Analysis of real driving data
to explore travelling needs in relation
to hybrid–electric vehicle solutions

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2013 is the first year when the average CO2 emissions are below the 2015 emissions target.

EU “Air Quality Plan” and concentration constraints
Aim

- **Project: E-VINCE**
  EU Vehicles for Innovative and interconnected road transport Compliant with EU aims from Energy, emissions, economics and mobility viewpoints (Politecnico di Torino - FCA, 2016-2017)

  - Analysis of **car driving habits** detected by using a **dataset** obtained from automobiles in use in Europe; aim to link the patterns of mobility (e.g. daily travelled distances) with the features of various **electric/hybrid** solutions for vehicles.

  - Some relevant travel aspects (variables) concern the **lengths and durations of journeys** by car related to their environment (urban, extra–urban and highway) and their **idle time**, both before and after the journey itself.

Two approaches applied for data analysis:
1. **Single journey** recorded
2. **Daily usage** of the vehicle
Dataset description for Journey Analysis

- **Analysis** of more than 220,000 *journeys* done by 1085 European *drivers* (UK, DE, FR, ES, IT) thanks to Eco Drive Data acquired on FCA vehicles.

- **Time Frame**: January 2015 to March 2016

- **Criteria for Data Filtering**:
  - Length > 50 m
  - Duration > 60 s
  - Fuel Consumption < 50 l/100 km

- **Variables** analyzed representing drivers’ behavior:
  1. Starting Trip Day of the Week
  2. Starting Trip Time
  3. Journey Type (Urban, Extra-urban and Highway)
  4. Trip Duration
  5. Journey Length
  6. Fuel Consumption
  7. Idle Times

- **Tools**: R-Studio, Microsoft Excel & VBA
Journey sample

Number of Journeys

Week

2015  2016
Clustering procedure

Parameters
- StartingTripDayOfTheWeek
- StartingTripTime
- JourneyType_num
- Trip_duration_s
- JourneyLength_km
- ECU_fuel_consumption
- Idle_minutes

Selection of the journeys closer the cluster centres
Data analysis: dendrogram scheme
The 35% of urban trips done by users in Europe cover a distance <5 km, the 90% is shorter than 10 km.

The 90% of the trips done by users in extra urban context is shorter than 30 km long, with trips around 10 and 30 km.

The 10% of the trips made along highways is shorter than 20 km, the 35% between 20 and 60 km; trips over 100 km are more than 55%.
Next steps: energetic analysis

**INPUT**

**POWERTRAIN**
- Conventional Vehicle
- Hybrid Electric Vehicle
- Plug-in Hybrid Electric Vehicle
- Battery Electric Vehicle

**TARGET**
- energy consumption and efficiency
  - WTW WTT TTW
- CO2 emissions
  - WTW WTT TTW
- TCO
  - Impact on the user
Starting Trip Day of the Week

- During weekdays, users’ cars are driven with similar frequency both in urban, extra-urban and highway context.

- On Sundays, trips are less than weekdays and urban trips are less than extra-urban and highway.
Cumulative plots help to select homogeneous time periods in which estimate a representative rate of departures (traffic flow) within a day.

Cars flows depend on curve gradient: higher is the gradient, higher the flow.
The averaged travel duration affects energy consumption and battery use. In fact, all onboard services require electricity to work that depends on time of use (audio/video, lights, air conditioning).

Approximately the 80% of highway trips is much longer than 30 minutes.

More than 40% of urban trips have a duration less than 5 minutes.
### Idle Times of the journey

- **[Pink]**: Journeys started in the morning (from 7 to 9 a.m.) have a previous idle time of 12 – 14 hours (e.g. night’s rest).

- **[Indigo]**: Another part of users used their cars from 17 to 20 after 10 hours of stop (e.g. full time job).

- **[Green]**: Other journeys started from 12 to 15 after a break of 4 hours (e.g. part time job).

- **[All]**: Lots of performed journeys have a short idle time before starting.

- **[All]**: Lots of performed journeys by users have a short idle times before starting.

- **[Pink]**: Journeys ended from 7 to 9 a.m. have two main peaks: 4 – 5 hours and 8 – 10 hours waiting before re-start (e.g. full time and part-time working).

- **[Indigo]**: Journeys ended from 17 to 20 remain stopped for 12 to 16 hours (e.g. ending of working day).

