Assessing the Shared Automated Vehicle´s fleet size using flow optimization in an interurban demand project

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UNIVERSIDADE D COIMBRA

Driving2Driverless project

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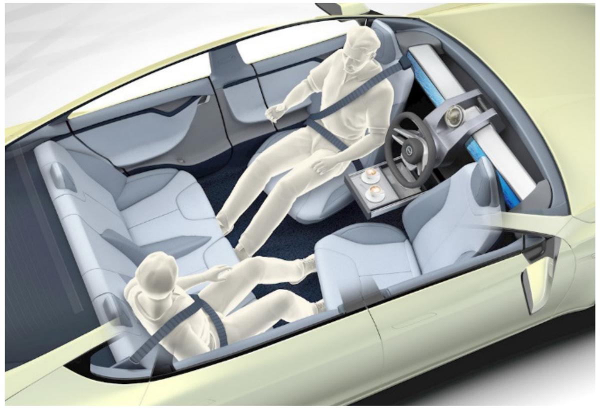
Outline



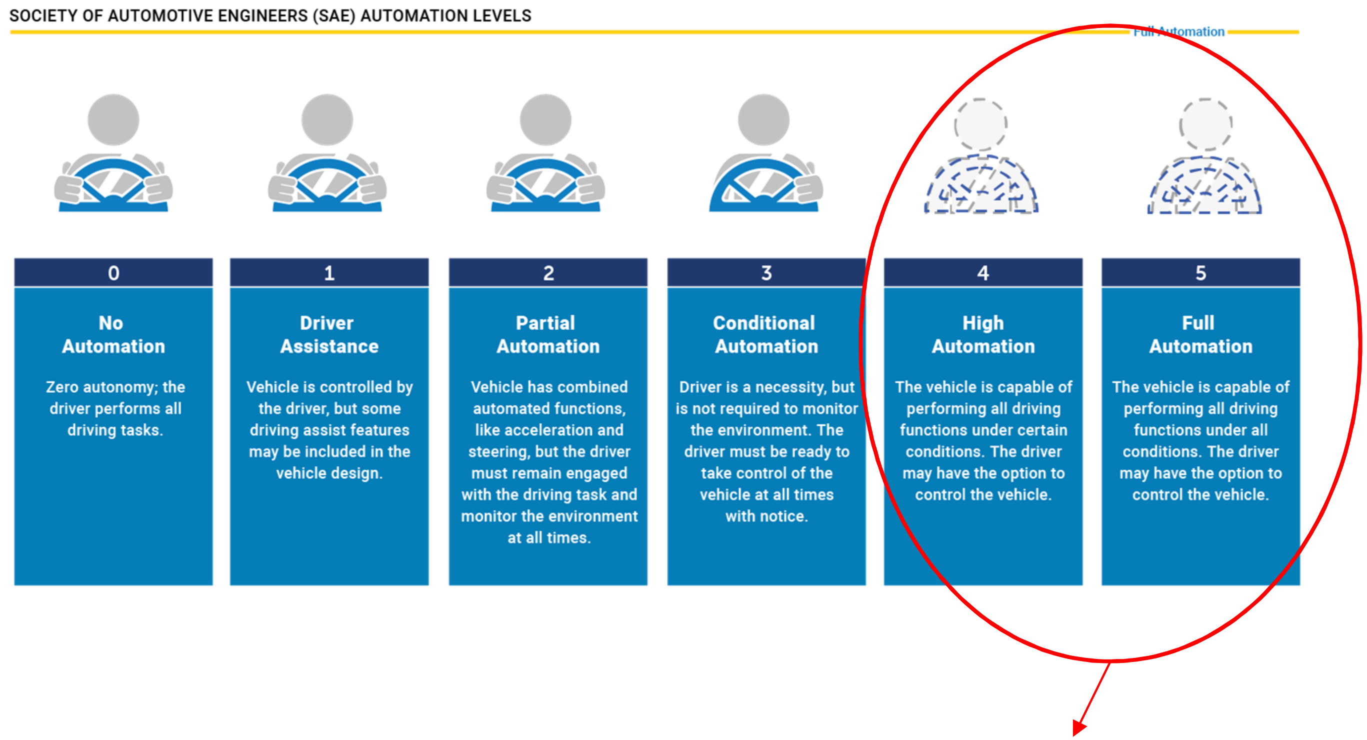
Rinspeed XchangE concept

- Introduction
- Driving2Driverless project
- Assessing fleet size
- Closing remarks
- Next steps

Wepod electric driverless bus, Netherlands

Introduction

- Automation is becoming part of driving



Self-driving vehicles (autonomous)

