Systemx
INSTITUT DE RECHERCHE TECHNOLOGIQUE

Accélérateur de la transformation numérique

INVESTISSEMENTS D'AVENIR

Shared Autonomous Vehicle (SAV) Service Design, Modeling and Simulation

Case study of Rouen metropole area

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GROUPE RENAULT

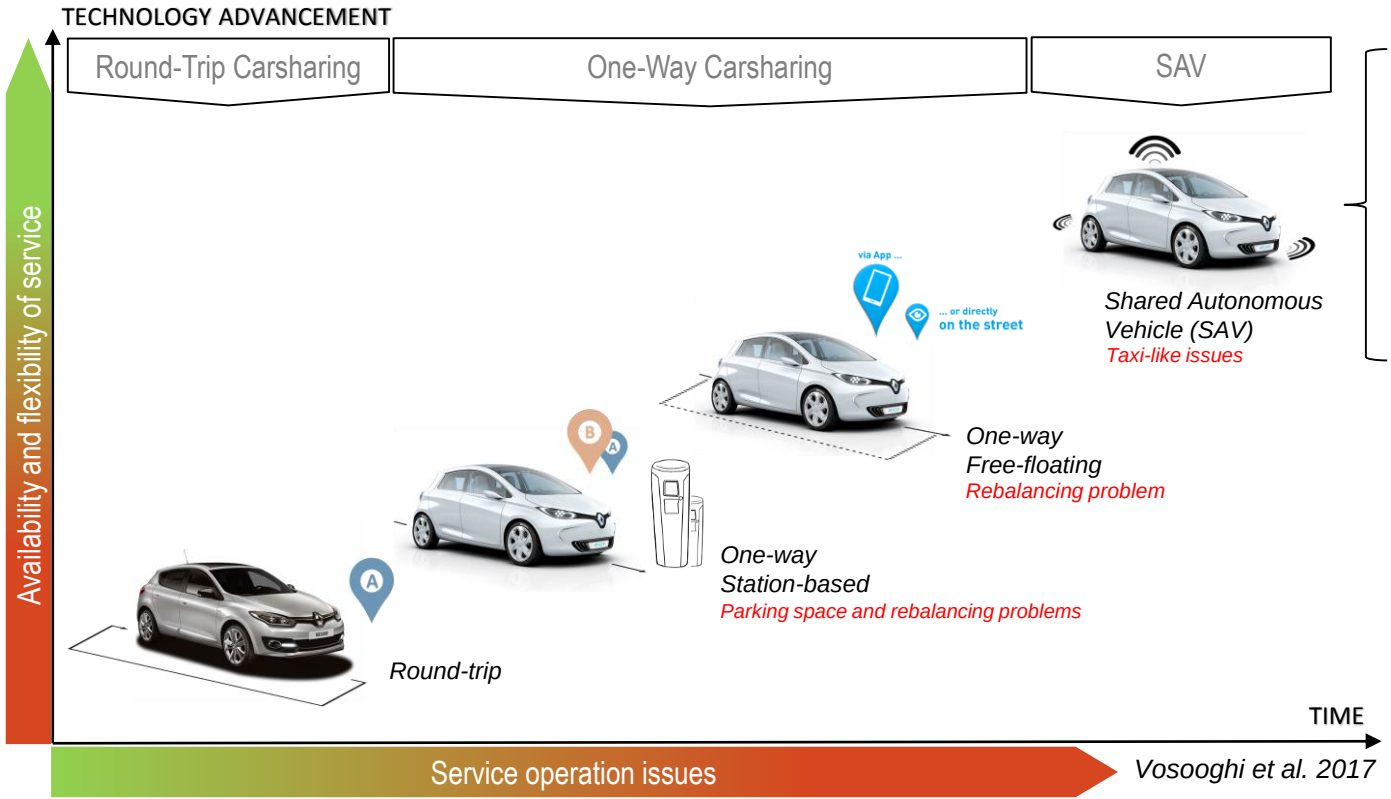
Outlines

- *Introduction / Problem statement*
- *Demand estimation approaches*
- *Activity-based multi-agent simulation*
- *Synthetic population generation*
- *Daily activity allocation*
- *Model set up and calibration*
- *User preferences*
- *Scenarios and KPIs*
- *Simulation results*

SAV is one of the forms of Shared Mobility

“Shifting the private mobility from ownership to service use”

Shared Mobility

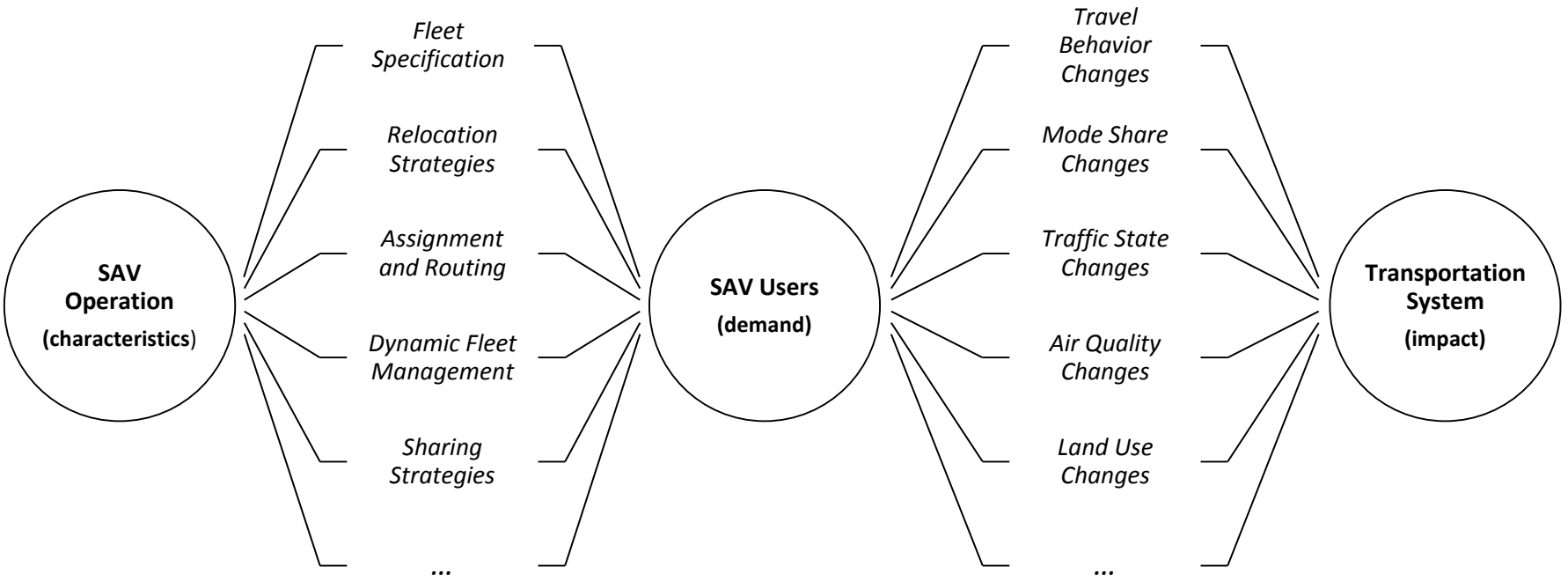


- *On-demand*
- *Empty pick-up ride*
- *Empty charging ride*
- *Derivation*
- *Request optimization*
- *Charging time*

How to design this new service?

‘’The first step in upstream planning is demand estimation”

Shared Mobility

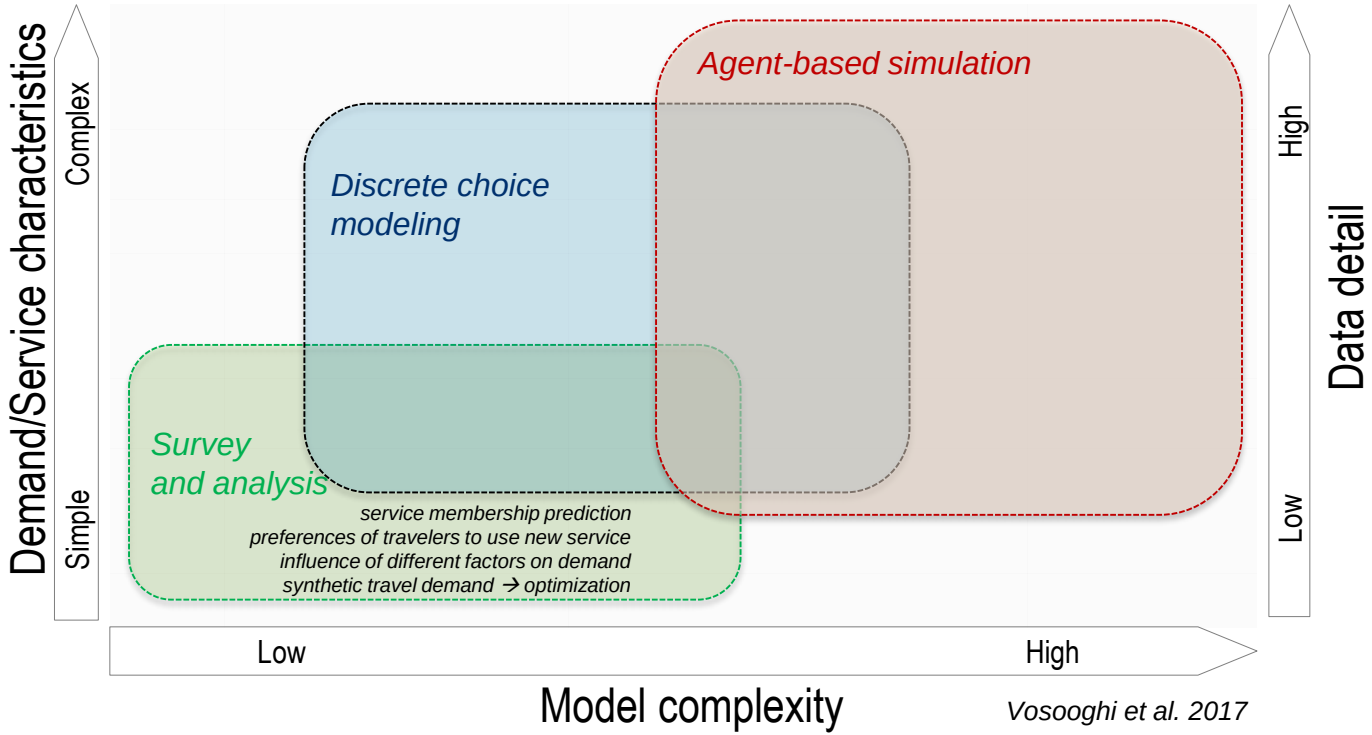


Any changes in SAV service configuration result in different service demand and, consequently, some other impacts on traveler behavior, congestion, urban form (in long-term) and the environment. These impacts cause a different mode choice subsequently.

