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Laboratoire d'Economie des Transports
Unité Mixte de Recherche du CNRS n° 5593
Université Lumière Lyon 2 - ENTPE

Taxi services modeling for decision making support

Session 4A : Transport Economics, Policy and Behaviour

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CERTH/HIT - UPC

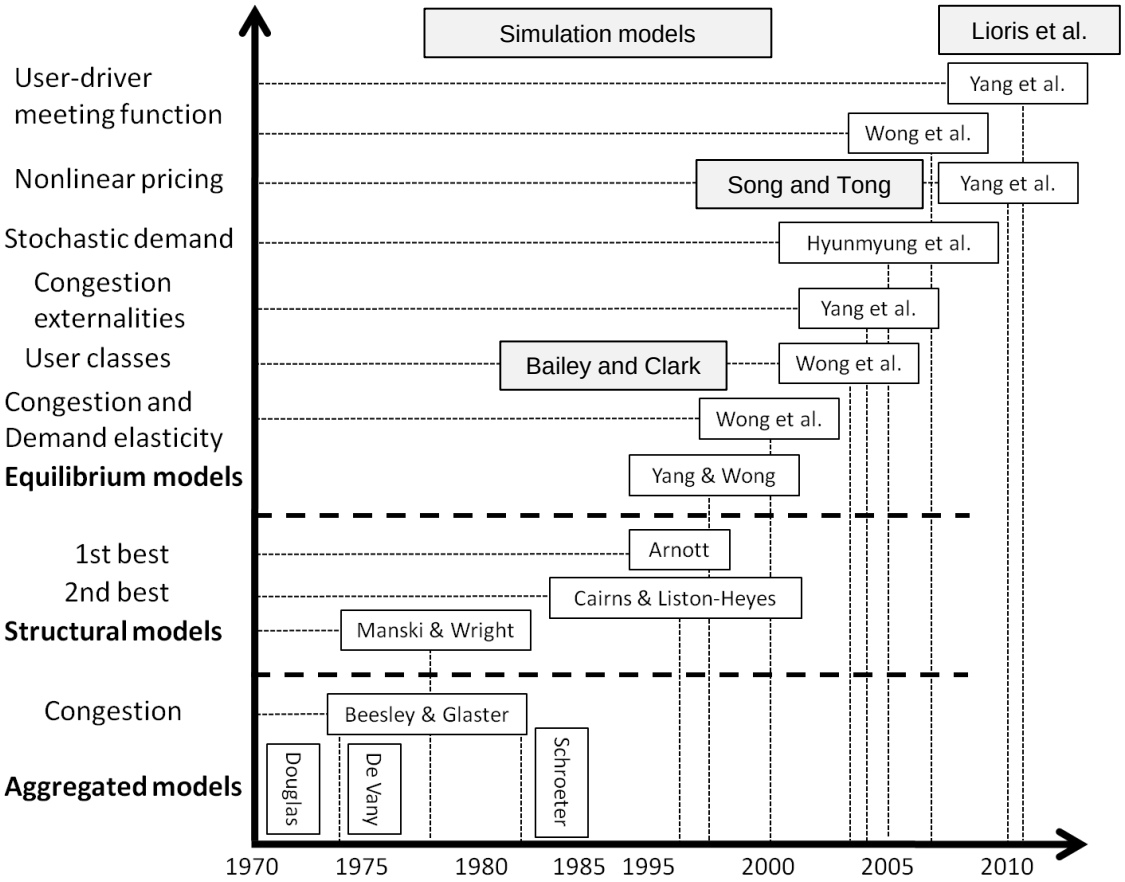
ECTRI
European Conference of Transport Research Institutes

FERSI
Road Safety Research

Objectives

- Brief review on taxi models
- Presentation of the two developed models for the estimation of the optimum size of the taxi fleet and the associated waiting time and unitary costs
  - Agreggated model: average values for the entire region
  - Agent-based model: micro simulation of the taxi market
- Application of the proposed models to the city of Barcelona
  - Minimum number of taxis
  - Optimum number of taxis (depending on the actor)