Potential of AV´s

The use of autonomous vehicles (AV) can potentially affect:

- Road safety (decrease the number of accidents EU Vision Zero);
- Mobility (namely to elders and people with disabilities);
- Productivity (perform other activities while traveling);
- Environmental (perform other activities while traveling);

The use of a shared fleet of AV´s (SAV) can increase:

- Access to AV technology (lower car ownership);
- Access to mobility (for those living in less dense areas);

Interurban mobility

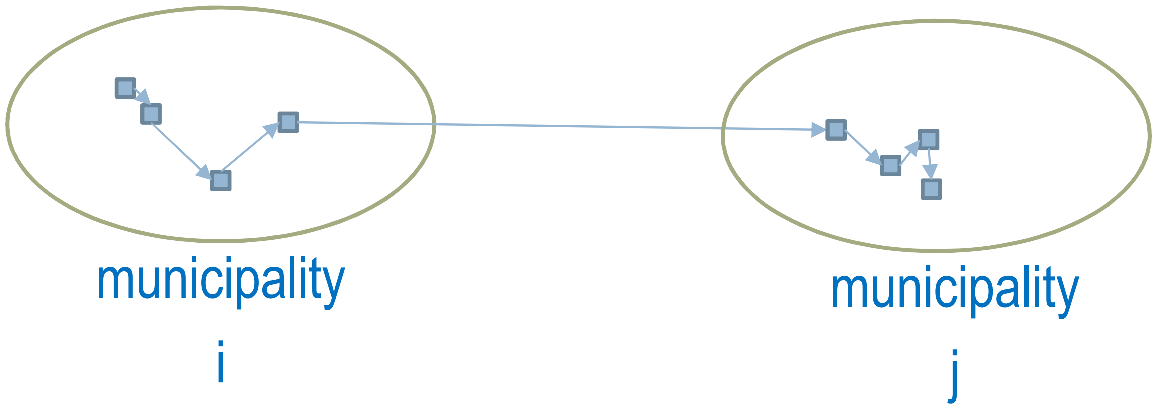
- The use of SAV has been studied in urban contexts (namely inside metropolitan areas);
- Heterogeneous regions (with low density areas) are more likely to benefit from the introduction of a SAV system;

Aim of the D2D project:
Look into a long term scenario where all demand is provided by Autonomous vehicles;
Interurban movements in **Coimbra and Aveiro**;
Address the **different components** (routing, network modeling, charging and parking).

Assessing fleet size
(Preliminary study: optimal fleet, profit)

Transport service

- Shared Autonomous Vehicles (SAV)
- Interurban transportation market;
- The trips are between municipalities;
- It is considered that vehicles gather clients inside the municipality of origin, travel to the municipality of destination and distribute clients to their individual destinations;



Scenarios

1) A fleet of minibus16 seats (autonomous, non-autonomous)

2) A fleet of autonomous vehicles with a 4 seat capacity

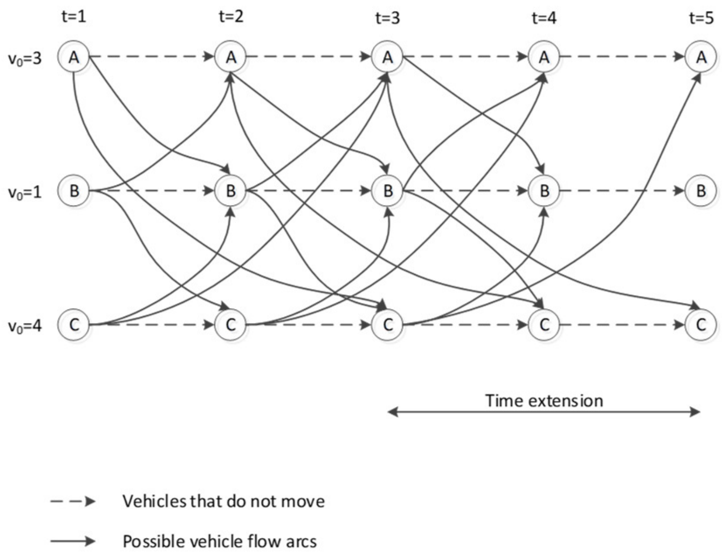
3) The importance of electric battery range constraint

4) Turn on and off municipalities (decided by optimization)

5) A mixed fleet of autonomous vehicles (4 and 16 seat capacity decided by optimization)

MIP model

- Routing np-hard
- Considers flows of vehicles (aggregated values)
- Time-space network
- Nodes represent municipalities; Edges represent flows
- Vehicles can relocate



