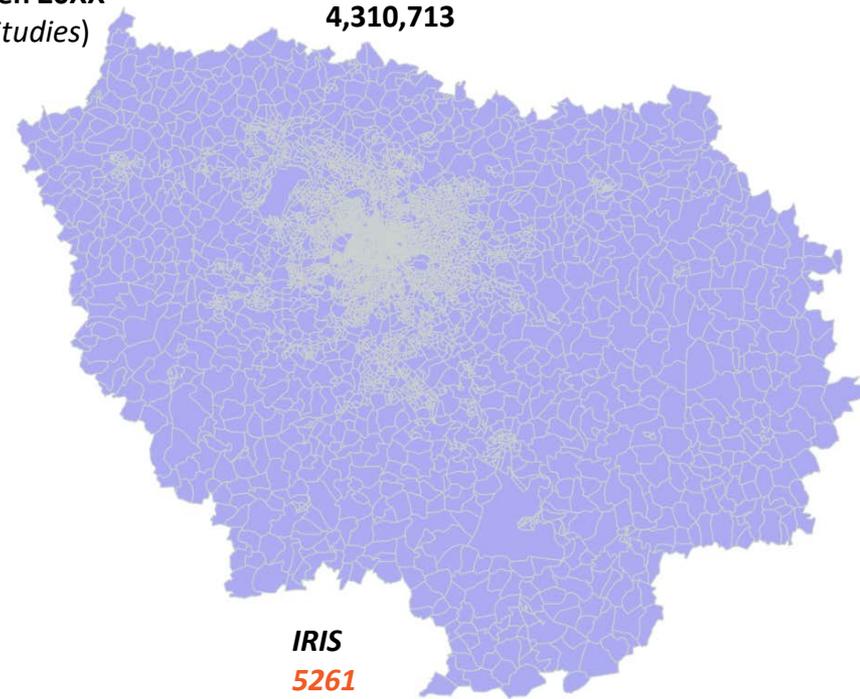
Synthetic population generation

Demographic
Population
and Census

INSEE : Individus localisés au canton-ou-ville en 20XX
(National Institute of Statistics and Economic Studies)

IRIS: IRIS code of place of residence

INSEE 2013
4,310,713



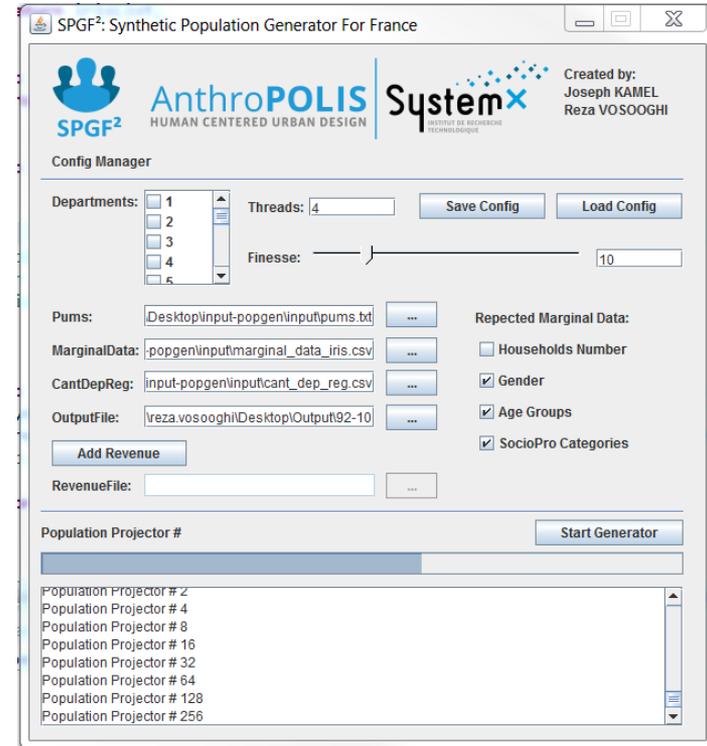
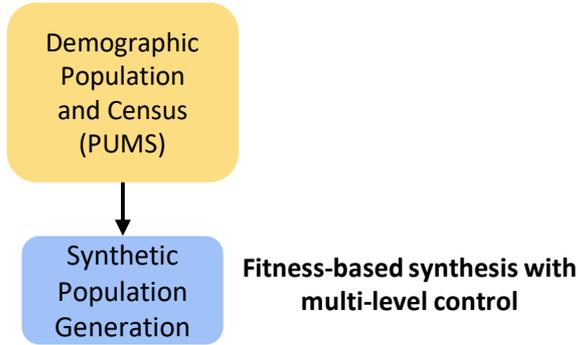
IRIS
5261

1	2	3	4	5	6	7	8
CANTVILLE	NUMMI	ACHLR	AEMMR	AGED	AGER20	AGEREV	AGEREVQ
7599	1	4	9	060	64	059	055
7599	1	4	9	062	64	061	060
7599	2	1	9	024	24	023	020
7599	3	3	9	052	54	051	050
7599	4	3	9	046	54	045	045
7599	4	3	9	016	17	015	015
7599	4	3	9	012	14	011	010
7599	4	3	9	045	54	044	040

Source : INSEE - fichier Individus (localisation au canton-ou-ville) 2013



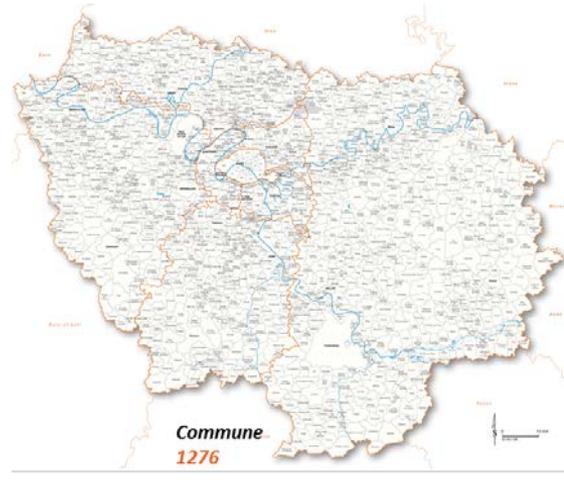
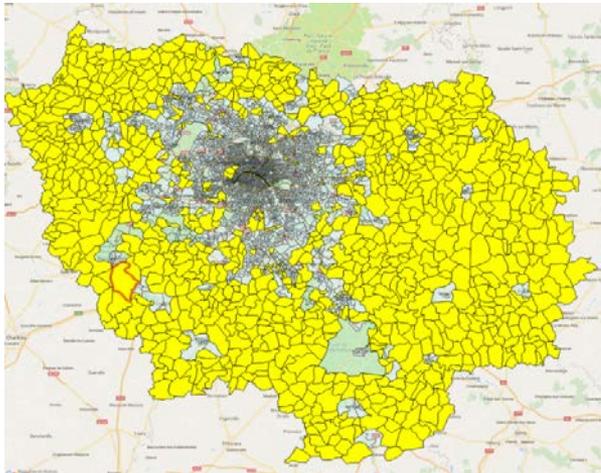
Synthetic population generation