Taxi modeling review



Proposed models

Aggregated model – the objective function

$$Min\ Z_d + Z_u + Z_c + G$$

Model outputs:
Z_d is the cost of the drivers (min) - z_d is the unitary cost of the drivers (min/trip)
Z_u is the cost of the users (min) - z_u is the unitary cost of the users (min/trip)
Z_c is the additional cost for the city (min) - z_c is the unitary cost for the city (min/trip)
G is the cost of the infrastructure (min) - g is the unitary infrastructure cost (min/trip)

T_W is the waiting time of users (min)
T_A is the access time of users (min)
$\bar{c}$ is the average trip cost (€)
$\bar{n}$ is the average number of trips per hour and driver (trips)
ΔT_v is the increase in the travel time of the other drivers caused by taxis (min)

Decision variables:
λ_d is the taxi hourly supply (vehicles per hour and area of service)
D is the flag-drop charge (€)
τ_{km} is the taxi fee per unit of distance (€/km)
τ_{sec} is the taxi fee per unit of time (€/min)

Proposed models

Aggregated model – the constraints

- Access and waiting time of users lower than maximum values.
- Benefit of taxi drivers higher than minimum value.
- Emissions lower than maximum value.
- Congestion level lower than the maximum congestion level.
- Infrastructure cost lower than maximum value.
- Number of licenses between minimum and maximum values.

$$T_A < T_{Amax}$$
$$T_W < T_{Wmax}$$
$$Z_d < -B_{dmin}$$
$$E_d + E_v < E_{max}$$
$$\Delta T_v < \Delta T_{vmax}$$
$$G < G_{max}$$
$$\lambda_{dmin} < \lambda_d < \lambda_{dmax}$$

Proposed models

Aggregated model – the users' cost function

$$Z_u = \lambda_u \cdot A \cdot \left[\alpha_A \cdot T_A + \alpha_W \cdot T_W + \alpha_{IV} \cdot T_{IV} + \frac{\bar{c}}{VoT_u}\right]$$

Model outputs:
T_W is the waiting time of users (min)
T_A is the access time of users (min)
$\bar{c}$ is the average trip cost (€)

Model inputs (variables):
λ_u is the hourly demand for taxi trips (trips per hour and area of service)
A is the area of the region (km^2)
T_{IV} is the in-vehicle time of users (min)

Model inputs (parameters):
VoT_u is the value of time of the taxi users (€/min)
α_A is the user perception factor of the access time
α_W is the user perception factor of the waiting time
α_{IV} is the user perception factor of the in-vehicle time

Proposed models

Aggregated model – the drivers' cost function

$$Z_d = \frac{\lambda_d \cdot A}{VoT_d}\left[\bar{n} \cdot \bar{c} - \left(\bar{n} \cdot \bar{d} \cdot C_{km} + C_h\right)\right]$$

Model outputs:
$\bar{n}$ is the average number of trips per hour and driver (trips)

Decision variables:
λ_d is the taxi hourly supply (vehicles per hour and area of service)

Model inputs (variables):
A is the area of the region (km^2)
$\bar{d}$ is the average distance of the trip (km)

Model inputs (parameters):
VoT_d is the value of time of the taxi drivers (€/min)
C_{km} is the operational cost per unit of distance of taxis (€/km)
C_h is the hourly operational cost of the moving taxis (€/min)

Proposed models

Aggregated model – the city cost function

$$Z_c = \lambda_v \cdot A \cdot \Delta T_v + \frac{\lambda_d \cdot A \cdot C_E \cdot E_d}{VoT_d} + \frac{\lambda_v \cdot A \cdot C_E \cdot \Delta T_v \cdot E_d}{VoT_v}$$

Model outputs:
ΔT_v is the increase in the travel time of the other drivers caused by taxis (min)

Decision variables:
λ_d is the taxi hourly supply (vehicles per hour and area of service)

Model inputs (variables):
A is the area of the region (km^2)
λ_v is the hourly circulating vehicles (vehicles per hour and area of service)
E_d are the hourly vehicle emissions (kg of CO_2)

Model inputs (parameters):
VoT_v is the value of time of the other drivers (€/min)
C_E is the emission unitary cost for all vehicles (€/kg of CO_2)

Proposed models

Aggregated model

Minimum fleet

$$\lambda_d A = \lambda_u A \frac{r A^{1/2}}{2\bar{v}} \varepsilon + A \left(\frac{\lambda_u \alpha_W VoT_u 0{,}4r}{2\bar{v} C_h} \right)^{2/3}$$