Which method(s) to estimate the demand ?

Demand estimation approaches

Dynamic demand (not market penetration)
Demand responsive to network and traffic
Multi-modal



Demand estimation approaches

Dynamic demand (not market penetration)
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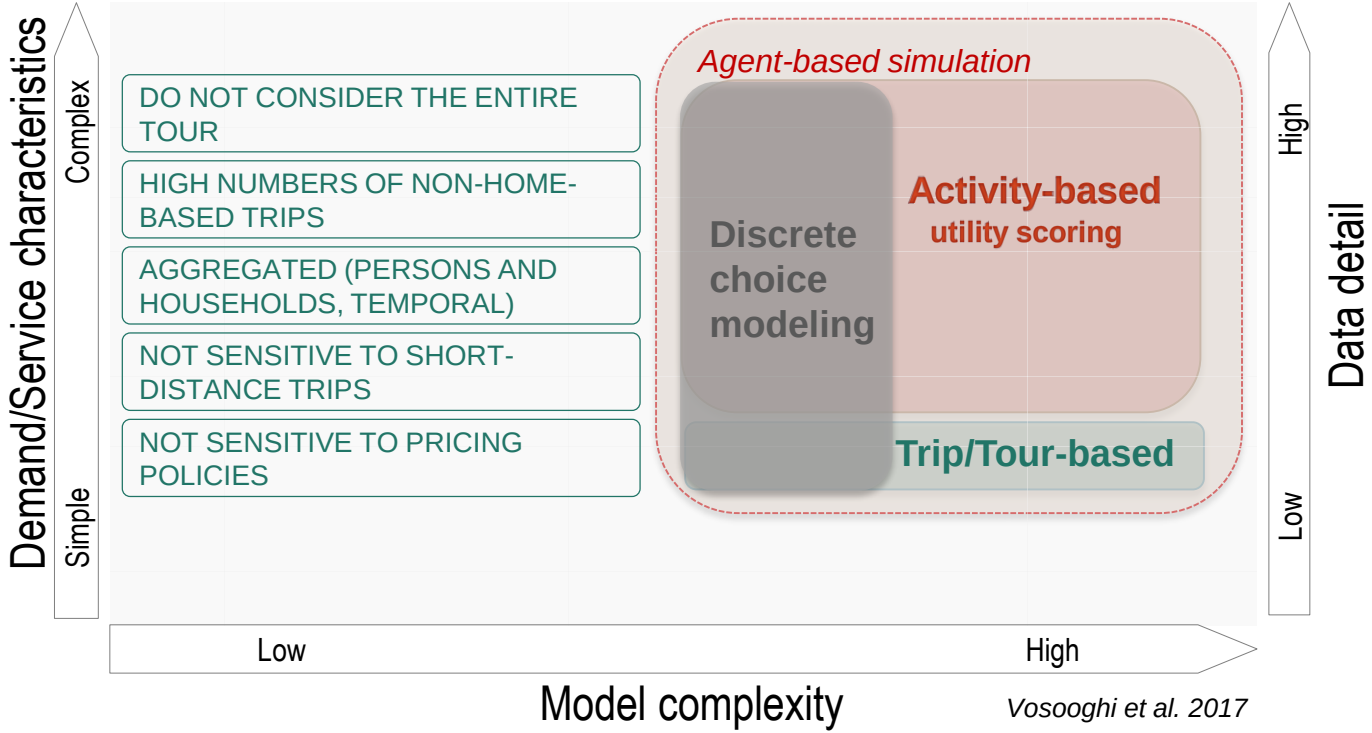
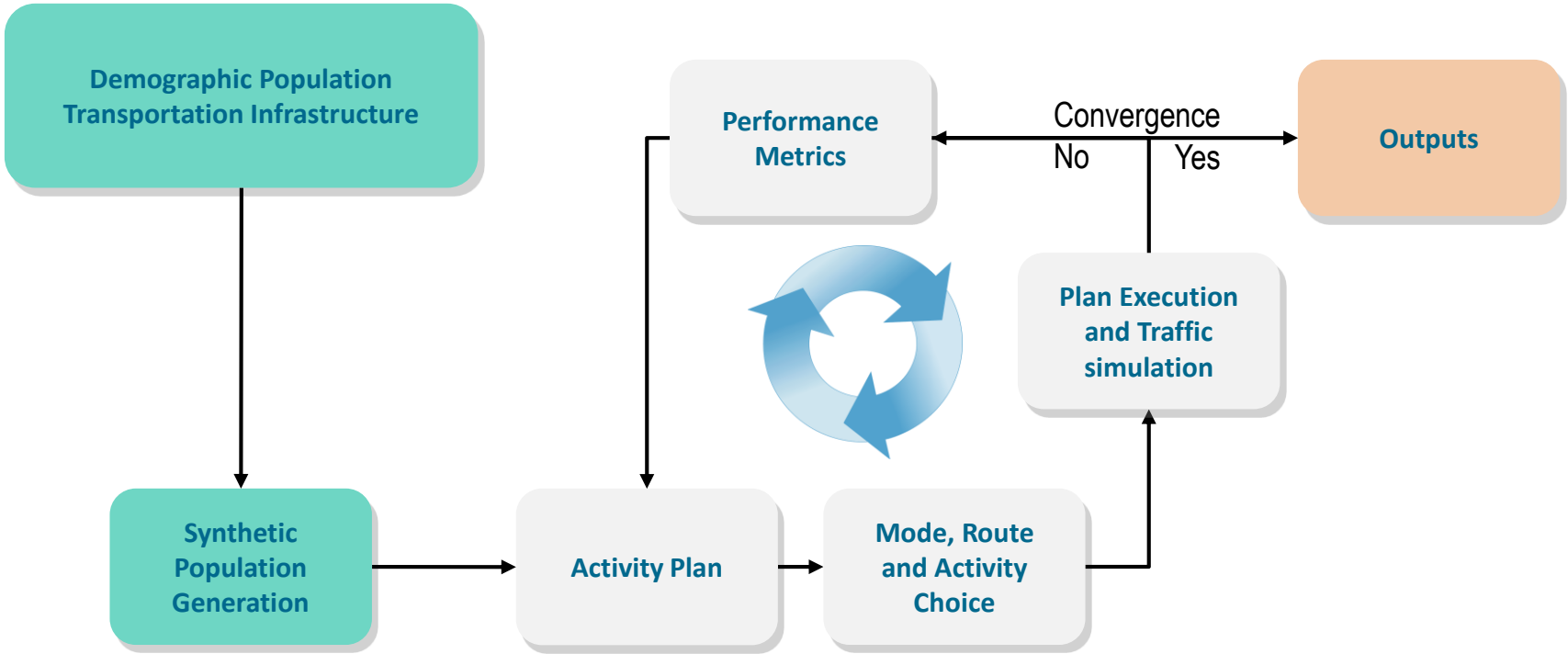



Demographic Population
Transportation Infrastructure
Performance Metrics
Convergence
No
Yes
Outputs
Plan Execution and Traffic simulation
Synthetic Population Generation
Activity Plan
Mode, Route and Activity Choice

Which platform to model personal pattern and transport network?

Current studies

MATSim (ETH Zürich) 2004
- *Open source*
- *Stand-alone*
- *Scoring and co-evolutionary algorithm*
- *Mesoscopic*
- *Queue based traffic simulator*
- *Large-scale application*

MobiTopp (Karlsruhe Institute of Technology) 2004
- *Open source*
- *Simulation period can be up to one week*
- *Rely on external traffic simulator*
- *Microscopic*
- *Short-term, long-term models*

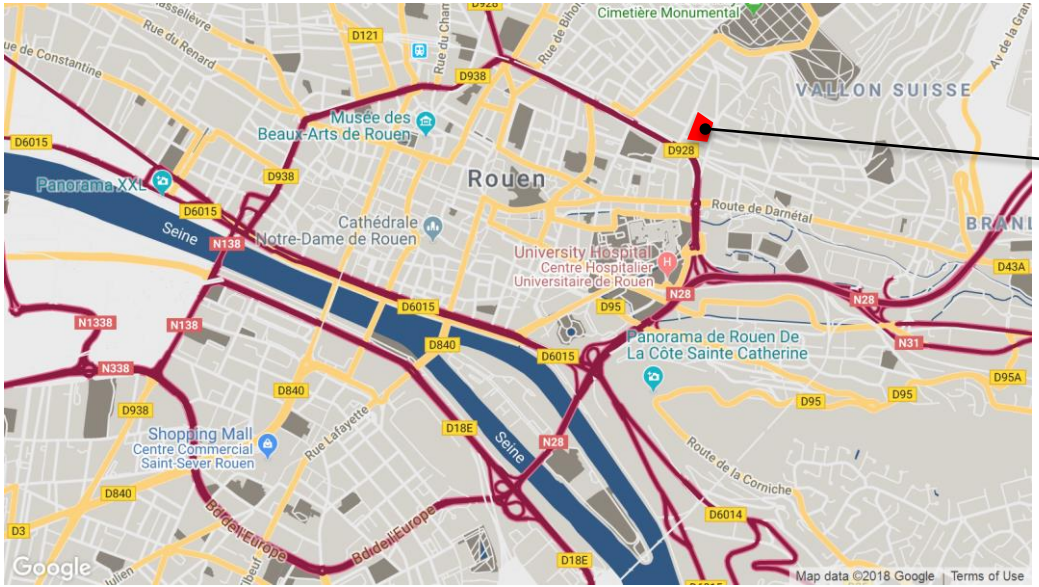
SimMobility (Intelligent Transportation System Lab MIT - ITS LAB) 2011
- *Open source*
- *Probabilistic model*
- *Land-use*
- *Communication interaction*
- *Short-term, mid-term, long-term models*
- *Micro, Meso and Macroscopic*
- *From second-by-second to year-by-year*

POLARIS (Federal Highway Administration TRANSIMS Research) 2015
- *Open source*
- *ITS covered*
- *Large-scale transportation systems*
- *Macroscopic traffic flow*

What are the issues?