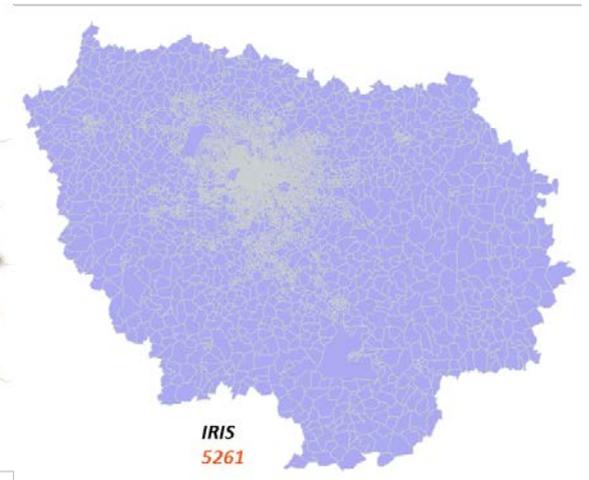
Synthetic population generation

Anonymized IRIS

304,525 over 4,310,713



Commune
1276

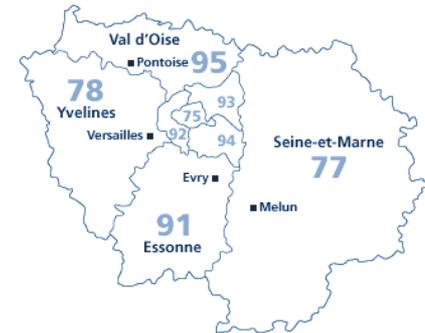
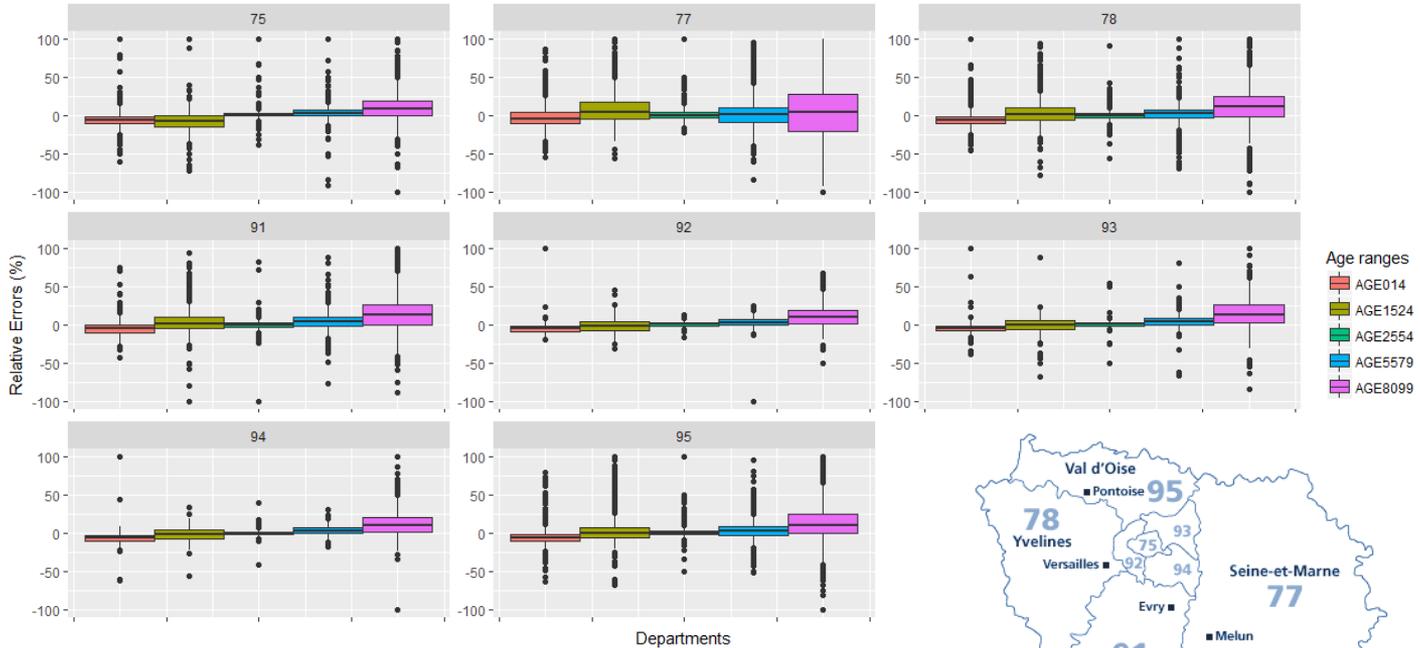