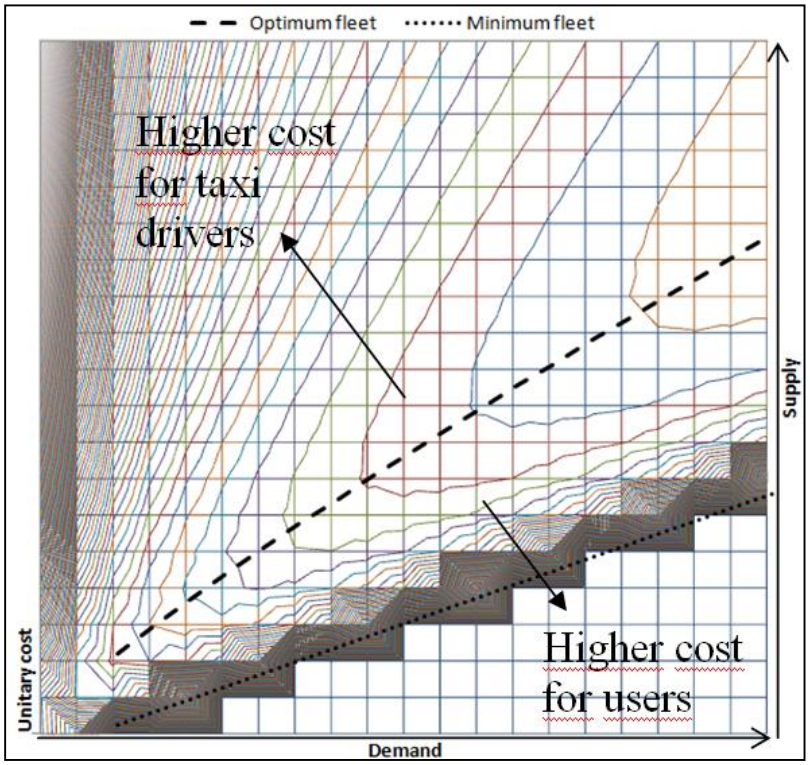
Extra fleet

$$T_W = \left(\frac{\alpha_W VoT_u}{0{,}32 \cdot C_h r^2} \lambda_u \bar{v}^2 \right)^{-1/3}$$

$$\frac{Z_u + Z_d}{\lambda_u \cdot A} = C_h \frac{r A^{1/2}}{2\bar{v}} \varepsilon + \left(28{,}125 \frac{\bar{v}^2 \lambda_u}{(\alpha_W VoT_u r)^2 C_h} \right)^{-1/3} + \frac{r A^{1/2}}{2\bar{v}} \cdot \left(C_{km} + \frac{\alpha_{IV} VoT_u}{\bar{v}} \right)$$