MIP model

Scenarios	models
1	Model constrains 1 to 4
2	Model constrains 1 to 4
3	Model constrains 1 to 4 and 5
4	Model constrains 1 to 4 and 6
5	Model constrains 1 to 4 adapted for two vehicle types; the service provider chooses the vehicle to send

Objective function (maximize profit)

$$\max(\Pi) = \sum_{(i_t, j_{t+t_{ij}}) \in A_1} p(i,j) \cdot \left[D\left(i_t, j_{t+t_{ij}}\right) - k\left(i_t, j_{t+t_{ij}}\right)\right]$$

$$- \sum_{(i_t, j_{t+t_{ij}}) \in A_1} c(i,j) \cdot \left(x\left(i_t, j_{t+t_{ij}}\right) + y\left(i_t, j_{t+t_{ij}}\right)\right) - (cdriver + c_v) \cdot v$$

Subject to:

(1) Ensure the conservation of vehicle flows.

$$s(i_{t-1}, i_t)_{(i_{t-1}, i_t) \in A_2} + \sum_{(j_{t-t_{ij}}, i_t) \in A_1} x\left(j_{t-t_{ji}}, i_t\right) + \sum_{(j_{t-t_{ij}}, i_t) \in A_1} y\left(j_{t-t_{ji}}, i_t\right)$$

$$- \sum_{(i_t, j_{t+t_{ij}}) \in A_1} x\left(i_t, j_{t+t_{ij}}\right) - \sum_{(i_t, j_{t+t_{ij}}) \in A_1} y\left(i_t, j_{t+t_{ij}}\right) - s(i_t, i_{t+1})_{(i_t, i_{t+1}) \in A_2}$$

$$= 0 \quad , \forall i_t \in V | t > 0$$

(2) The number of persons transported by vehicles do not overpass its capacity

$$D\left(i_t, j_{t+t_{ij}}\right) - k\left(i_t, j_{t+t_{ij}}\right) \leq m \times x\left(i_t, j_{t+t_{ij}}\right) \quad , \forall \left(i_t, j_{t+t_{ij}}\right) \in A_1$$

(3) Rejected demand cannot overpass demand

$$k\left(i_t, j_{t+t_{ij}}\right) \leq D\left(i_t, j_{t+t_{ij}}\right) \quad , \forall \left(i_t, j_{t+t_{ij}}\right) \in A_1$$

(4) decide the number and position of vehicles at the first instant

$$\sum_{i \in N} s(i_0, i_1) = v$$

(5) the number of kms moving (in aggregate numbers) must be less or equal than the capacity of batteries.

$$\sum_{t=1}^{t=k} x\left(i_t, j_{t+t_{ij}}\right) \cdot d_{ij} + \sum_{t=1}^{t=k} y\left(i_t, j_{t+t_{ij}}\right) \cdot d_{ij} \leq R_0 \cdot v + C_r \cdot \sum_{t=1}^{t-k} s(i_t, i_{t+1}), \forall k \in I, \left(i_t, j_{t+t_{ij}}\right) \in A_1, (i_t, i_{t+1}) \in A_2$$

(6) the optimization model decides which municipalities are worth to explore through a profit point of view.

$$D\left(i_t, j_{t+t_{ij}}\right) = D'\left(i_t, j_{t+t_{ij}}\right) \times a(i,j), \forall \left(i_t, j_{t+t_{ij}}\right) \in A_1$$

$$a(i,j) \leq r(j), \forall i,j \in N$$

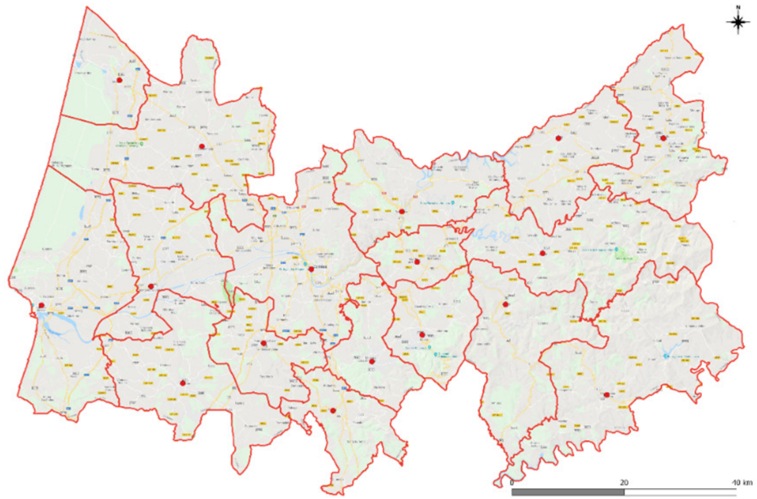
$$a(i,j) \leq r(i), \forall i,j \in N$$

$$a(i,j) \geq r(i) - M(1 - r(j)), \forall i,j \in N$$

$$r(i) \in \{0,1\}$$

Case study

- Region of Coimbra (17 municipalities)