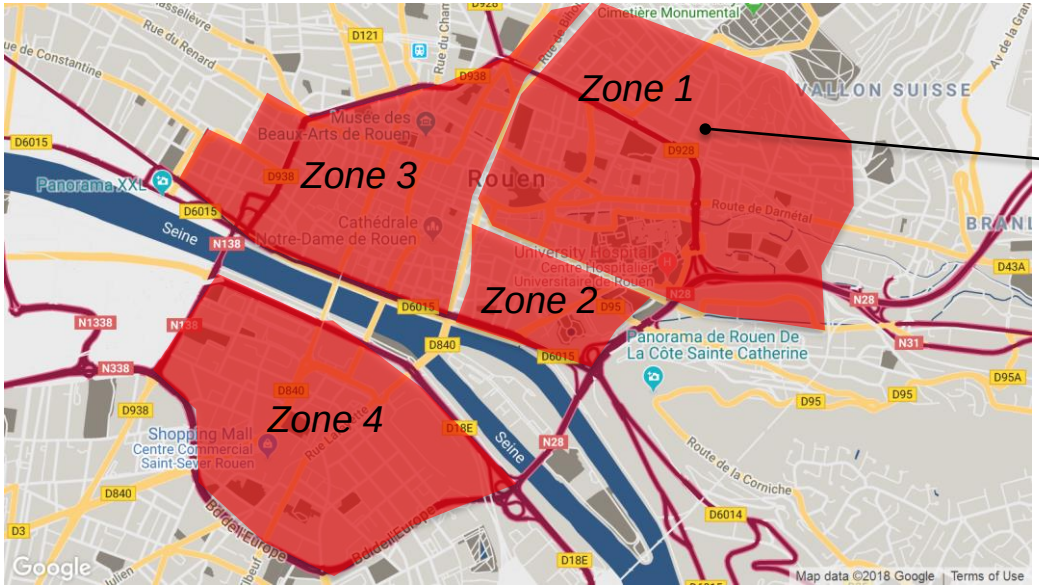
1. *Input data (synthetic population, activity chaining)*
2. *Homogeneous structure of behaviour*
3. *Robo-Taxi service performance indicators*

What is a Synthetic Population?



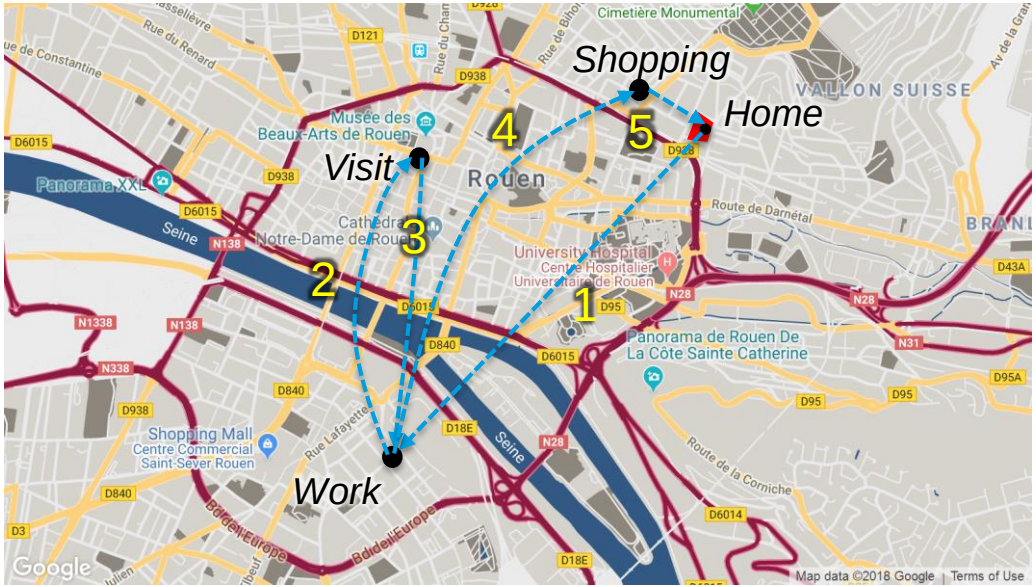
	Jean	Pierre	Marie	Isabelle
Age	38	8	6	35
Status	Worker	Student	Student	Homemaker
Auto	Yes (2)			
Income	46 000 €			

Synthetic Population



	HH	Person	Age 0-5	Worker
Zone 1	215	783	35	82
Zone 2	189	633	47	66
Zone 3	245	780	44	91
Zone 4	368	1246	76	143

What is an Activity Chain?

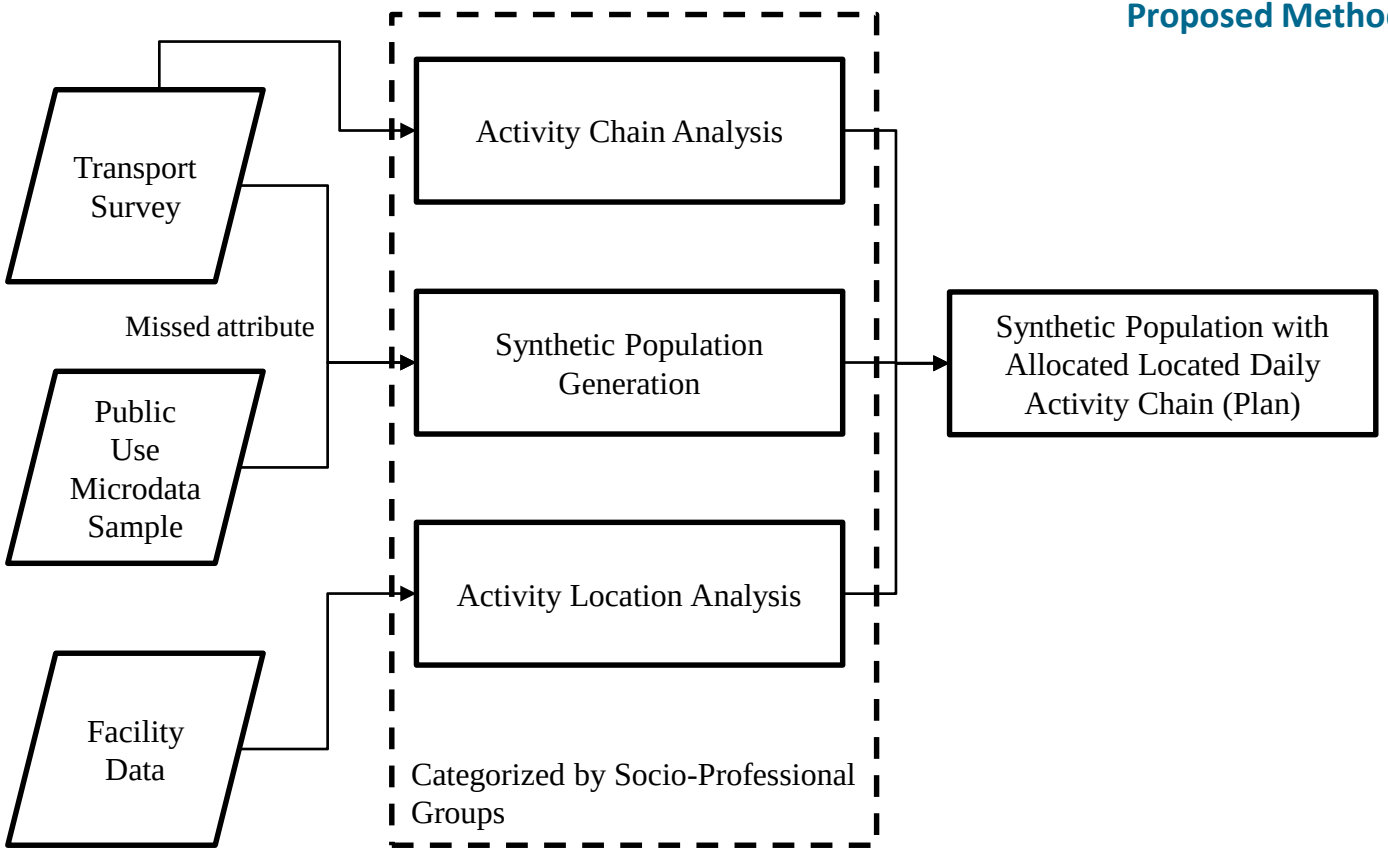


Jean

	Start Time	End Time
Home	-	8:30
Work	8:45	12:15
Visit	12:25	13:45
Work	14:00	17:05
Shopping	17:20	17:35
Home	17:45	-

Synthetic population generation and daily activity allocation

Proposed Method



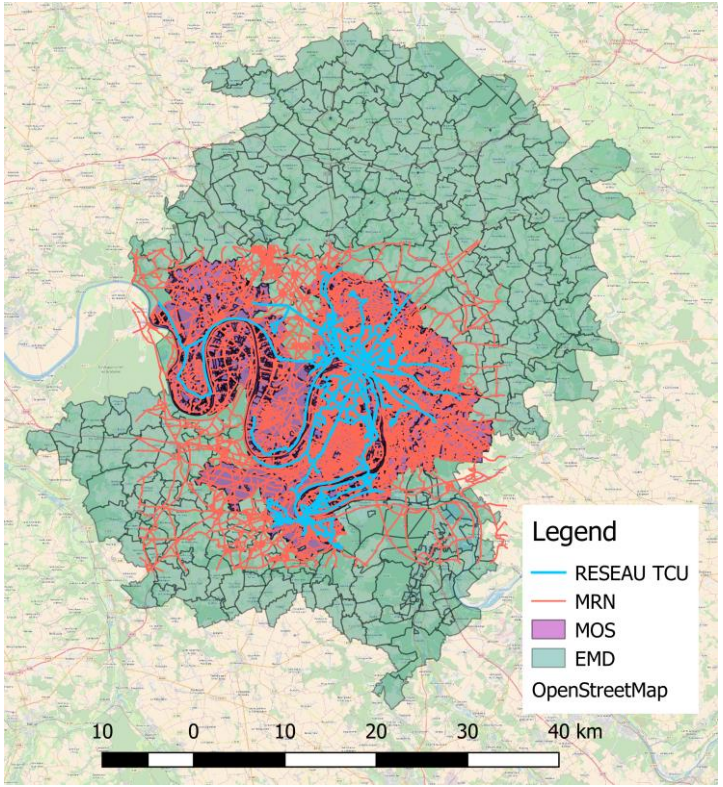
Synthetic population generation and daily activity allocation

