SIMULATION APPROACH FOR PREDICTING THE ENVIRONMENTAL FOOTPRINT
OF CONNECTED AND AUTONOMOUS MOBILITY

SYMPOSIUM ECAV (ELECTRIC, CONNECTED AND AUTONOMOUS VEHICLE FOR SMART MOBILITY)

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AGENDA

I. Context

II. Modeling the impact of the car’s connecting system in terms of energy consumption for traction and associated emissions
   a. Emissions analysis methodology of the connected vehicle
   b. Case study: A comparative analysis of emissions between a non-connected and a connected vehicle

III. Large scale emissions analysis of autonomous transport service
   a. Environmental impact assessment methodology of autonomous transport service
   b. Case study: Modeling the current emissions map of the city of Lyon
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CONTEXT

The reduction of transport emissions is a significant challenge:

- The transport sector is the largest emitter of CO₂ in France (more than 30%).
- The transport sector represents more than 50% of NOx emissions and more than 15% of PM emissions in France.

New technology solutions are also emerging:

1. New engine technology
2. New exhaust gas aftertreatment technology
3. Electric mobility
4. Hydrogen mobility
5. Shared mobility
6. Smart mobility
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CONTEX

- Connected and intelligent mobilities have been identified as key technologies for reducing emissions and increasing transport efficiency:

1. Route choice optimization (Eco-Routing)
2. Driving behaviors optimization (Eco-Driving)
3. Choice of the charge stations (Eco-Charging)
4. Traffic control
5. Fleet management
6. Mobility management
7. MaaS (Mobility as a Service)

How can we also predict the emissions reduction enabled by intelligent mobility?
II. MODELING THE IMPACT OF THE CAR’S CONNECTING SYSTEM IN TERMS OF ENERGY CONSUMPTION FOR TRACTION AND ASSOCIATED EMISSIONS
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EMISSIONS ANALYSIS METHODOLOGY OF THE CONNECTED VEHICLE

Objectives

- **Realistically simulate the behavior of the connected vehicle.**
- **Quantify the impact of the car’s connecting system in terms of energy consumption for traction and associated emissions.**
- **Provide a comparative analysis between a non-connected and a connected car.**

Definition of the connected vehicle used for simulation

a. **Technical improvement of engines are considered (downsizing, vehicle hybridization, etc.)**

b. **Optimization of the speed profiles to reduce the consumption (eco-driving assumption)**

c. **Optimization of the route choice (eco-routing assumption)**
EMISSIONS ANALYSIS METHODOLOGY OF THE CONNECTED VEHICLE

- Geco air data → real-world connected data (1Hz vehicle speed, acceleration, road slope, external temperature)
EMISSIONS ANALYSIS METHODOLOGY OF THE CONNECTED VEHICLE

The model was validated on a total of 265 vehicles including all technologies and all European emission standards.
Why do we use a microscopic emissions model?

The microscopic model suggests a significant evolution by accounting for the acceleration and the slopes.

**Figure 1**: Comparison of NOx emissions for a Euro 5 Diesel vehicle on a RDE
Optimal vehicle speed computation is the core of the eco-driving strategy:

1. The trip is divided into displacements and each displacement is divided into sub-displacements.
2. An optimal velocity trajectory is calculated for each sub-displacement using an optimal control algorithm.
3. A complete vehicle powertrain model is used to give an accurate estimation of the consumption.

Figure 2: Different phases of a trip
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CASE STUDY: A COMPARATIVE ANALYSIS OF EMISSIONS BETWEEN A NON-CONNECTED AND A CONNECTED VEHICLE

Vehicle and engine parameters:
- 1.5 TSI EVO
- ICE Power: 131 Hp
- Car mass: 1269 kg

Table:

<table>
<thead>
<tr>
<th></th>
<th>Non-connected car</th>
<th>Connected car</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption (gCO₂/km)</td>
<td>198</td>
<td>171</td>
<td>14%</td>
</tr>
<tr>
<td>CO (mg/km)</td>
<td>398</td>
<td>259</td>
<td>35%</td>
</tr>
<tr>
<td>PM10 Brake &amp; Tire (mg/km)</td>
<td>16</td>
<td>9</td>
<td>44%</td>
</tr>
</tbody>
</table>

Figure 3: Example of an urban trip

Figure 4: Optimal velocity trajectory of a sub-displacement (ICE powertrain)
III. LARGE SCALE EMISSIONS ANALYSIS OF AUTONOMOUS PUBLIC TRANSPORT SERVICE
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Objectives

1. Produce current emissions/consumption maps with high temporal and spatial resolution.
2. Produce the predicted emissions/consumption map on a future scenario. This scenario considers the large-scale deployment of an autonomous public transport service.

Reference emissions/consumption map

Comparison

Predicted emissions/consumption map

Addition of an autonomous/connected on-demand public transport service
1. Produce current emissions and consumption maps with high temporal and spatial resolution

- **GIS data**
  - Location
  - Date, time

- **Mobility demand model**
  - Demographic data
  - Mobility data

- **Assignments prediction model**
  - Modal choice → the number of trips for each mode of transport
  - GIS Data → road signs, network topography, etc.
  - Traffic flow, speed and traffic density for each road segment of the network

- **Emissions model**
  - Driver model (vehicle speed)
  - The velocity profiles for each road segment

- **Fleet composition**
  - Fleet distribution

**Reference emissions/consumption map**
2. Produce the predicted emissions/consumption map on a future scenario

Assumption
An autonomous on-demand public transport service is introduced in the study area. A large-scale deployment is expected by 2030.

How to adapt the previous methodology to map the situation to 2030?

Figure 5: Autonomous on-demand shuttle operating on the university campus of Saclay (SAM project – Experiment 7).
2. Produce the predicted emissions/consumption map on a future scenario

1. Update of the distribution model ➔ Areas served by the new transport service can become more attractive.

2. Update of the modal choice model ➔ The creation of a new public transport line may reduce the use of individual transport.

3. Update the fleet composition model ➔ We must use a fleet composition of the 2030 horizon (IFSTTAR data).

Update the driver model (speed profiles prediction model) ➔ Speed profiles of autonomous/connected vehicles must be added (eco-driving). We have to update the speed profiles of vehicles that interact with the new service.
- **SAM PROJECT**: Environmental evaluation of experiments 7 and 8 (Saclay and Rouen)
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CASE STUDY: MODELING THE CURRENT EMISSIONS MAP OF THE CITY OF LYON

- Location: Métropole de Lyon
- Time: 8 am → 9 am

Figure 6: Actual NOx emissions levels map [mg/s]

Figure 7: Histogram of the NOx emissions levels [mg/km]
CONCLUSIONS

- The developed method is a combination of our expertise in various fields:
  - Vehicle and engine modeling
  - Advanced optimization algorithms for Eco-Driving and Eco-Routing
  - Traffic modeling

- The overall approach is flexible and can take as input the mobility data (Geco air) for increased accuracy.

- A high spatial and temporal resolution emissions map can be obtained.

- Various mobility scenarios can be analyzed and compared at high precision.
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