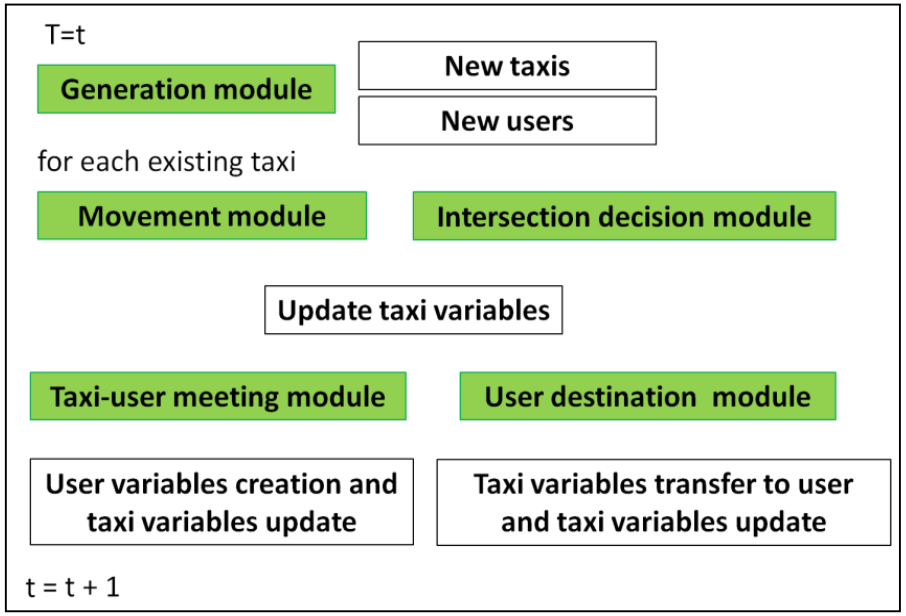
Proposed models

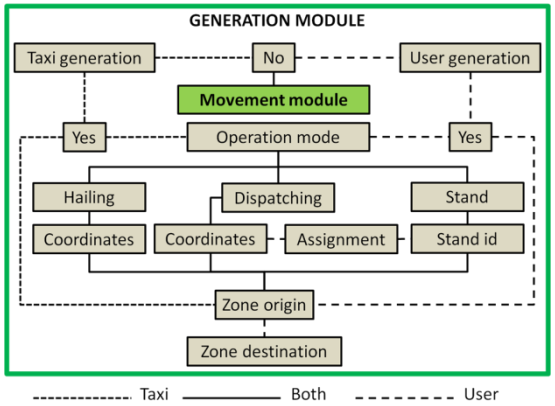
Aggregated model

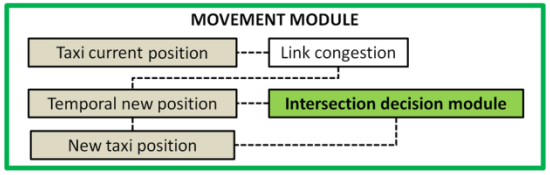


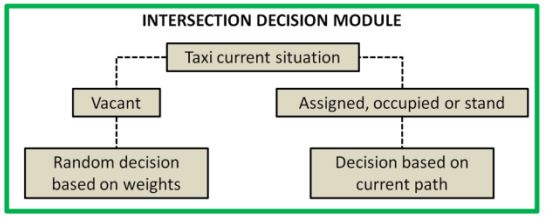
Proposed models

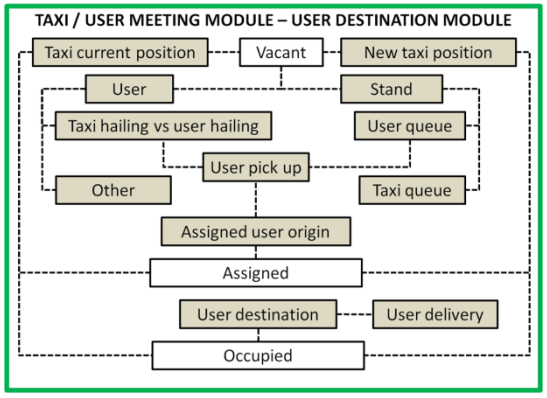
Agent-based model





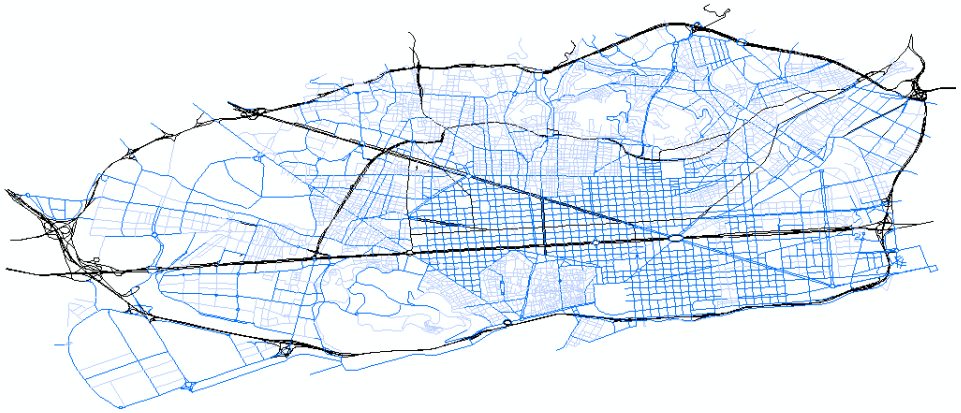






Use case: Barcelona

<u>The area of study</u>
18 municipalities
2.650.000 habitants
330 km^2
more than 12.800.000 daily trips