IRIS
5261

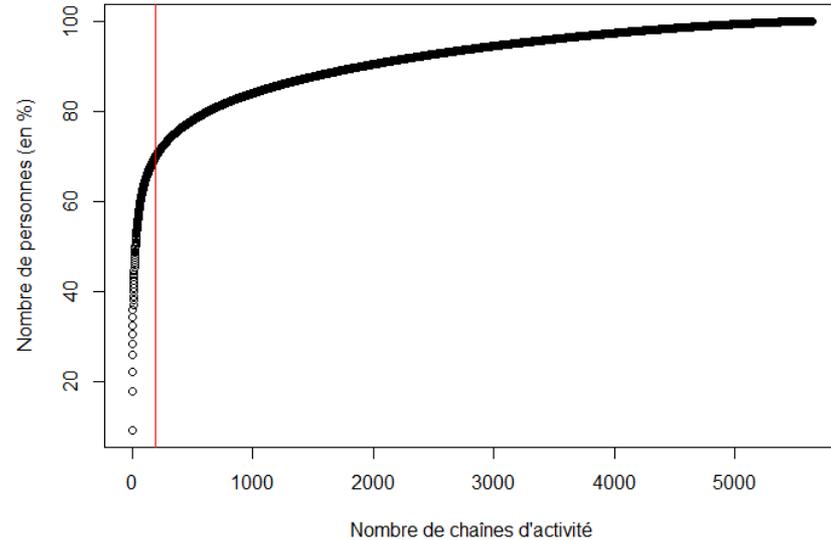
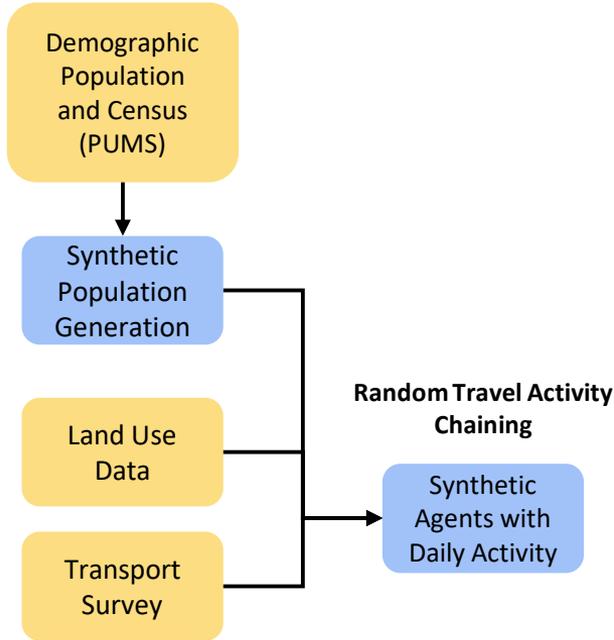


Synthetic population generation

Relative errors of synthetic and real populations by age ranges and departments



Activity chain allocation

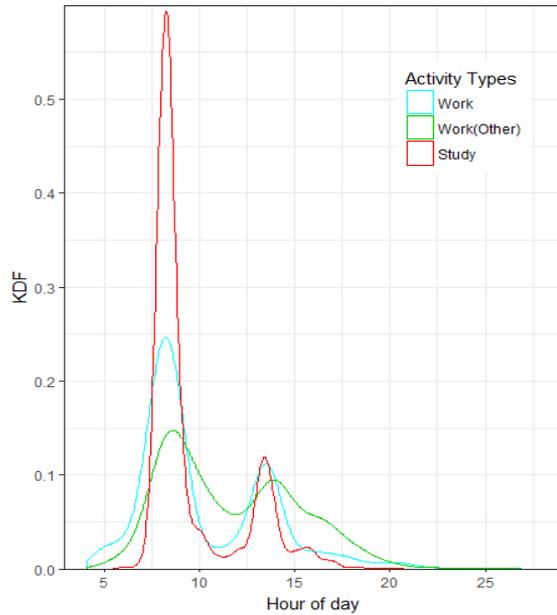


5,637 Different activity chains
200 Common activity chains for **75%** of persons