- **[Dark Pink]**: Idle times between 8 to 12 hours followed stops started from 20 to 7 a.m. (e.g. overnight break).
Idle time after journey of journeys higher than 50 km (totally higher 200 km in a day). Each box correspond to the percentage of total travel.

| Journey Length [km] | Idle Time After Journey [h] |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---------------------|-----------------------------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60                  | 0                           | 1 | 0,1% | 0,1% | 8,5% | 8,7% |
| 70                  | 0,1%                        | 0,1% | 0,1% | 6,9% | 7,1% |
| 80                  | 0,1%                        | 6,6% | 7,1% |
| 90                  | 0,1%                        | 6,4% | 6,5% |
| 100                 | 0,2%                        | 7,7% | 7,9% |
| 110                 | 0,3%                        | 8,0% | 8,3% |
| 120                 | 0,1%                        | 6,6% | 6,8% |
| 130                 | 0,1%                        | 4,7% | 4,9% |
| 140                 | 0,1%                        | 4,5% |   |
| 150                 | 0,1%                        | 3,6% | 3,8% |
| 160                 | 4,0%                        | 4,0% |   |
| 170                 | 3,2%                        | 3,2% |   |
| 180                 | 0,1%                        | 2,5% | 2,7% |
| 190                 | 0,1%                        | 2,3% | 2,4% |
| 200                 | 0,1%                        | 2,6% | 2,7% |
| 210                 | 0,2%                        | 3,0% | 3,3% |
| 220                 | 0,1%                        | 2,1% | 2,2% |
| 230                 | 0,1%                        | 1,8% | 1,9% |
| 240                 | 0,1%                        | 1,2% | 1,3% |
| 250                 | 1,0%                        | 1,0% |   |
| 260                 | 0,1%                        | 1,2% | 1,3% |
| 270                 | 0,1%                        | 0,8% | 0,9% |
| 280                 | 0,1%                        | 1,0% | 1,0% |
| 290                 | 0,1%                        | 0,8% | 0,8% |
| 300                 | 0,1%                        | 0,9% | 1,0% |
| **Total**           | **92%**                     | **2%** | **1%** | **0%** | **0%** | **0%** |**
Energy Analysis: compute best hybrid solution using specific algorithms using speed profiles for each typical journey / user

Previous results: 15 representative journeys

<table>
<thead>
<tr>
<th>Cluster ID</th>
<th>Model</th>
<th>Powertrain</th>
<th>Start Trip Week</th>
<th>Start Trip Time</th>
<th>Journey Type</th>
<th>Duration (s)</th>
<th>Length km</th>
<th>V 100k</th>
<th>Idle min before</th>
<th>Charge system</th>
<th>Cluster %</th>
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</thead>
<tbody>
<tr>
<td>11</td>
<td>1.6 Mustang 120hp MB FWD</td>
<td>Weekend</td>
<td>Afternoon</td>
<td>Urban</td>
<td>Short (5-16 min)</td>
<td>Very short (&lt;6 km)</td>
<td>9.6</td>
<td>6-2.5</td>
<td>Fast charge PHEV</td>
<td>12.2 PHEV</td>
<td>11.9 PHEV</td>
</tr>
<tr>
<td>6</td>
<td>1.4 Mustang 140hp MB FWD</td>
<td>Weekend</td>
<td>Evening</td>
<td>ExtraUrban</td>
<td>Short (6-15 min)</td>
<td>Short (0-20 km)</td>
<td>7.1</td>
<td>&lt;30 min</td>
<td>None</td>
<td>11.9 HEV</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.4 Mustang 140hp DOT FWD</td>
<td>Weekday</td>
<td>Evening</td>
<td>ExtraUrban</td>
<td>Medium (15-30 min)</td>
<td>Short (5-20 km)</td>
<td>7.9</td>
<td>6-13</td>
<td>Slow charge PHEV</td>
<td>10.9 REEV</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1.6 Mustang 120hp MB FWD</td>
<td>Weekday</td>
<td>Evening</td>
<td>Urban</td>
<td>Short (6-15 min)</td>
<td>Very short (&lt;6 km)</td>
<td>9.7</td>
<td>&lt;30 min</td>
<td>Supercharger EV</td>
<td>10.9 BEV</td>
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<tr>
<td>8</td>
<td>1.6 Mustang 120hp MB FWD</td>
<td>Weekend</td>
<td>Morning</td>
<td>ExtraUrban</td>
<td>Short (6-15 min)</td>
<td>Short (0-20 km)</td>
<td>7.2</td>
<td>&lt;30 min</td>
<td>None</td>
<td>9.9 HEV</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1.4 Mustang 140hp MB FWD</td>
<td>Weekend</td>
<td>Morning</td>
<td>Urban</td>
<td>Short (6-15 min)</td>
<td>Very short (&lt;6 km)</td>
<td>9.0</td>
<td>0-6.7</td>
<td>Slow charge PHEV</td>
<td>0.6 PHEV</td>
<td></td>
</tr>
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<td>10</td>
<td>1.8 Mustang 120hp MB FWD</td>
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<td>Morning</td>
<td>ExtraUrban</td>
<td>Short (6-15 min)</td>
<td>Short (0-20 km)</td>
<td>7.4</td>
<td>&lt;30 min</td>
<td>None</td>
<td>9.2 REEV</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.6 Mustang 120hp MB FWD</td>
<td>Weekday</td>
<td>Afternoon</td>
<td>Urban</td>
<td>Very short (&lt;6 min)</td>
<td>Very short (&lt;6 km)</td>
<td>19.2</td>
<td>&lt;30 min</td>
<td>None</td>
<td>3.3 HEV</td>
<td></td>
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<td>3</td>
<td>1.6 Mustang 120hp MB FWD</td>
<td>Weekday</td>
<td>Afternoon</td>
<td>Urban</td>
<td>Long (30-60 min)</td>
<td>Medium short (20-35 km)</td>
<td>8.1</td>
<td>&lt;30 min</td>
<td>Fast charge PHEV</td>
<td>4.9 PHEV</td>
<td></td>
</tr>
<tr>
<td>14</td>
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<td>Weekday</td>
<td>Afternoon</td>
<td>HighWay</td>
<td>Very long (&gt;60 min)</td>
<td>Very long (&gt;60 min)</td>
<td>&gt;0</td>
<td>None</td>
<td>None</td>
<td>0.8 PHEV</td>
<td></td>
</tr>
</tbody>
</table>