<u>The network</u>
1.600 km
8.000 intersections
20.000 links

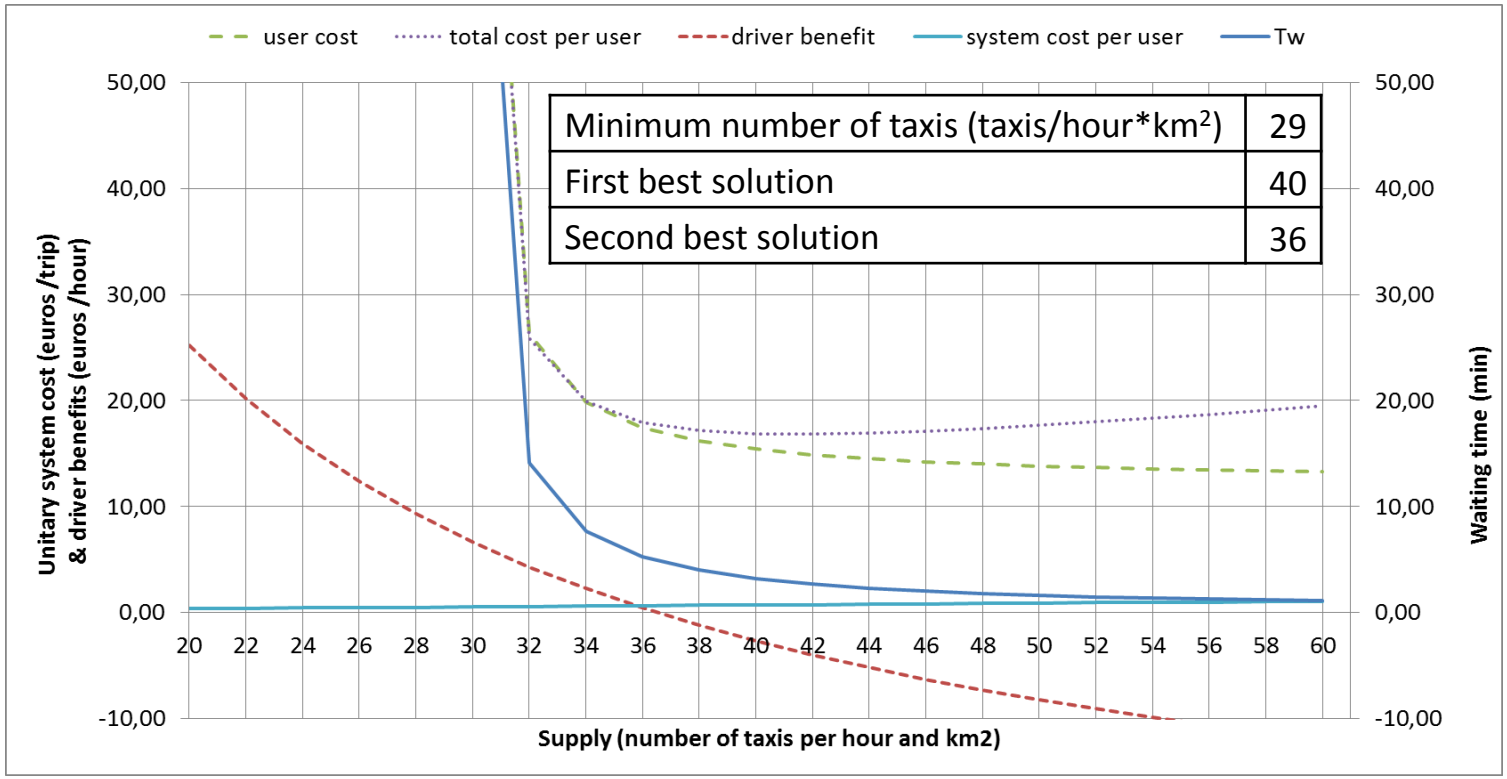
<u>The taxi market</u>
10.482 taxis
11.076 driver licenses
24 dispatching centers
272 taxi stands
225.000 daily trips

<u>The taxi trips database</u>
9 years (2004-2012)
1.200.000 valid taxi trips
10.000.000 km (50% occupied)
600.000 hours (33% occupied)
270.000 trips with GPS data