EMD 2017 (transport survey)

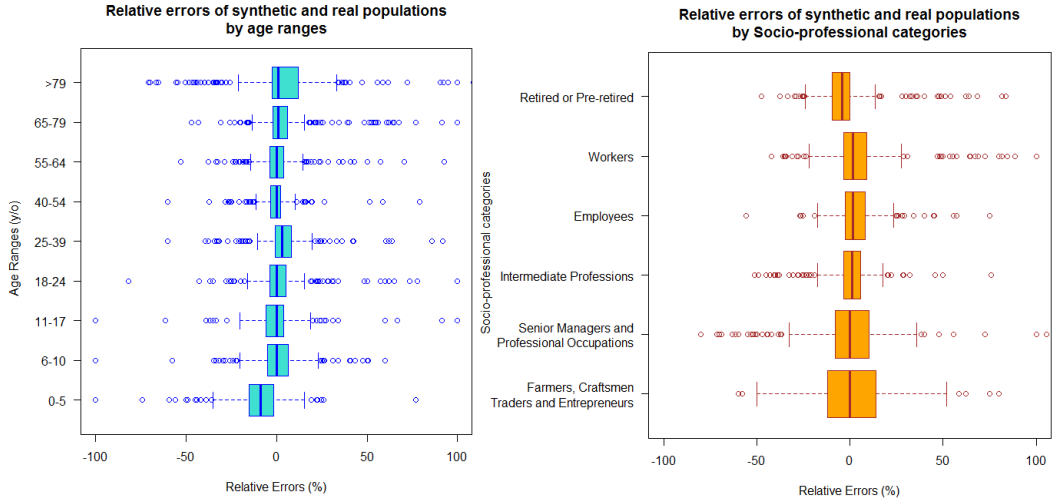
- 5,059 Households
- 11,107 Individuals (9,247)
- 38,146 Trips
- 30,342 Journey

INSEE 2014 (census)

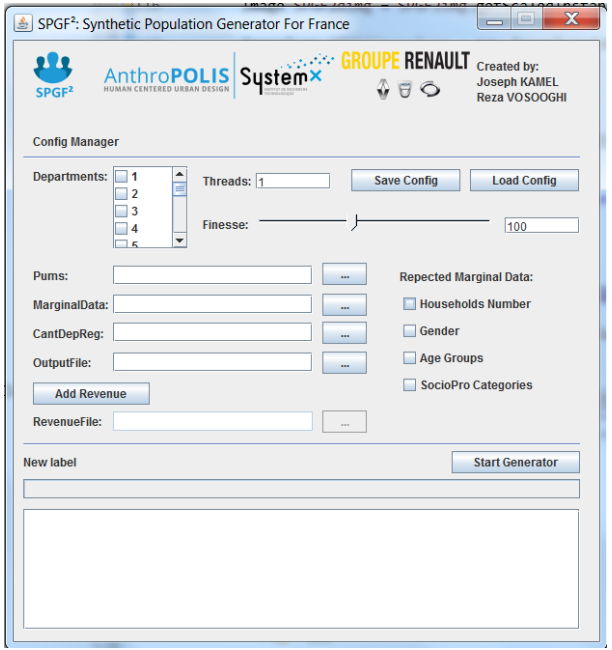
- Rouen Normandie 2014 : 499,570



Fitness-Based Synthesis with Multilevel Controls (FBS-MC)



(Rouen Normandie 2014 : 499,570)

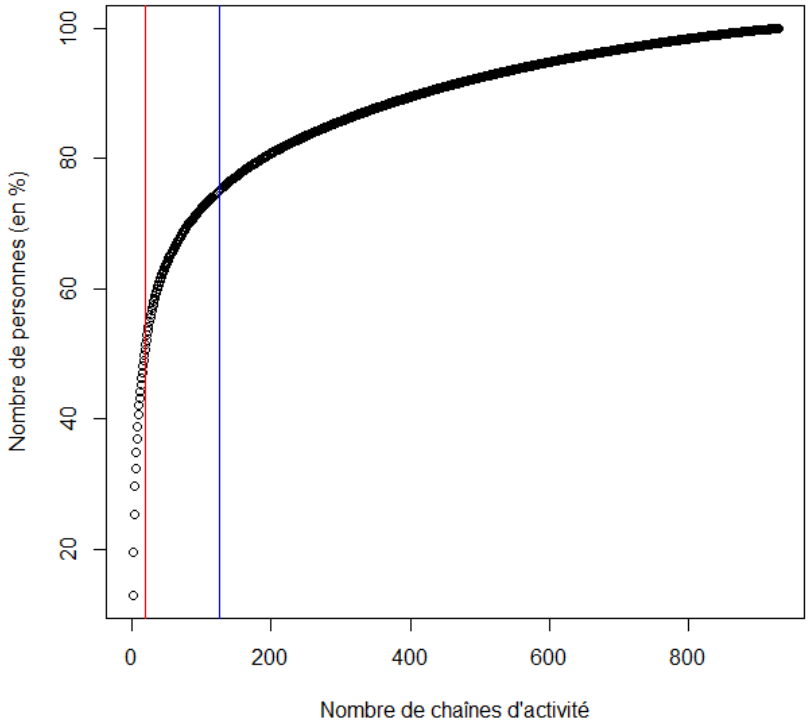


https://github.com/josephkamel/SPGF2

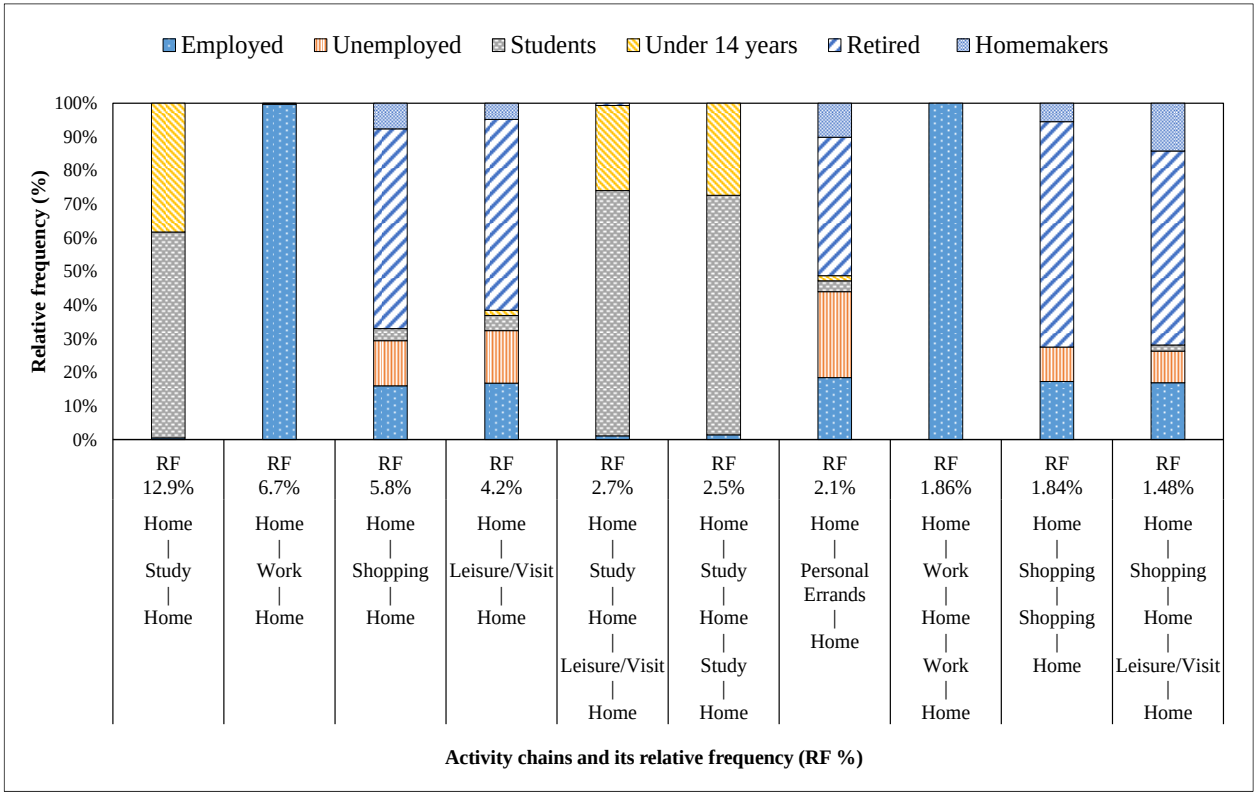
Synthetic population generation and daily activity allocation

Activity Chain allocation

- 929 Activity Chains
- 19 ones are common for 50%
- 124 ones are common for 75%

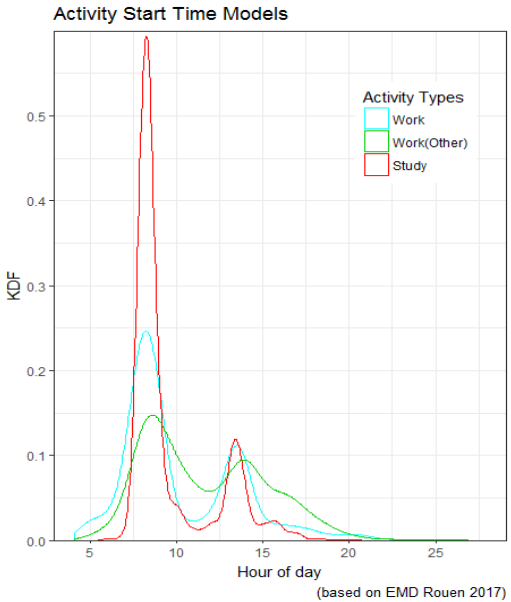


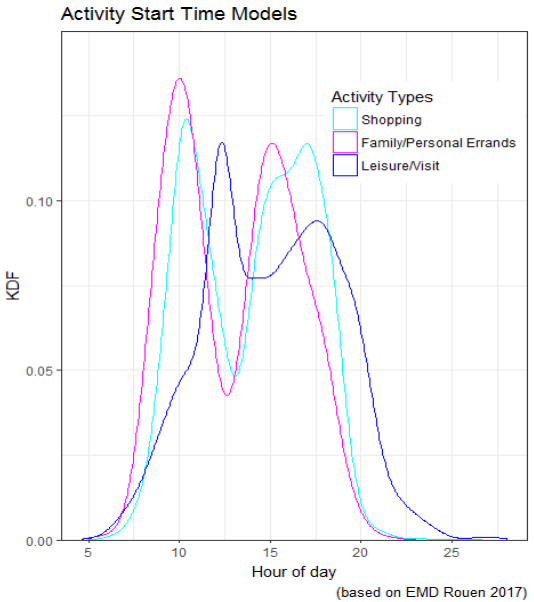
Synthetic population generation and daily activity allocation