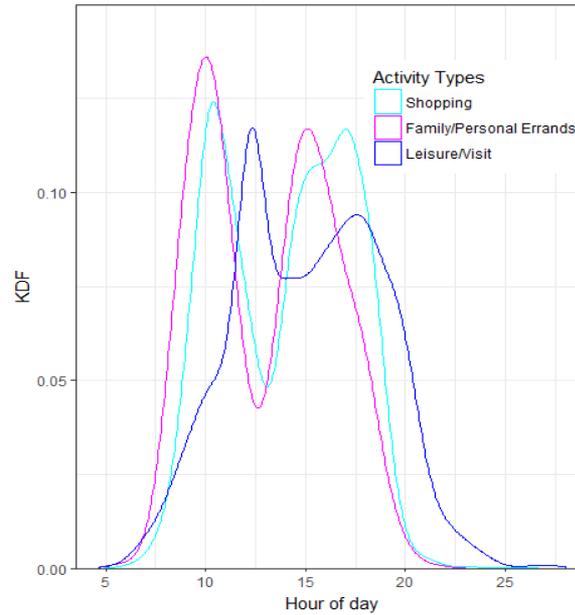


Activity chain allocation

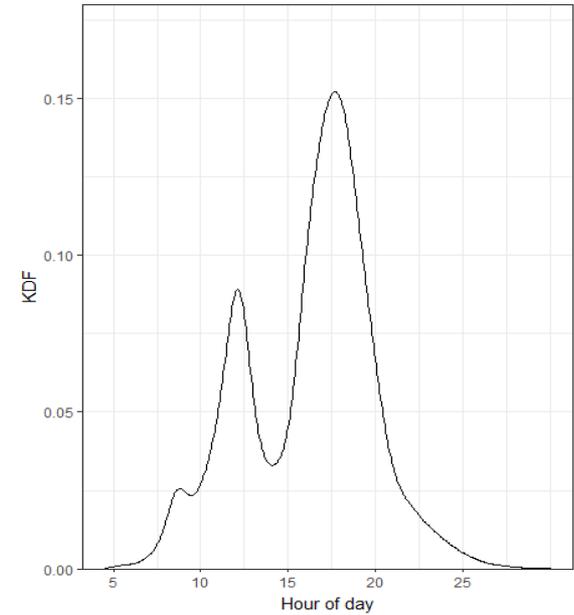
Activity Start Time Models



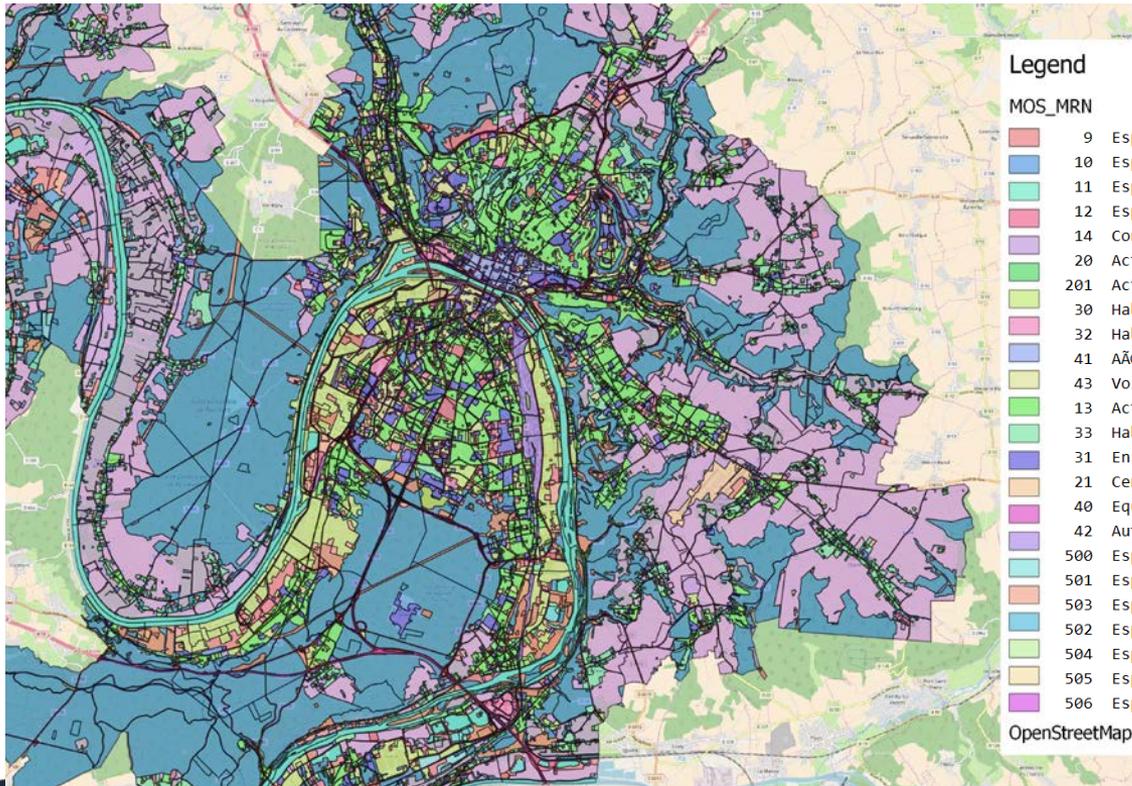
Activity Start Time Models



Home Activity Start Time Model



Activity chain allocation



Legend

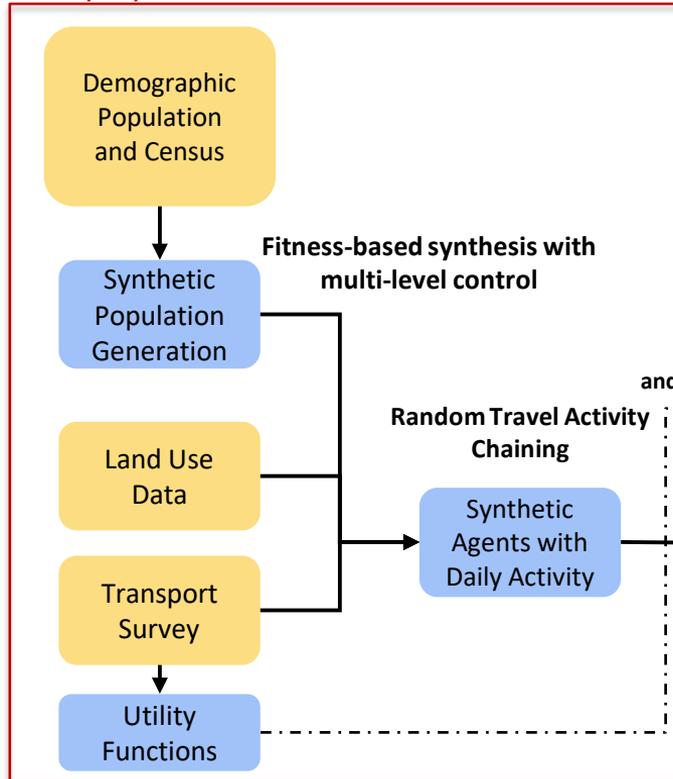
MOS_MRN

- 9 Espace non boisé, non agricole
- 10 Espace boisé
- 11 Espace naturel aquatique
- 12 Espaces de loisir et d'agrément
- 14 Construction en milieu rural
- 20 Activités industrielles et/ou artisanales et/ou tertiaires, hors carrières
- 201 Activités de carrières
- 30 Habitat dense, continu, hypercentre
- 32 Habitat individuel dense
- 41 Aéroport, ports et installations portuaires, gare routière, ferroviaire,
- 43 Voie ferrée
- 13 Activité agricole
- 33 Habitat individuel peu dense
- 31 Ensemble d'habitat collectif dominant
- 21 Centre commercial, hypermarché, supermarché
- 40 Equipement avec son parking (public, privé)
- 42 Autoroute, route essentielle, échangeur
- 500 Espaces en cours d'évolution sans affectation
- 501 Espaces en cours d'évolution pour les espaces ruraux
- 503 Espaces en cours d'évolution pour l'activité commerciale
- 502 Espaces en cours d'évolution pour l'activité non commerciale
- 504 Espaces en cours d'évolution pour l'habitat
- 505 Espaces en cours d'évolution pour les équipements
- 506 Espaces en cours d'évolution pour les équipements modaux