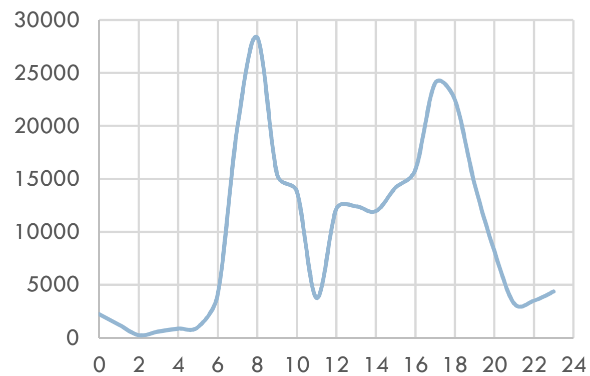


- Demand gathered from survey IMM2008

  total intermunicipal trips: 238490

  average distance: 32.5 km;

  average speed ≈ 60km/h;



- Diferent demand values considered

Service price and costs

- Service price considered: 10cts/km

(less than half of the urban service drivenow lisboa 27cts/min, considering an average speed of 60km/h)

- Vehicles:

	Minibus (Iveco Daily electric)	Car (Renault Zoe)
Capacity	16 passengers	4 passengers
Price	68000€	23195€
Depreciation (20% depreciation on the first 3 years)	37€ /day	13€ /day
Range	250km	250km
Normal charging rate	0.42km/min	1km/min
Running cost	7€/100km	4€/100km

Results - Mixed fleet vs Mono fleet

	No rejection		
	D (%)	#vehicles	profit(k€)
Autonomous car	10	743	78
	25	3388	405
	100	6715	813
Autonomous minibus	10	391	70
	25	1241	423
	100	2347	858

- Profit increase due to efficient use of capacity.

	D (%)	#cars	#minibus	Profit(k€)
Mixed fleet	10	285	141	81
	25	590	857	431
	100	964	1767	867

Allowing trip rejection

	No rejection			With trip rejection		
	D (%)	#vehicles	profit	#vehicles	profit	#rejected trips
Autonomous car	10	743	77542	(-94)	77979	210 (0.88%)
	25	3388	404770	(-172)	405446	532 (0.45%)
	100	6715	813007	(-273)	814021	923 (0.39%)
Autonomous minibus	10	391	69851	(-120)	72932	992 (4.18%)
	25	1241	422814	(-162)	425104	1506 (1.26%)
	100	2347	858217	(-218)	860445	2463 (1.03%)

- Trip rejection leads to 1% increase in profit
- Low service level

Electric capacity constraint

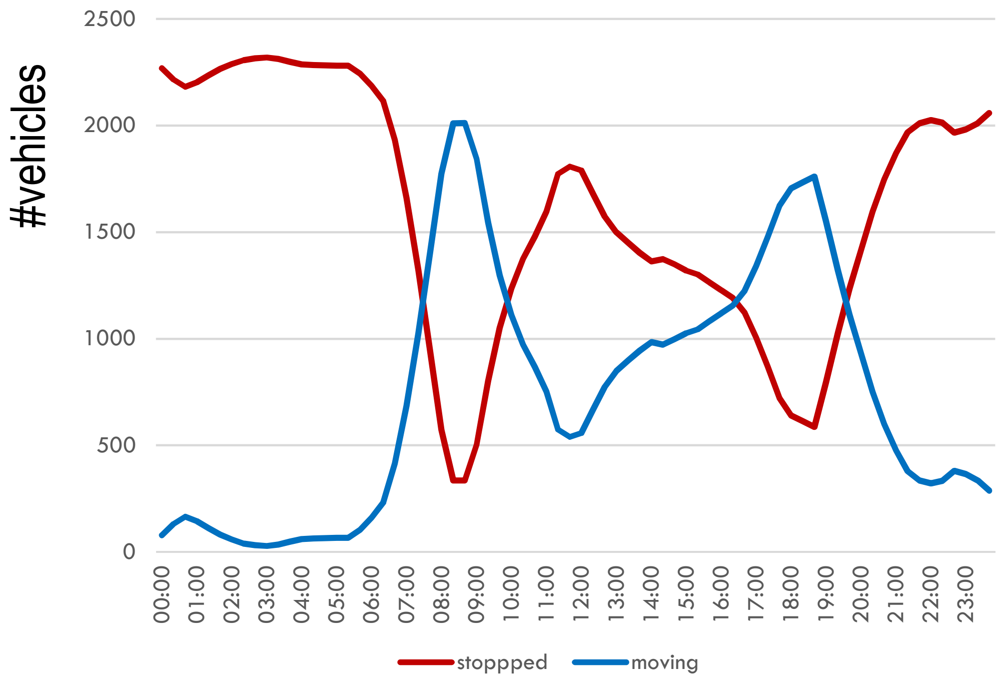
- The electric capacity constraint doesn´t affect the results (considering that the vehicle charges every time it stops; no limitations in number of chargers and location)