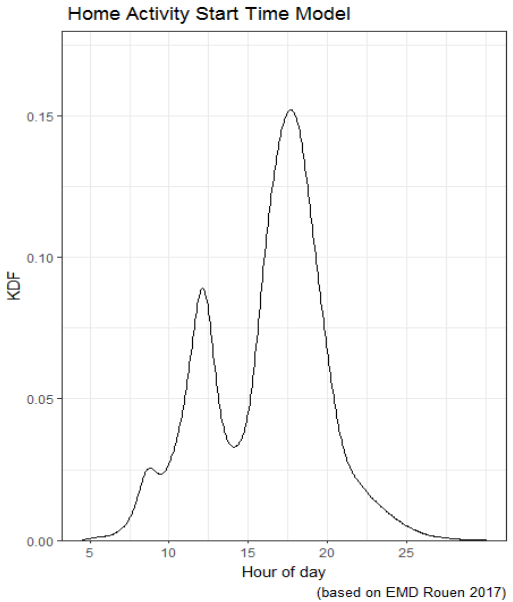


Synthetic population generation and daily activity allocation

Activity start time models

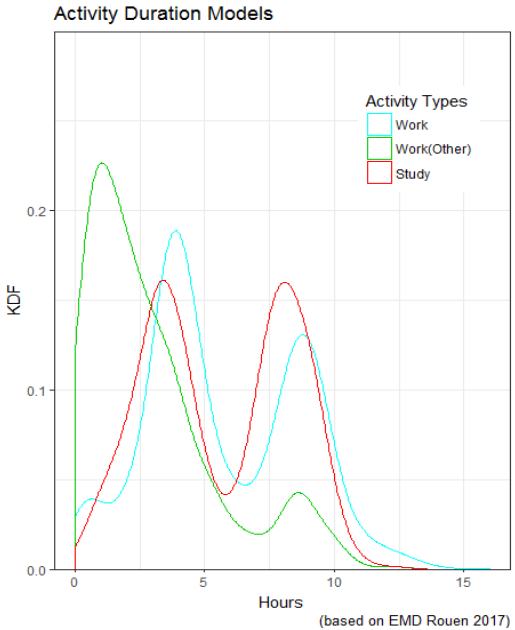


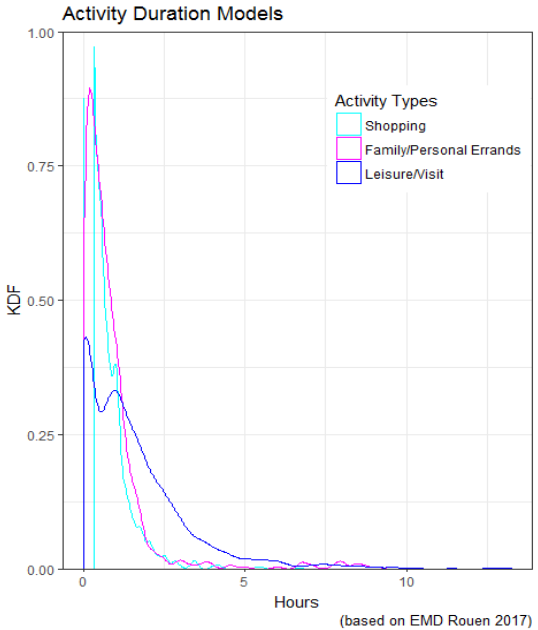


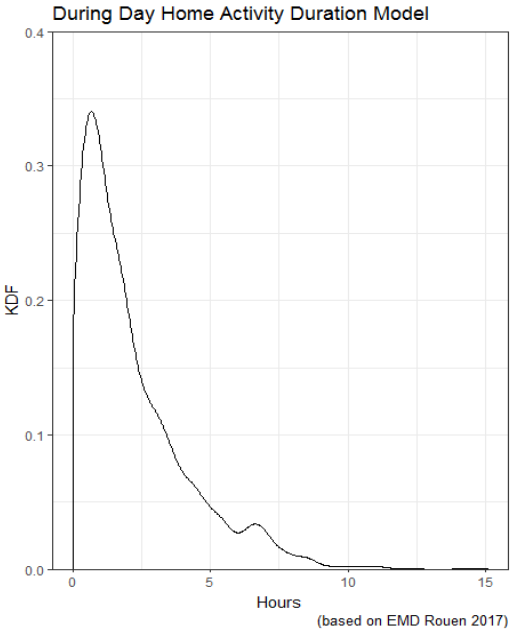


Synthetic population generation and daily activity allocation

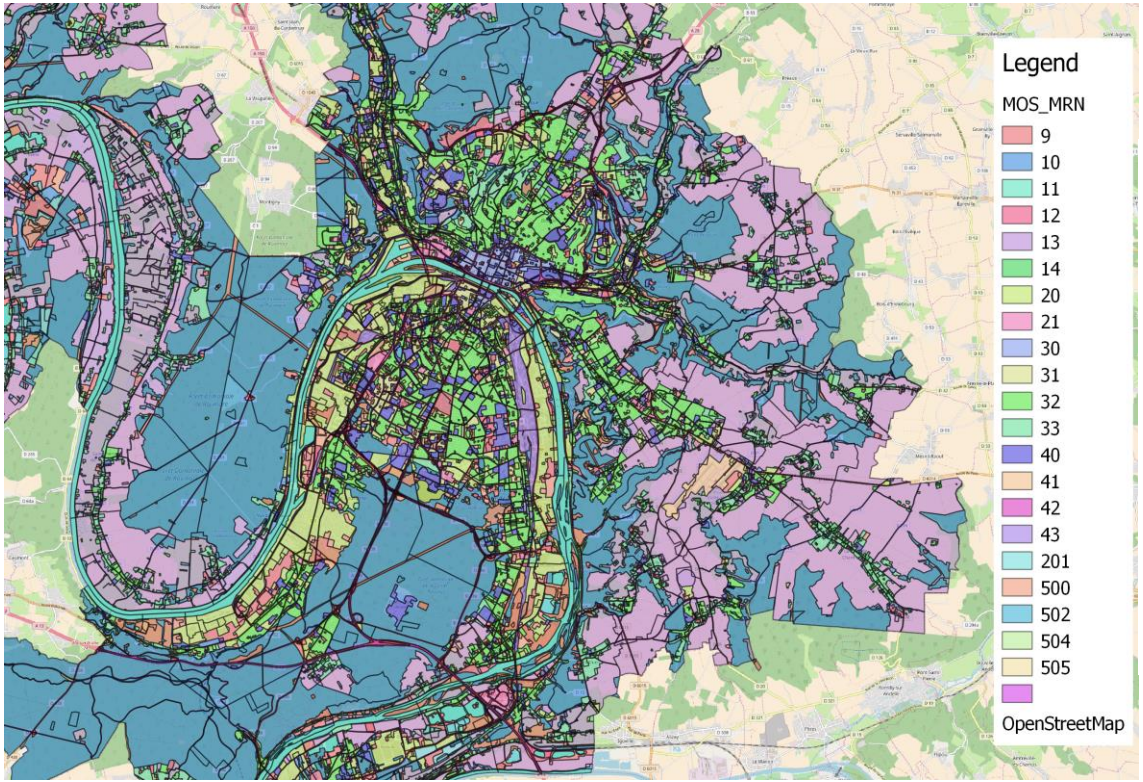
Activity duration models







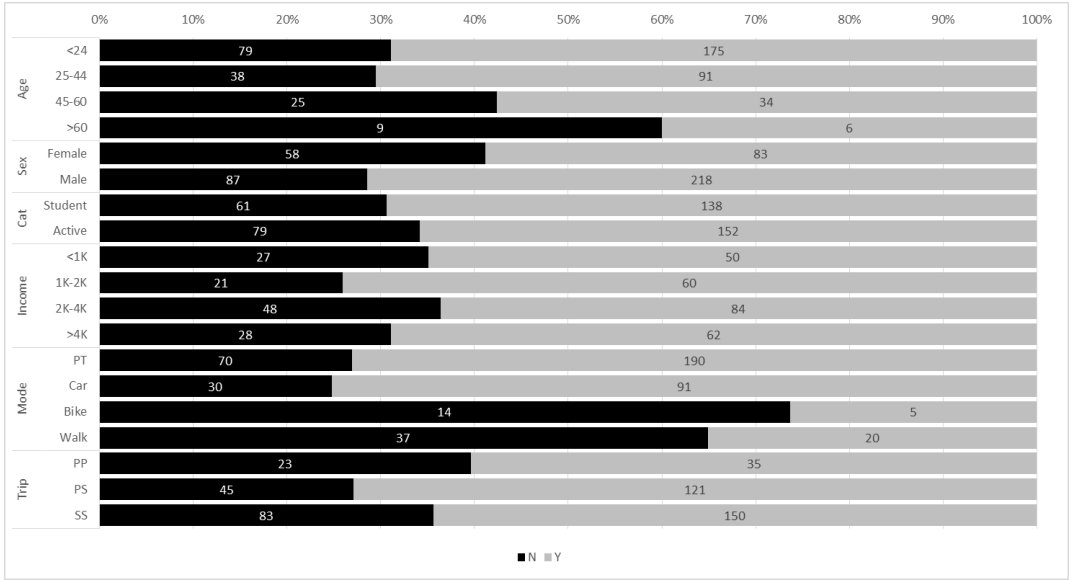
Synthetic population generation and daily activity allocation