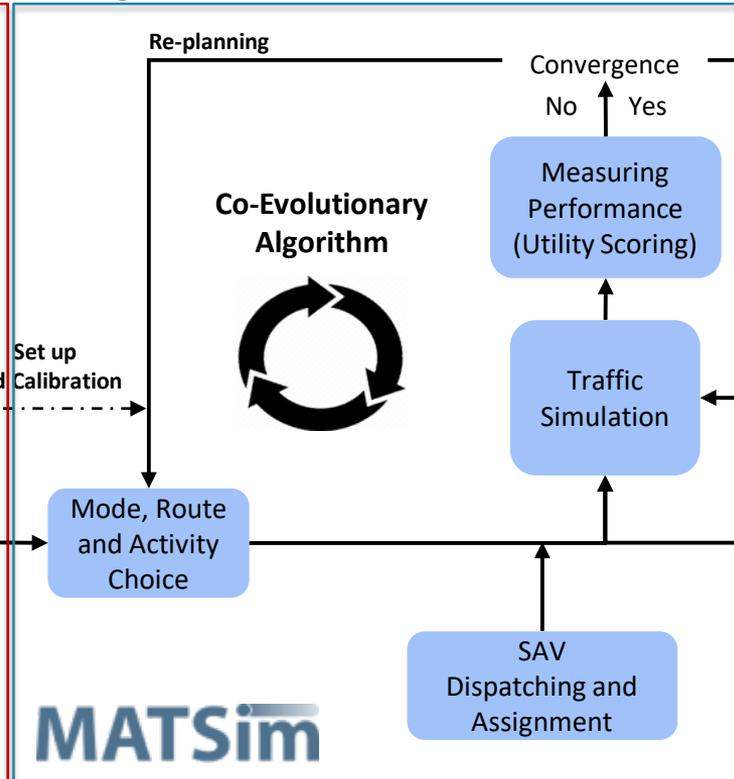
OpenStreetMap



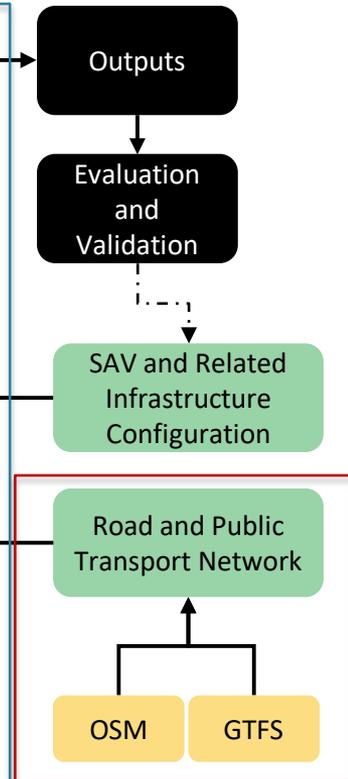
Data preparation



Multi-agent simulation

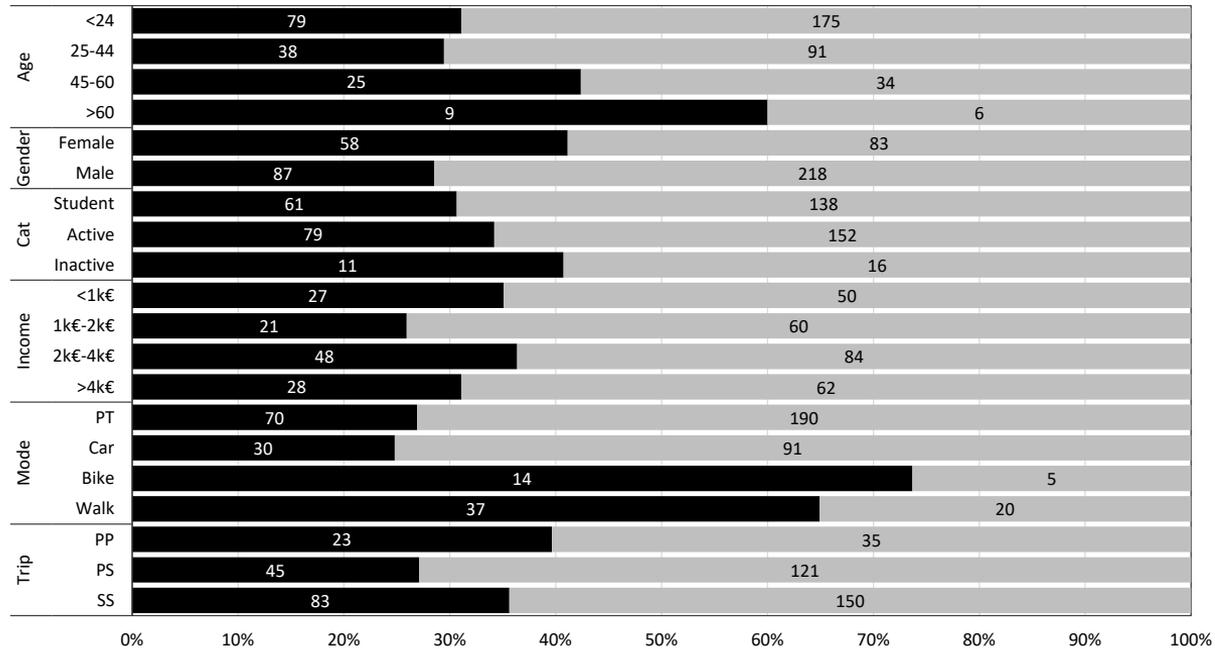


Simulation framework



ANSWER A PRIORI

Results – User Trust



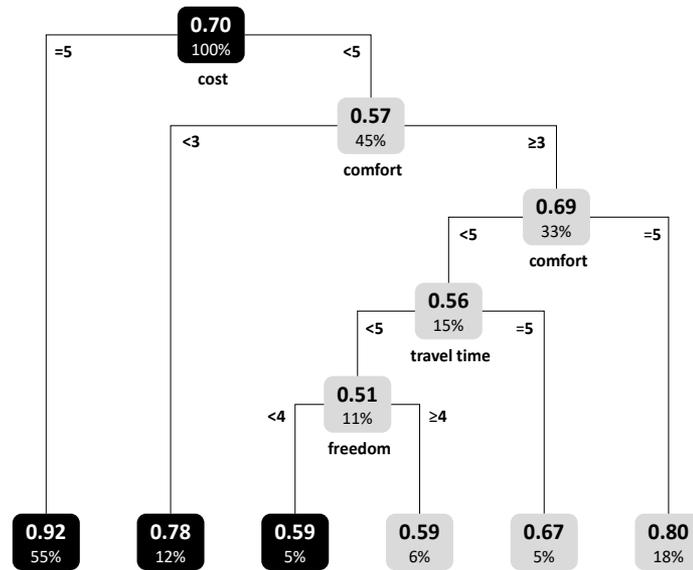
PP: Paris-Paris
PS: Paris-suburban
SS: suburban-suburban