CENIT
CENTRE D'INNOVACIÓ DEL TRANSPORT

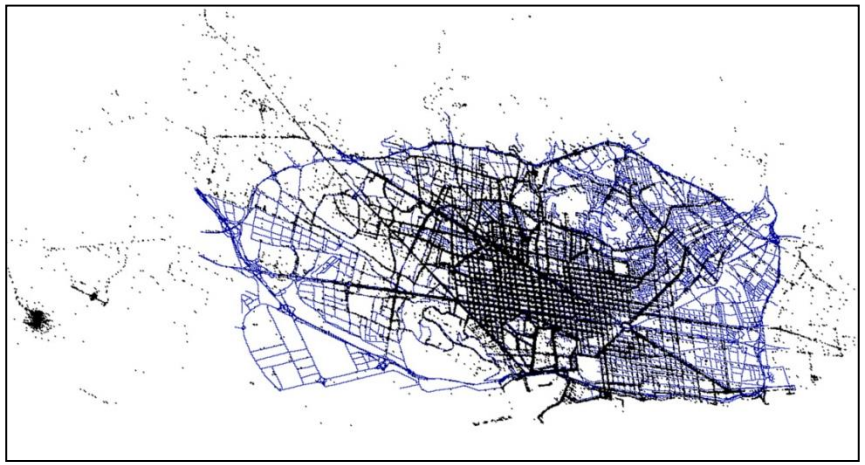
Use case: Barcelona

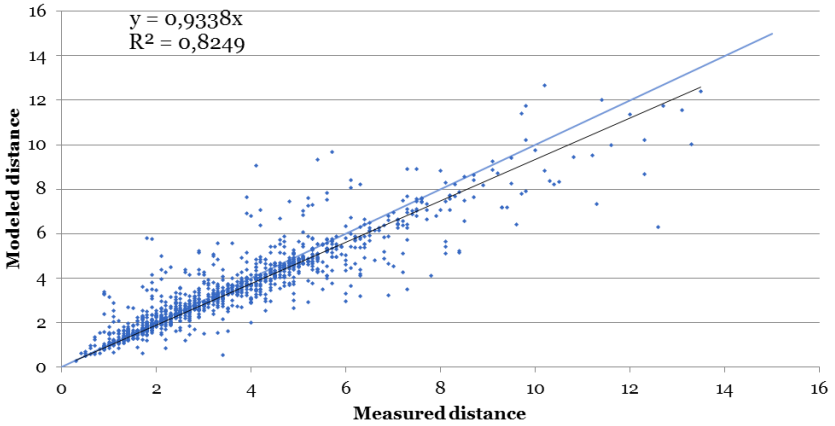
The aggregated model

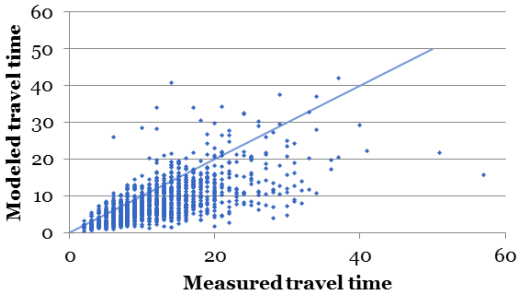


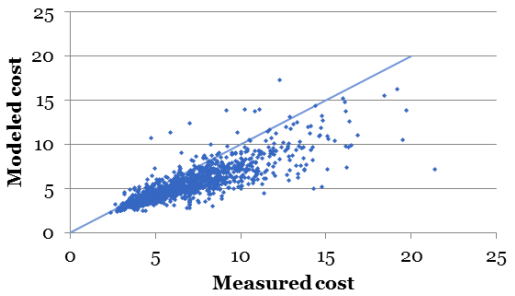
Use case: Barcelona

The agent-based model



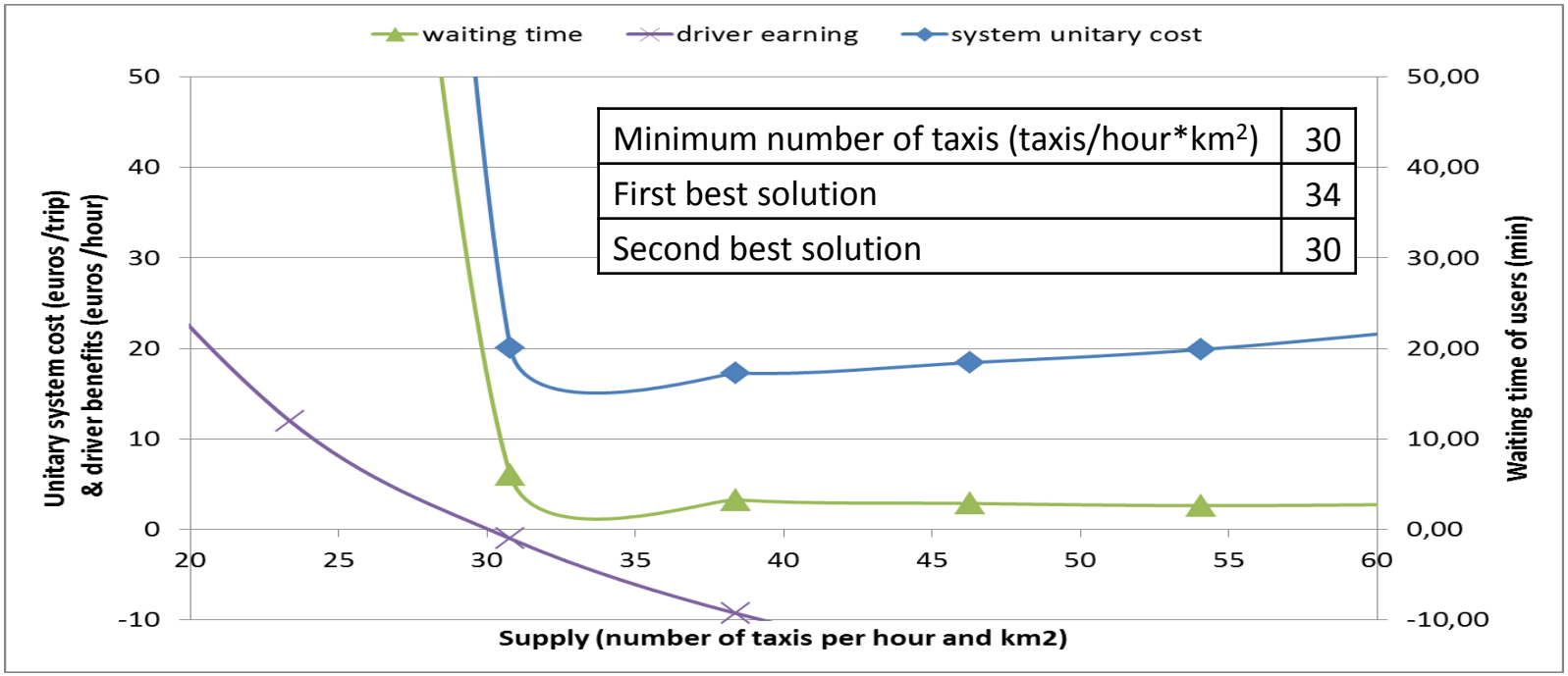






Use case: Barcelona

The agent-based model



Conclusions

Aggregated models can analyze **global performance** of the taxi services system but they cannot reflect local particularities of the network or provide detailed results for different parts of the city. They are also **limited in terms of outputs**, being unable to provide detailed results for all the involved actors. They are based on average and statistical values, therefore the data necessities are easier to fulfill than in more detailed models and their process time is zero.

Simulation models can provide much more **detailed outputs**, both in spatial and time terms. They need much **more detailed data** which is difficult to collect and process, and their **process time is much higher** than the one in the aggregated models.

The **combination of both models** can produce significant benefits to decision makers since they can analyze the taxi market macroscopic planning using aggregate models and then refine the results by using simulation models, from which they can obtain operational performance values and fine-tune their policies taking into account particularities of the network.

Conclusions

The two proposed models have been applied to the **city of Barcelona** using real data form both, the real network and the real taxi trips. The models have been validated with **real data collected during 9 years** from the taximeters of more than 100 taxis, which have realized more than **1.200.000 trips** during this period. The results obtained in terms of vehicles per hour and area by the simulation model are slightly lower than the ones obtained by the aggregated model. The models have concluded that the **system optimum number of taxis in Barcelona is 34 – 40 vehicles per hour and km^2**, while the **drivers optimum is slightly lower (30 – 36 vehicles per hour and km^2)**. They also provide the subsidization value needed for obtaining the first best and having the lowest unitary cost without causing losses to taxi drivers. These results can be used by decision makers when planning policy for the taxi sector while more detailed and localized data can be obtained from the simulation model in order to analyze the operational performance level of the taxi services.