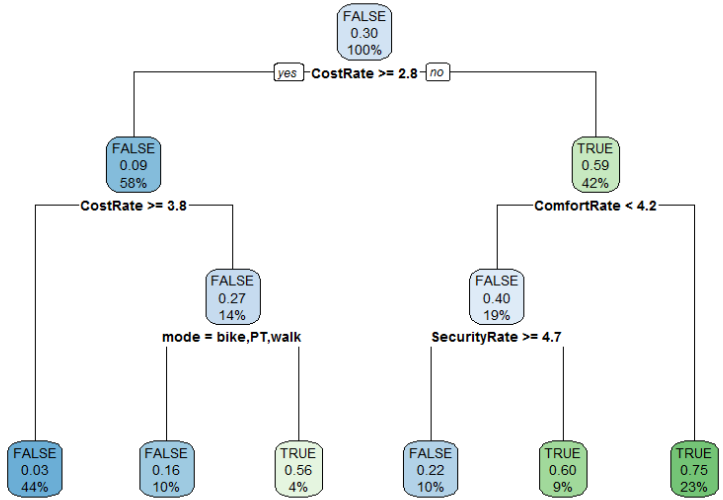
9	Espace non bosÃ©, non agricole
10	Espace boisÃ©
11	Espace naturel aquatique
12	Espaces de loisir et d'agrÃ©ment
14	Construction en mileu rural
20	ActivitÃ©s industrielles et/ou artisanales et/ou tertiaires, hors carriÃ¨
201	ActivitÃ©s de carriÃ¨res
30	Habitat dense, continu, hypercentre
32	Habitat individuel dense
41	AÃ©roport, ports et installations portuaire, gare routiÃ¨re, ferroviaire,
43	Voie ferrÃ©e
13	ActivitÃ© agricole
33	Habitat individuel peu dense
31	Ensemble d'habitat collectif dominant
21	Centre commercial, hypermarchÃ©, supermarchÃ©
40	Equipement avec son parking (public, privÃ©)
42	Autoroute, route essentielle, Ã©changeur
500	Espaces en cours d'Ã©volution sans affectation
501	Espaces en cours d'Ã©volution pour les espaces ruraux
503	Espaces en cours d'Ã©volution pour l'activitÃ© commerciale
502	Espaces en cours d'Ã©volution pour l'activitÃ© non commerciale
504	Espaces en cours d'Ã©volution pour l'habitat
505	Espaces en cours d'Ã©volution pour les Ã©quipements
506	Espaces en cours d'Ã©volution pour les Ã©quipements modaux

How to integrate user preferences in agent-based simulation?

- *Introduction of User trust and Willingness to use based on local survey*



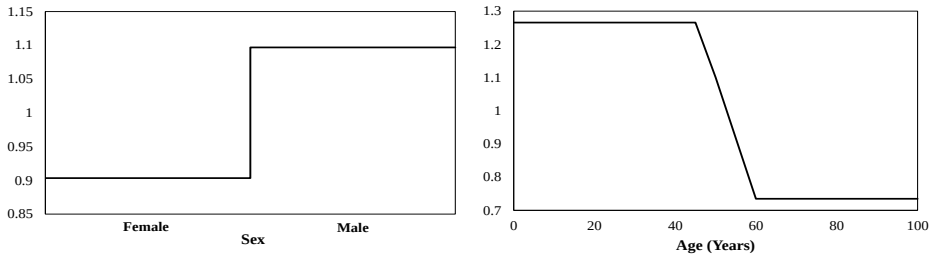
User trust



Willingness to use

- *Modification of scoring function*

$$S'_{trav,cat} = \kappa_{ut} \times C_{m,cat} + \beta_{trav,m,cat} \times (\kappa_{ivt} \times t_{ivt} + \kappa_{wt} \times t_{wt}) + \beta_{dist,m,cat} \times d_{trav} + \nu_{co,m,cat} + \gamma_{pl,m,cat}$$



Non-electric SAV

1. Individual 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)

Scenario	Mode \ Fleet size	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

Total duration of in-service drive over total duration of all tasks

0	10	20	30	40	50	60	70	80	90	100

(a) S1 : non-ridesharing

Fleet size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6000	0	0	1	2	7	28	51	77	86	86	70	59	60	67	67	66	70	75	73	60	54	31	14	4
5500	0	0	1	3	9	32	59	82	94	95	74	63	67	76	79	72	75	78	80	75	64	40	18	5
5000	0	0	1	3	9	33	64	79	96	97	76	64	71	84	84	81	80	83	82	76	64	37	17	5
4500	0	1	1	4	10	37	65	86	100	99	79	67	74	83	83	82	86	88	89	81	73	45	20	5
4000	0	0	1	4	11	39	66	86	100	99	86	70	80	88	91	86	85	90	92	82	76	43	21	7
3500	0	0	2	4	12	45	73	89	100	99	81	69	81	88	91	86	86	88	92	82	78	49	26	8
3000	0	0	1	4	15	48	72	92	100	98	78	75	85	92	92	85	82	79	86	80	75	48	26	9
2500	0	1	2	5	15	53	77	92	98	78	61	70	77	80	82	79	75	66	64	65	74	52	30	10
2000	0	1	2	5	15	51	68	90	81	31	28	44	59	53	52	52	47	38	23	26	35	32	25	7

Hour of day

(c) S3 : ridesharing (standard 4-seats car)

Fleet size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6000	0	0	1	2	6	18	37	65	74	66	51	38	35	38	42	43	48	54	59	56	40	19	10	3
5500	0	0	1	2	7	21	42	71	74	68	57	44	39	42	46	48	50	56	64	62	43	21	11	3
5000	0	0	1	3	8	20	42	69	75	72	57	43	39	42	47	49	52	58	63	67	49	22	12	4
4500	0	0	1	3	7	26	49	74	81	80	65	49	48	49	51	53	59	68	74	72	53	25	13	5
4000	0	0	2	3	9	26	49	77	87	84	67	50	48	50	53	58	62	69	75	77	56	27	14	4
3500	0	0	1	4	10	32	60	87	91	84	68	59	59	61	68	70	76	77	77	76	60	31	17	6
3000	0	1	2	4	12	37	64	86	90	83	68	62	62	63	69	75	74	73	75	76	68	39	19	5
2500	0	0	2	5	14	39	73	91	87	76	64	65	65	66	70	71	68	67	68	73	76	40	22	8
2000	0	1	2	5	16	47	77	94	92	74	55	59	63	64	64	68	71	72	64	60	59	37	27	9

Hour of day

(b) S2 : ridesharing (2-seats small car)

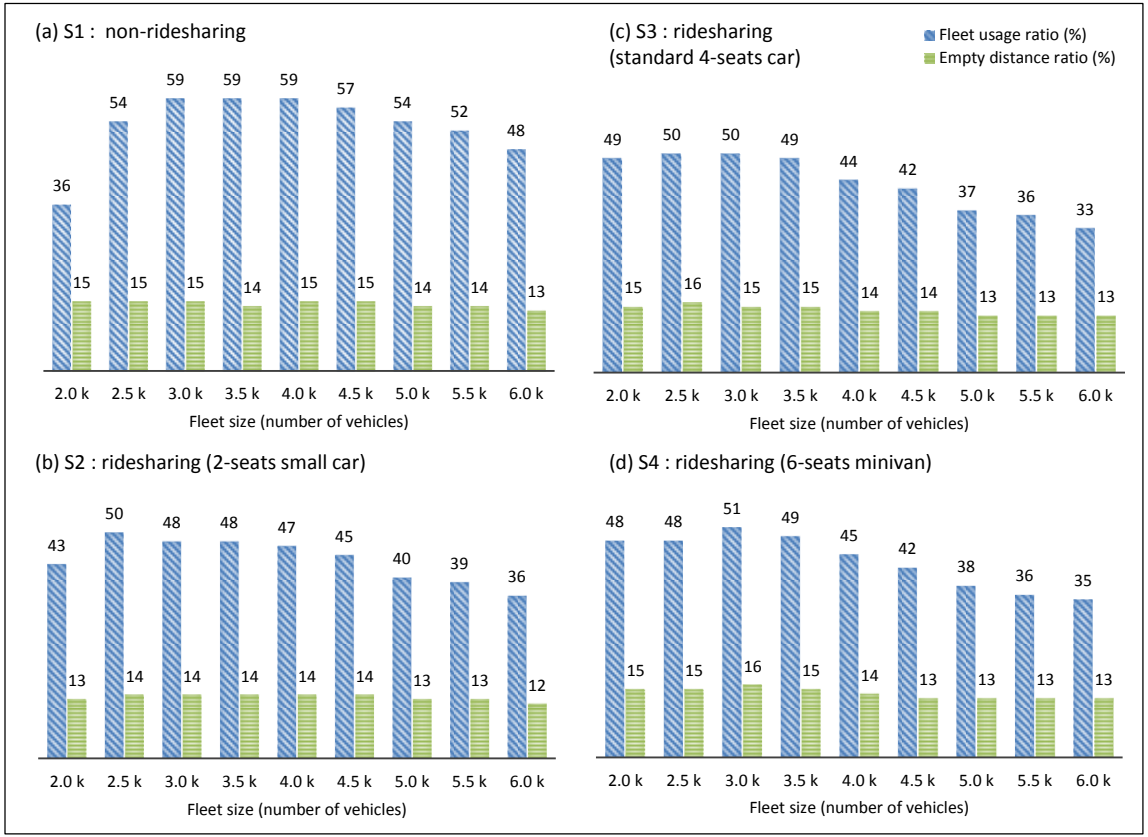
Fleet size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6000	0	0	1	2	6	20	40	70	76	69	55	41	39	41	43	45	51	60	67	58	42	20	11	4
5500	0	0	1	2	7	22	43	74	79	74	58	44	43	45	49	52	56	65	70	65	44	22	12	3
5000	0	0	1	3	7	23	46	73	80	77	60	46	44	47	50	54	59	66	72	66	45	24	12	4
4500	0	0	1	3	9	27	54	79	89	84	65	49	50	55	60	61	65	71	78	78	56	27	13	4
4000	0	0	1	3	10	29	55	84	92	87	67	52	51	58	60	64	70	75	81	79	60	30	16	5
3500	0	0	1	4	10	33	61	84	89	86	70	61	59	63	69	73	74	80	83	82	65	34	17	6
3000	0	0	1	5	11	36	61	82	85	80	64	57	60	63	67	71	71	70	74	76	65	36	20	5
2500	0	0	2	5	13	40	73	91	89	77	63	62	64	66	67	68	71	71	73	73	69	38	21	6
2000	0	1	2	6	14	42	66	86	84	53	44	57	62	61	61	59	54	49	44	49	59	40	25	8