■ No ■ Yes

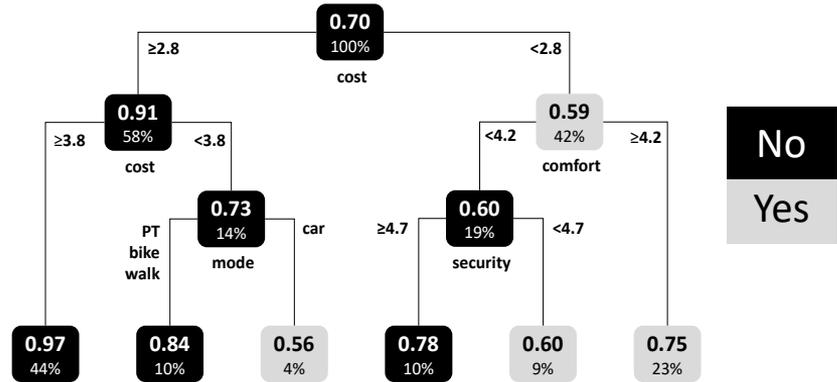
A POSTERIORI ANSWER

Results – Willingness to Use

(a)



(b)



No
Yes

SAVs regression trees of
(a) willingness-to-use and (b) unwillingness-to-use

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Data preparation

2

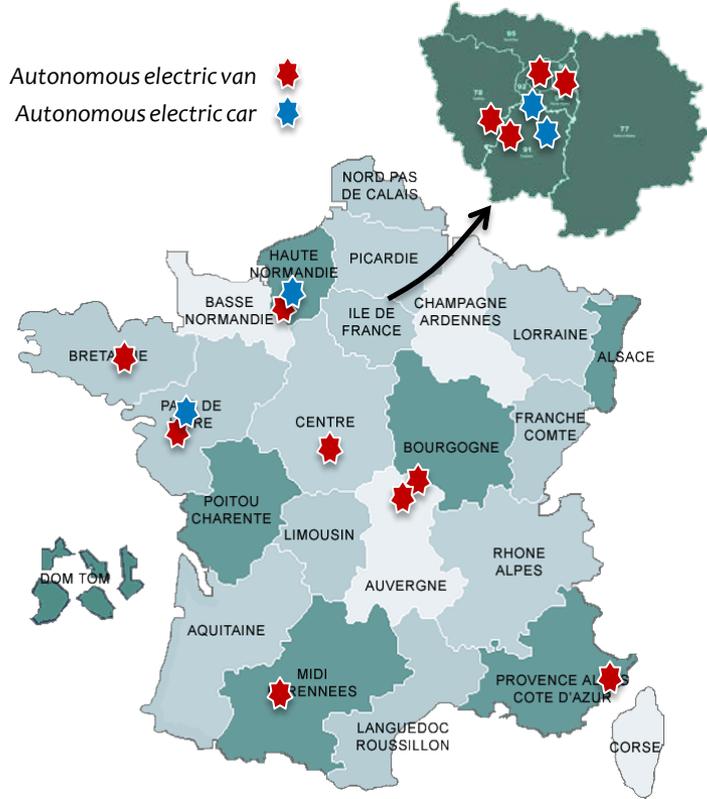
Case studies

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Limitations and issues

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Conclusion



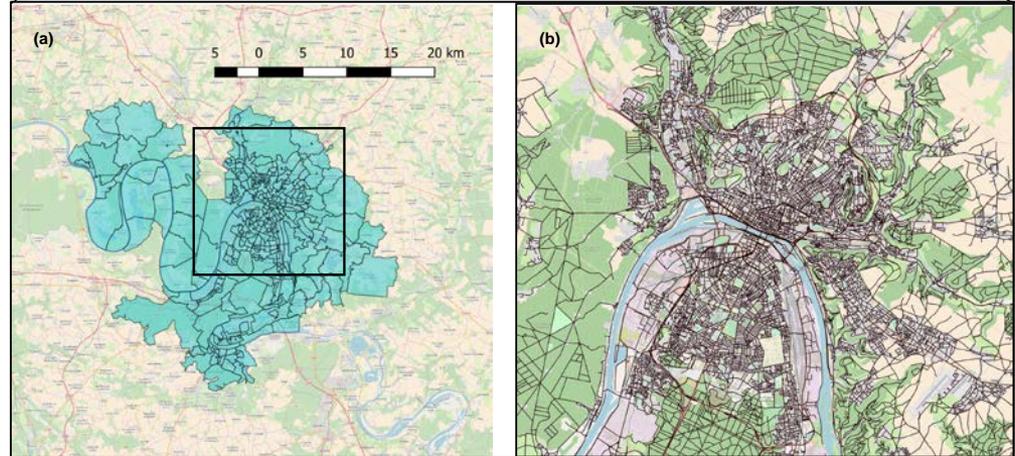
SAV ongoing experimentations in France



Real-world case study

Rouen Normandie metropolitan area

- ◆ about **500,000** inhabitants
- ◆ Recent transport survey (EMD 2017)
- **5,059** Households
- **11,107** Individuals (**9,247**)
- **38,146** Trips
- **30,342** Journey
- **929** Activity Chains
- **19** ones are common for 50%
- **124** ones are common for 75%



Scenarios

1. *Single ride (S1)*

- Price : 0.5 € per kilometer

2. *Ridesharing*

- Price : 0.4 € per kilometer
- Vehicle capacities :
 - 2-seats small car (S2)
 - standard 4-seats car (S3)
 - 6-seats minivan (S4)

3. *Rebalancing*

- Cost flow minimization

4. *Various fleet size (2.0 k to 6.0 k)*





Results - Modal splits

Scenario	Fleet size Mode	2000	2500	3000	3500	4000	4500	5000	5500	6000
S1- non-ridesharing										
	Car	59.3	58.8	58.5	58.3	58.0	57.7	57.6	57.4	57.5
	Walk	28.3	28.3	28.2	28.2	28.2	28.2	28.2	28.1	28.1
	SAV	3.1	4.4	5.3	6.0	6.5	6.9	7.2	7.5	7.6
	PT	9.2	8.4	8.0	7.6	7.3	7.1	7.1	6.9	6.8
S2- ridesharing (2-seats small car)										
	Car	59.1	58.8	58.5	58.3	58.1	57.8	57.7	57.8	57.7
	Walk	28.3	28.3	28.3	28.2	28.2	28.3	28.3	28.2	28.2
	SAV	3.8	4.6	5.2	5.9	6.3	6.5	6.7	6.9	7.0
	PT	8.8	8.3	8.0	7.6	7.5	7.3	7.2	7.1	7.1
S3- ridesharing (standard 4-seats car)										
	Car	58.9	58.7	58.3	58.1	58.0	57.9	57.8	57.7	57.7
	Walk	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
	SAV	4.0	4.6	5.3	5.9	6.0	6.4	6.6	6.8	6.8
	PT	8.7	8.3	8.0	7.7	7.6	7.4	7.3	7.2	7.2
S4- ridesharing (6-seats minivan)										
	Car	59.1	58.8	58.4	58.2	58.0	57.9	57.8	57.8	57.7
	Walk	28.2	28.3	28.3	28.3	28.3	28.3	28.3	28.2	28.2
	SAV	4.1	4.6	5.4	5.9	6.1	6.4	6.8	6.7	6.9
	PT	8.6	8.3	7.9	7.6	7.5	7.4	7.3	7.2	7.1