2347 vehicles

599551kms

avg: **256** km/vehicle

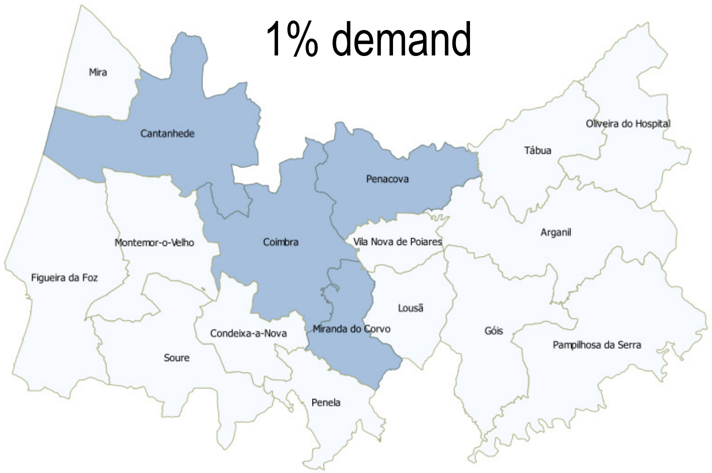
Initial charge: **250**km



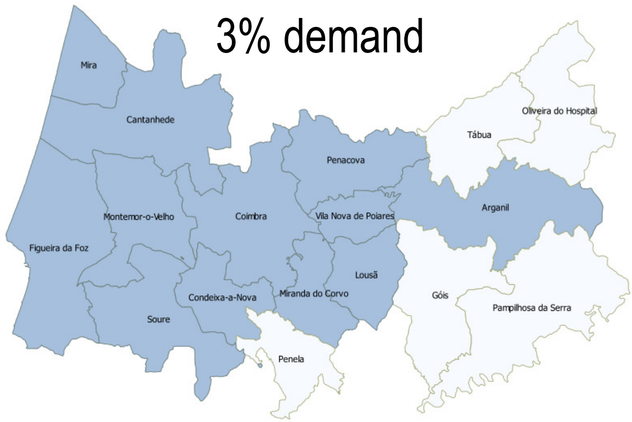
Turn on-off municipalities

- The turn on off restriction is used activated for low demand levels (once there is no fixed cost associated to service expansion)

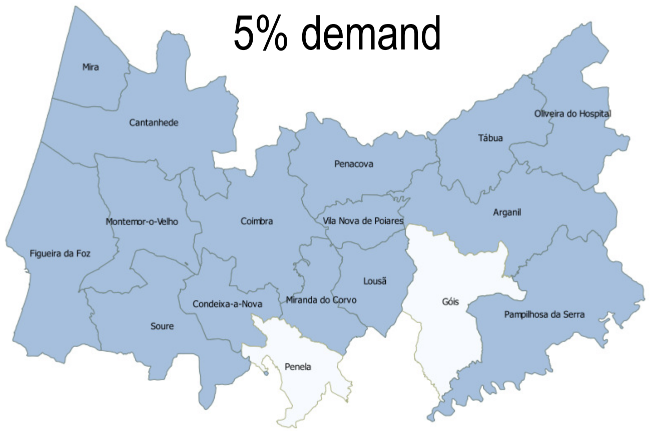
Autonomous minibus



1% demand



3% demand



5% demand

Closing remarks

- The use of a SAV system for interurban trtps is profitable (daily profit rounding 800k€ for Coimbra region);

- The number of vehicles needed to satisfy all interurban potential demand in Coimbra region are 6715 cars or 2347 minibus;

- The electric battery constraint is not important if number and location of charging stations are considered unlimited;

- Allowing trip rejection leads to a increase of 1% in profit;

Next research steps

- Expand the analysis to the **region of Aveiro**;
- Introduce pick up and delivery time;
- add maintenance cost;
- Consider the **train** as an alternative mode;
- Include **discrete choice model** inside the optimization model.

Thank You!

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