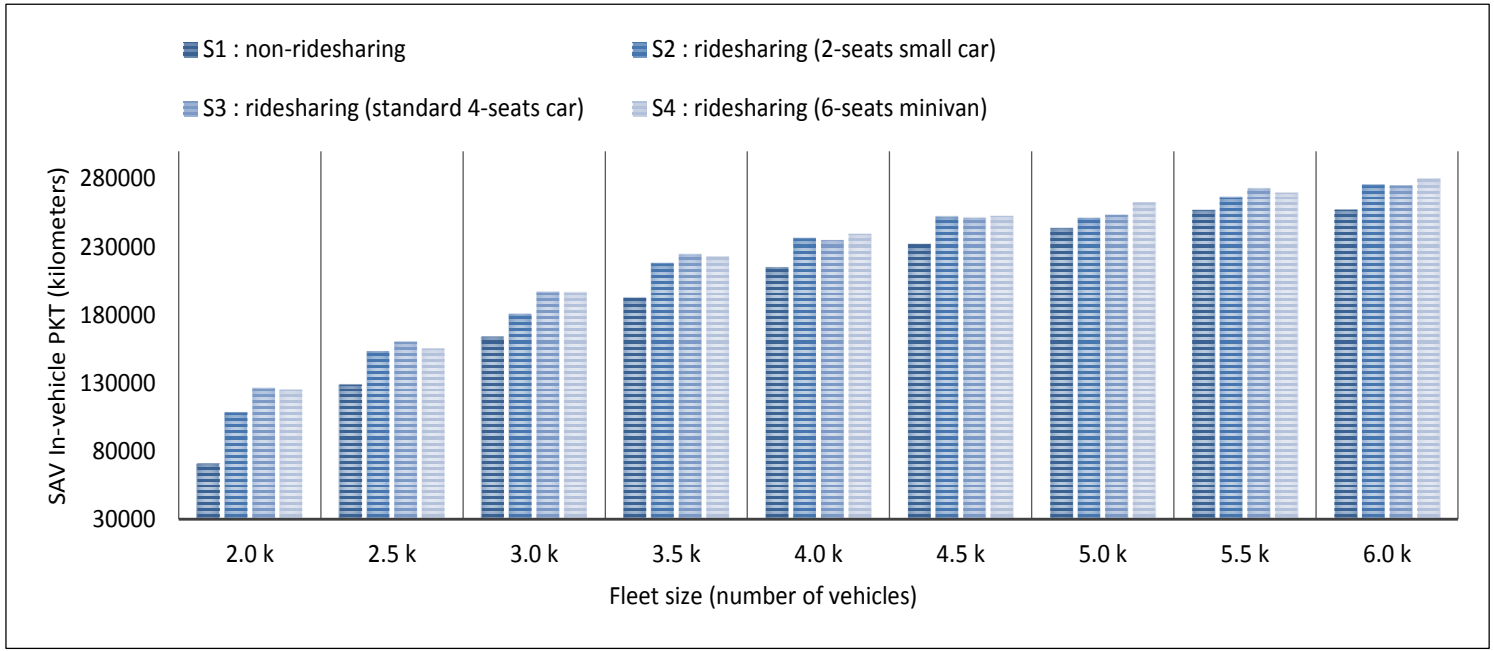
Hour of day

(d) S4 : ridesharing (6-seats minivan)

Fleet size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6000	0	0	1	2	7	19	38	67	74	65	53	40	38	39	40	43	48	54	59	60	44	19	10	4
5500	0	0	1	2	7	21	41	69	74	68	55	44	40	41	44	46	51	59	65	61	43	20	11	4
5000	0	0	1	3	7	23	43	71	76	73	59	44	42	44	46	48	54	64	70	67	47	22	11	4
4500	0	0	1	3	8	25	49	77	81	78	63	52	47	48	51	54	59	67	72	68	49	25	15	4
4000	0	0	1	4	10	28	53	79	84	82	66	55	53	54	59	61	64	71	76	72	55	26	14	4
3500	0	1	1	4	10	34	61	83	91	87	70	62	59	59	66	69	72	75	77	75	63	31	17	5
3000	0	0	2	4	10	35	67	89	90	83	69	63	63	65	71	71	72	73	78	81	68	38	20	6
2500	0	1	2	4	13	41	68	85	82	72	61	58	62	62	64	69	70	67	67	73	68	38	21	7
2000	0	1	3	6	15	46	75	97	94	67	52	62	68	69	68	69	68	66	59	63	63	42	26	7

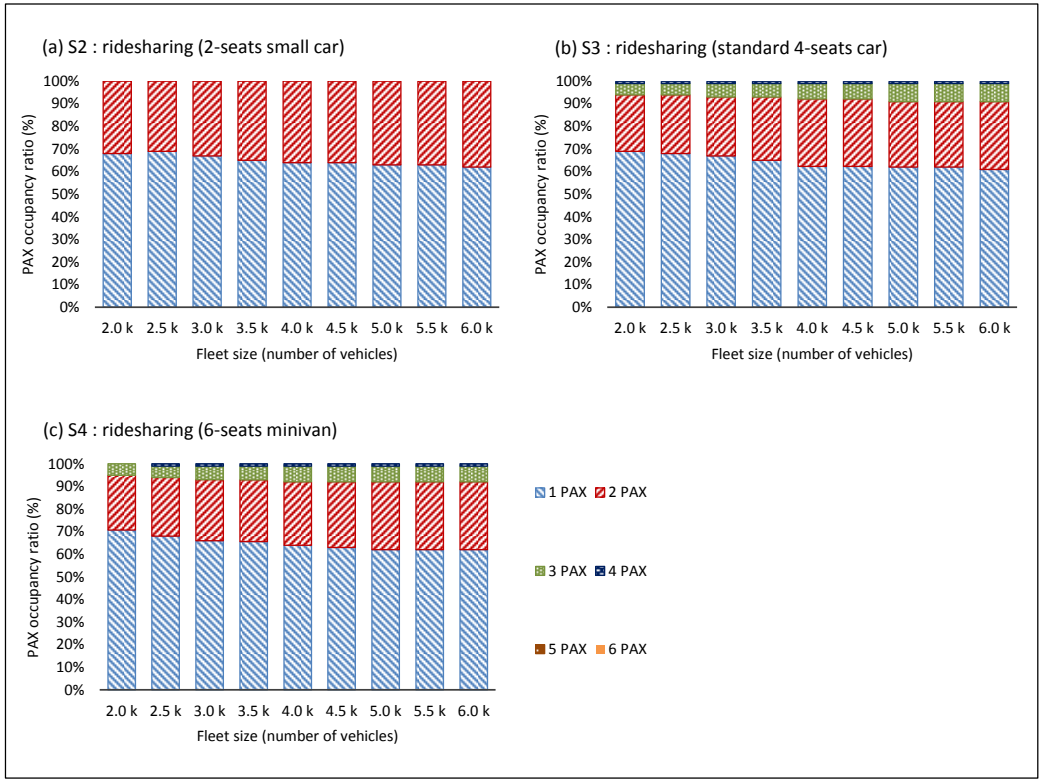
Hour of day


(a) S1 : non-ridesharing
36 54 59 59 59 57 54 52 48
15 15 15 14 15 15 14 14 13
2.0 k 2.5 k 3.0 k 3.5 k 4.0 k 4.5 k 5.0 k 5.5 k 6.0 k
Fleet size (number of vehicles)
(c) S3 : ridesharing (standard 4-seats car)
Fleet usage ratio (%)
Empty distance ratio (%)
49 50 50 49 44 42 37 36 33
15 16 15 15 14 14 13 13 13
2.0 k 2.5 k 3.0 k 3.5 k 4.0 k 4.5 k 5.0 k 5.5 k 6.0 k
Fleet size (number of vehicles)
(b) S2 : ridesharing (2-seats small car)
43 50 48 48 47 45 40 39 36
13 14 14 14 14 14 13 13 12
2.0 k 2.5 k 3.0 k 3.5 k 4.0 k 4.5 k 5.0 k 5.5 k 6.0 k
Fleet size (number of vehicles)
(d) S4 : ridesharing (6-seats minivan)
48 48 51 49 45 42 38 36 35
15 15 16 15 14 13 13 13 13
2.0 k 2.5 k 3.0 k 3.5 k 4.0 k 4.5 k 5.0 k 5.5 k 6.0 k
Fleet size (number of vehicles)

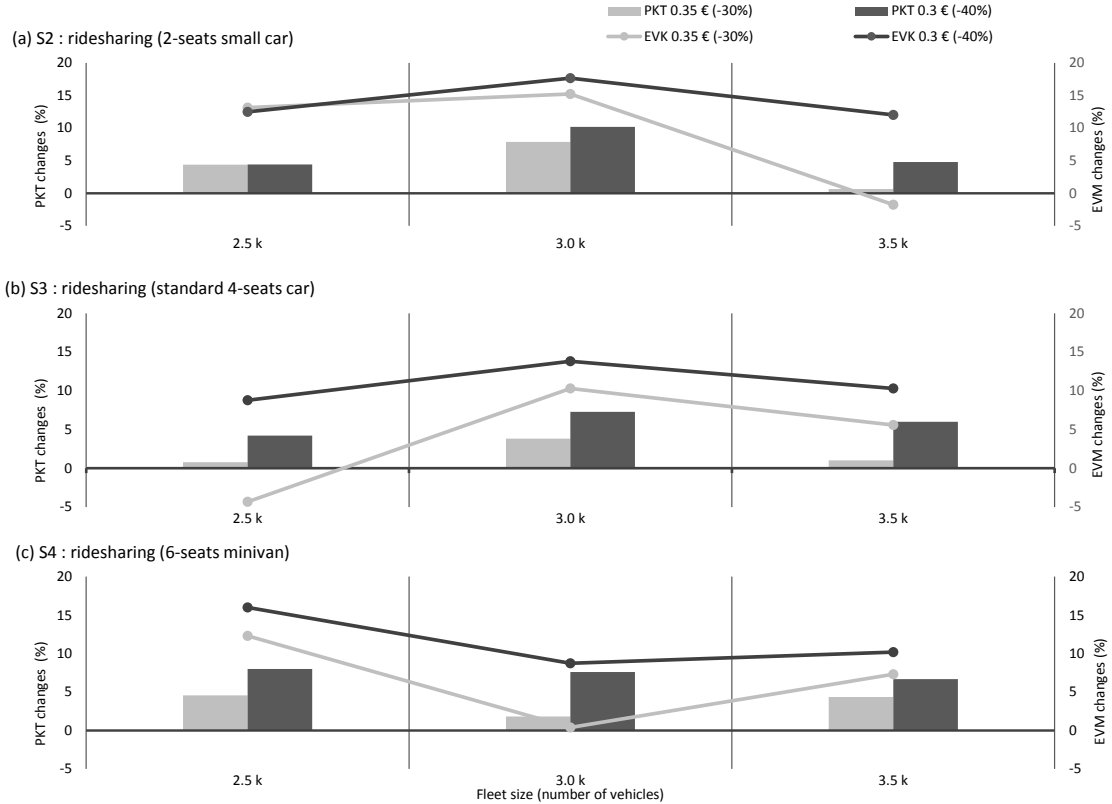

S1 : non-ridesharing
S2 : ridesharing (2-seats small car)
S3 : ridesharing (standard 4-seats car)
S4 : ridesharing (6-seats minivan)
SAV In-vehicle PKT (kilometers)
280000
230000
180000
130000
80000
30000
2.0 k
2.5 k
3.0 k
3.5 k
4.0 k
4.5 k
5.0 k
5.5 k
6.0 k
Fleet size (number of vehicles)