Best scenario - 3000 SAVs (standard 4setas car)

	SAV service with unlimited range
SAV modal share (%)	5.3
Average waiting time (min)	20.7
Average in-vehicle time (min)	46.0
Average detour time (min)	6.1
Fleet usage ratio (%)	50
Empty distance ratio (%)	15
In-vehicle PKT (km)	1.97 M
1 PAX ratio (%)	67
2 PAX ratio (%)	26
3 PAX ratio (%)	6
4 PAX ratio (%)	1
Average driven distance (km)	546
Max. driven distance (km)	866

SAEV

- 3000 standard 4-seats car
- Price : 0.4 € per kilometer
- Renault Zoe specification
- Battery capacities : 41 and 50 kWh
- Ride-sharing
- No rebalancing

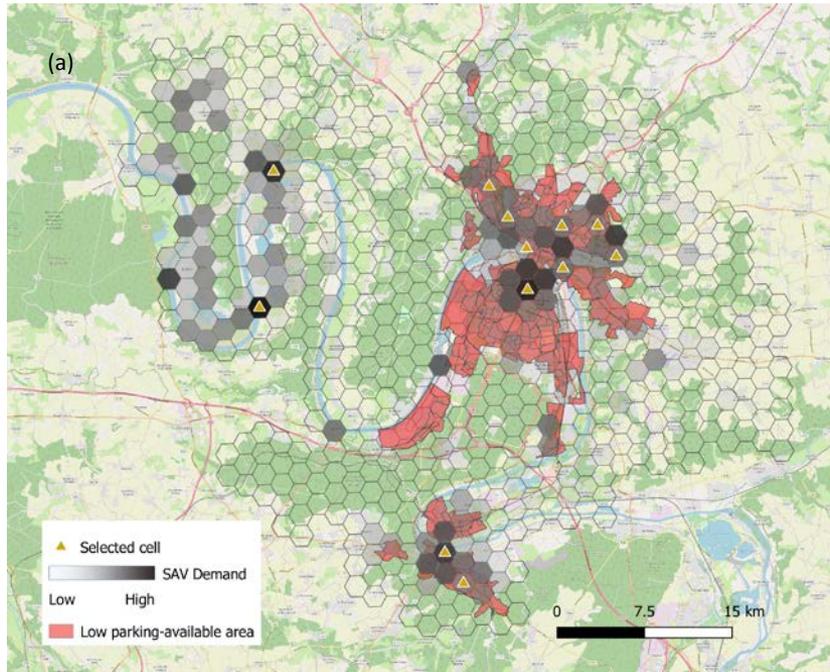
1. CS placement

- Medium and long range
- Normal (22) Rapid charging (43)