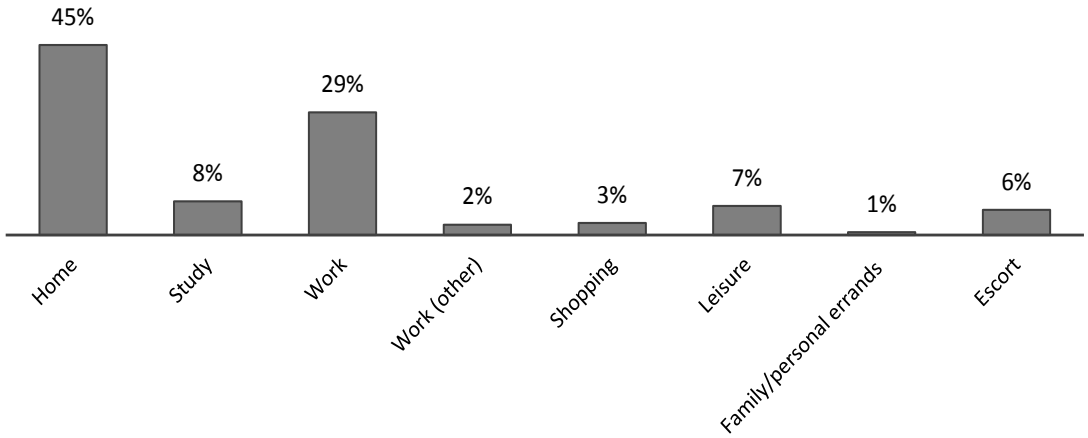
Simulation Results 1

On-board occupancy rates by number of passenger



Scenario	Non-ridesharing (3.5 k)		Ridesharing 2-seats small car (2.5 k)		Ridesharing standard 4-seats car (3.0 k)		Ridesharing 6-seats minivan (3.0 k)	
	no rebalancing	with rebalancing	no rebalancing	with rebalancing	no rebalancing	with rebalancing	no rebalancing	with rebalancing
SAV modal share (%)	6.0	6.3	4.6	5.2	5.3	6.4	5.4	6.4
Average waiting time (min)	18.5	18.4	18.9	13.9	20.7	13.1	21.1	14.8
Average in-vehicle time (min)	38.5	38.7	43.9	44.1	46.0	45.2	46.0	44.8
Average detour time (min)	N/A	N/A	4.7	5.2	6.1	5.8	6.0	5.9
Fleet usage ratio (%)	59	68	50	66	50	66	51	67
Empty distance ratio (%)	14	20	14	26	15	24	16	24
In-vehicle PKT (km)	1.93 M	2.08 M	1.53 M	1.81 M	1.97 M	2.40 M	1.97 M	2.41 M
1 PAX ratio (%)	100	100	69	63	67	59	66	61
2 PAX ratio (%)	N/A	N/A	31	37	26	33	27	31
3 PAX ratio (%)	N/A	N/A	N/A	N/A	6	7	6	7
4 PAX ratio (%)	N/A	N/A	N/A	N/A	1	1	1	1
5 PAX ratio (%)	N/A	N/A	N/A	N/A	N/A	N/A	<1	<1
6 PAX ratio (%)	N/A	N/A	N/A	N/A	N/A	N/A	0	0
Average driven distance (km)	647	746	549	715	546	707	552	723
Max. driven distance (km)	894	978	880	964	866	896	888	939


PKT 0.35 € (-30%)
PKT 0.3 € (-40%)
EVK 0.35 € (-30%)
EVK 0.3 € (-40%)
(a) S2 : ridesharing (2-seats small car)
(b) S3 : ridesharing (standard 4-seats car)
(c) S4 : ridesharing (6-seats minivan)
PKT changes (%)
EVM changes (%)
20
15
10
5
0
-5
2.5 k
3.0 k
3.5 k
Fleet size (number of vehicles)



Activities in origin and destination of trips performed by SAVs

SAEV

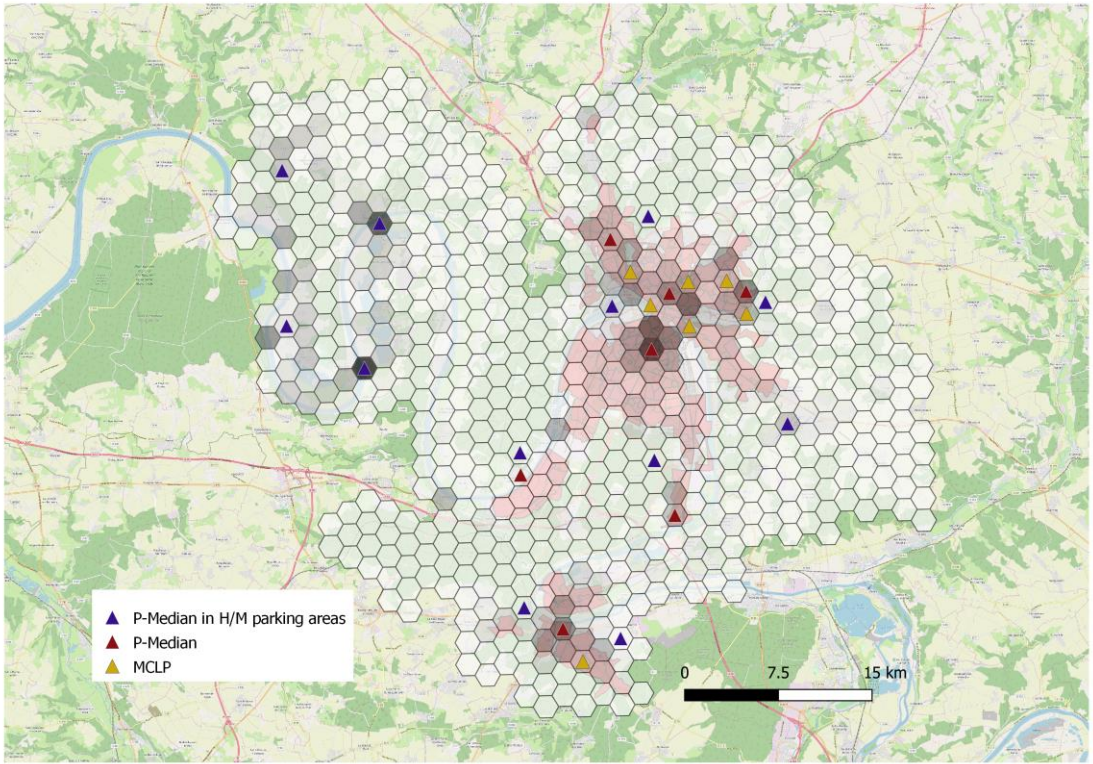
- 3000 standard 4-seats car
- Price : 0.4 € per kilometer
- Renault Zoe specification
- Battery capacities : 41 and 50 kWh
- Ridesharing
- No rebalancing

1. CS placement

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

2. BSS

- Medium and long range


P-Median in H/M parking areas
P-Median
MCLP
0
7.5
15 km

- P-Median with constraint remains the optimal strategy among all scenarios for both SAEV battery capacities of 60 ESEV outlets
- By providing rapid charging infrastructure, significant improvements on in-vehicle PKT and queue time are observed
- By providing more charging space, the P-Median strategy of charging station placement become relatively more efficient in terms of in-vehicle PKT.
- By providing BSS infrastructure, P-Median with constraint and long range SAEVs become the better-optimized scenario.

Min										Max
0	10	20	30	40	50	60	70	80	90	100

(a) SAV hourly in-sevice rate

N/A	0	1	2	4	12	37	64	86	90	83	68	62	62	63	69	75	74	73	75	76	68	39	19	5
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**

Day hour

Number of outlet units per station

(b) P-Median, Medium-Range SAEV hourly total plugged time (hour)

100	0	0	0	0	0	0	141	193	131	238	558	687	780	859	714	478	458	369	288	340	547	728	614	325

(c) P-Median, Long-Range SAEV hourly total plugged time (hour)

90	0	0	0	0	0	0	111	187	128	153	432	512	504	767	823	624	529	517	538	568	631	854	655	415

(d) P-Median with constraint, Medium-Range SAEV hourly total plugged time (hour)

80	0	0	0	0	0	0	113	203	151	235	573	675	743	711	703	573	534	524	488	498	515	585	493	340

(f) P-Median with constraint, Long-Range SAEV hourly total plugged time (hour)

90	0	0	0	0	0	0	176	235	163	168	468	492	469	697	758	663	650	523	580	565	651	597	480	492
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**

Day hour

Conclusion

- Trip patterns and activity chains are highly correlated to the socio-pofessional and sociodemographic attributes.
- Robo-Taxi service design must be taken into account according to the demographic structure of the city or region of interest as well as the preferences variation of its inhabitants.
- The optimum fleet sizes for individual ride and ridesharing scenarios are different.
- There are no improvements in terms of service performance when vehicle extra-capacity is provided (e.g. standard 4-seats car and 6-seats minivan).
- Enabling vehicle rebalancing is found to have a profound effect on both user and service related metrics.
- Future SAVs with todays' rang specifications will necessarily require some recharging infrastructure.

Systemx
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Accélérateur
de la transformation
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INVESTISSEMENTS D'AVENIR

Thank you!

LGi
Laboratoire Génie Industriel

GROUPE RENAULT