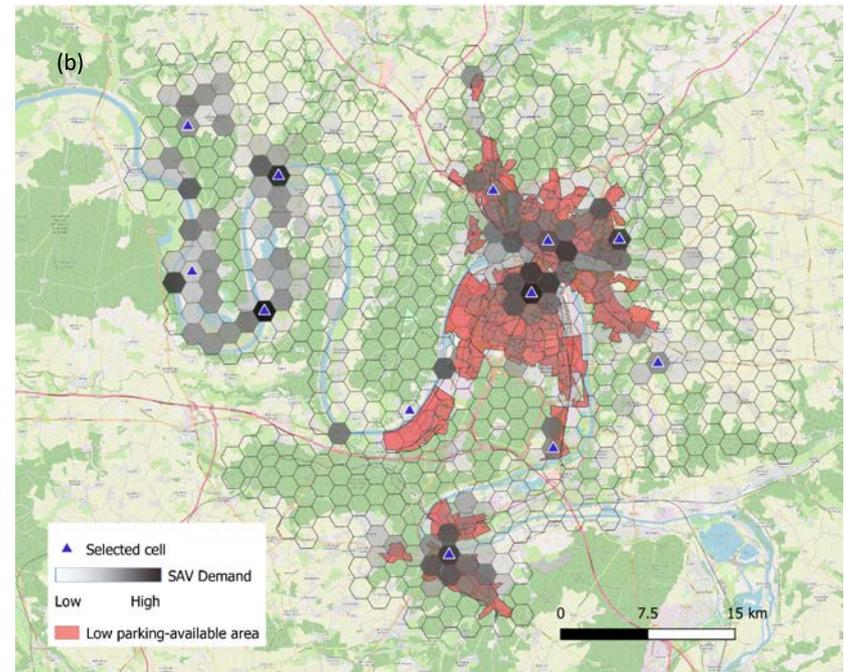
2. BSS

- Medium and long range

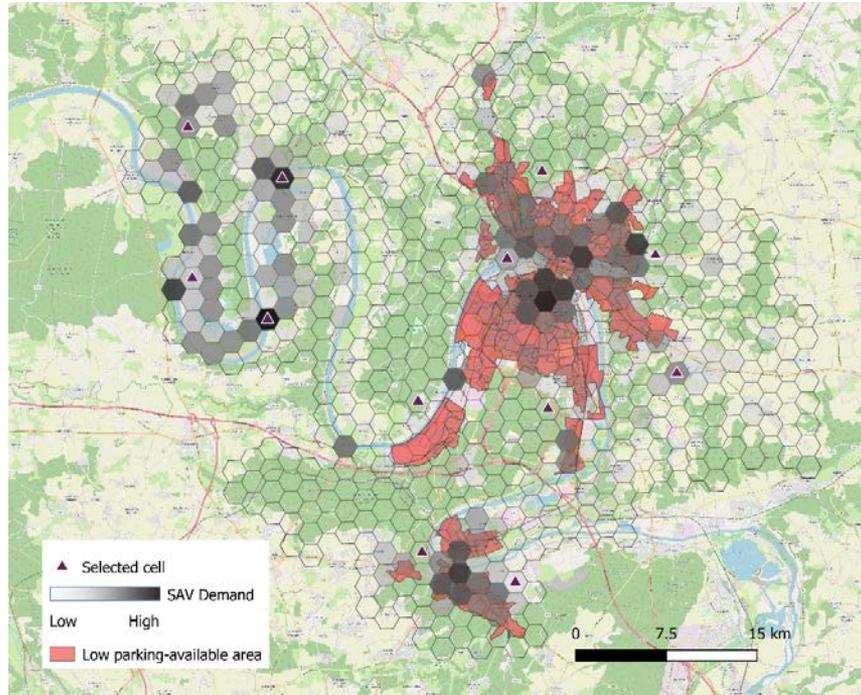




(a) MCLP



(b) P-Median



Locating charging stations outside the areas with low parking availability
employing P-Median optimization

Normal charging

Summary of SAEV service performance and user-related indicators.

Scenario	MCLP		P-Median		P-Median with constraint	
	Medium-Range	Long-Range	Medium-Range	Long-Range	Medium-Range	Long-Range
<i>SAEV</i>						
Battery capacity (kWh)	41	50	41	50	41	50
Modal share (%)	3.8	4.0	4.2	4.4	4.1	4.3
Fleet usage ratio (%)	31.5	34.5	36.5	38.7	35.6	41.3
Empty distance ratio (%)	21.7	19.9	19.6	18.6	19.1	18.7
In-vehicle PKT (km)	1.04 M	1.19 M	1.13 M	1.38 M	1.22 M	1.44 M
Average driven distance (km)	336	365	385	409	373	443
Max. driven distance (km)	660	682	650	698	735	667
<i>Charging station</i>						
Total plugged time (min)	381 300	399 700	433 800	451 150	443 300	496 500
Total queue time (min)	400 500	518 550	571 250	606 300	383 800	486 900
<i>User</i>						
Average waiting time (min)	13.5	13.4	13.3	13.9	13.3	13.2
Average in-vehicle time (min)	41.4	42.2	43.2	43.6	42.7	44.2
Average detour time (min)	4.7	4.9	5.0	4.8	4.9	5.3
1 PAX ratio (%)	72	72	67	67	70	70
2 PAX ratio (%)	24	24	28	28	25	25
3 PAX ratio (%)	3	3	4	4	4	4
4 PAX ratio (%)	<1	<1	<1	<1	<1	<1

Fast charging

Summary of SAEV service performance indicators and the changes after deploying rapid charging infrastructures.

Scenario	MCLP		P-Median		P-Median – with constraint	
	Medium-Range	Long-Range	Medium-Range	Long-Range	Medium-Range	Long-Range
<i>SAEV</i>						
Fleet usage ratio (%)	37.5	41.2	41.4	42.7	41.6	42.3
(relative change)	(+19%)	(+19%)	(+13%)	(+10%)	(+14%)	(+2%)
Empty distance ratio (%)	22.8	22.7	19.2	18.3	21.1	18.8
(relative change)	(+5%)	(+14%)	(-2%)	(-2%)	(+10%)	(+1%)
In-vehicle PKT (km)	1.24 M	1.39 M	1.43 M	1.56 M	1.42 M	1.56 M
(relative change)	(+19%)	(+17%)	(+27%)	(+13%)	(+16%)	(+8%)
<i>Charging station</i>						
Total plugged time (min)	212 950	226 400	229 700	240 250	245 050	242 700
(relative change)	(-44%)	(-43%)	(-47%)	(-47%)	(-45%)	(-51%)
Total queue time (min)	92 100	143 650	203 950	122 650	19 700	79 150
(relative change)	(-77%)	(-72%)	(-64%)	(-80%)	(-95%)	(-84%)

Battery swapping

20 units of battery swapping equipment (5 min of battery change)

- Up to 88-95% of initial in-vehicle PKT (unlimited-range SAV) may be achieved

Performance indicators of SAEV service with BSS infrastructure.

Scenario	P-Median		P-Median with constraint	
	Medium-Range	Long-Range	Medium-Range	Long-Range
<i>SAEV</i>				
Fleet usage ratio (%)	49.9	50.9	50.1	53.0
Empty distance ratio (%)	20.9	19.6	21.5	19.8
In-vehicle PKT (km)	1.77 M	1.82 M	1.73 M	1.88 M
Total VKT (km)	1.62 M	1.64 M	1.61 M	1.69 M
<i>BSS</i>				
Total queue time (min)	2 700	3 050	1 050	1 060
Extra battery (unit)	2 050	2 260	1 960	2 350

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Data preparation

- Persons without any associated household
- Poor quality of OSM data (road network, land use)
- Many efforts to clean network file
- Missing GTFS for many big cities in France



Computation time

*Paris Greater Area
(Ile de France)*
11,735,966
10000 SAVs

Population 100%

Bullx supernode S6130
CPU: Intel® Xeon® E7
88 threads
RAM: 1TBs DDR4

Time: 7-8 hrs/Iter
(29 iters → 9 days!!)

Paris
2,229,621
1700 SAVs

10% population

Local Machine
CPU : Intel® Xeon® E5
8 threads
RAM: 32GBs DDR4

Time: 16 mins/Iter
(~360 iters → 4 days)

Rouen
500,000
300 SAVs

10% population

Local Machine
CPU : Intel® Xeon® E5
8 threads
RAM: 32GBs DDR4

Time: 6 mins/Iter
(~150 iters → 20 hours)

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- **Activity-based** travel demand modeling coupled with **multi-agent simulation** can provide required data with enough granularity to design Shared Mobility services and to assess its impacts in a multimodal network.
- Such an approach requires essentially very **fine-grained data as input**, particularly **synthetic population** and **activities or trip-chains** of each individual.
- The **computational time** is a big issue in multi-agent simulation of big cities (network size, population)
- Conducted survey and simulation results highlight the importance of **considering user taste variation** in **multi-agent simulations**.
- The **performances** of SAVs and SAEVs are strongly correlated with the **service configuration** (fleet size, the strategy of the ride, rebalancing, charging station placement, etc.).



Which **policies** to avoid **modal shifts** from public transportation to shared autonomous vehicles?

Thank you!