- First analysis of users’ usage reveal that current batteries ranges (PHEV ≈ 50 km) satisfy almost urban and extra-urban driving behavior
- According with Idle Times, slow charging could be used during nights and weekdays at home and at working places

selection of 15 speed profiles different journeys different users
Once the analysis reached the most representative trips and energy study produces the best hybrid / electric vehicle architecture, we can take a look on daily point of view.

- Which is the averaged daily trip length?
- Which is the averaged daily trip duration?
- Other aims
• 50% of days per users travelled between 0 to 5 km/day

• 99.9% of days per users travelled is less than 50 km/day

Only 25 days per users exceeded 50 km/day. 21 out 25 are users (2% of total users or 21 on 1037) who have done at least one trip during the period of observation.

• Around 5 km is the most performed daily trip length done in urban context
• More than 50% of urban days per users have a shorter duration than 16 minutes, 90% less than 52 minutes and 99% less than 107 minutes

518 users (50% of journeys) made at least one trip longer than 52 minutes and 125 (24% of journeys) longer than 107 minutes
Global Daily Travelled Distance

- 99% of days per users covered less than 400 km/day, 60% less than 50 km/day

Who have done at least one trip:
- >35 km/day: 90% of users (977 out of 1085)
- >70 km/day: 82% of users (892 out of 1085)
- >395 km/day: 20% of users (219 out of 1085). Extra-urban and highway types
Global Daily Travelled Time

- More than 50% of daily travelled time is less than 64 minutes, 90% less than 2.5 hours and 99% less than 5.2 hours.

89% of users travelled at least one time over 64 minutes, 69% over 2.5 hours and 22% over 5.2 hours.
The frequency of long journeys decreases increasing the daily distance covered.

![Graph showing frequency and cumulative percentage of daily distances](image-url)
Combining idle time and energy consumption

The analysis of idle time is useful to identify the best recharging solutions according to the vehicle usage.

From travelled time and distances the energy used is estimated and the available idle time before or after the trip, if it is adequate, could be used to recharge and recover the energy consumed.

The focus is on the number of single trips longer than 20 km operated in days in which the total travelled distance is longer than 100 km.
Energy recovery opportunities during idle time

Linking the idle time after a journey, the energy consumed during the last trip and power supply (3kW, 22kW, 43kW, 135kW) to estimate the number of rechargeable travels.
Declared Electric Ranges (Supply)

BEV Market (2017)

BEV Models

PHEV Market (2017)

PHEV Models
Final considerations [1]

Electric Range from Market (NEDC):
- BEV: 632 ÷ 100 km (100 – 7,2 kWh)
- PHEV: 56 ÷ 30 km (17,3 – 6 kWh)
- HEV: 5 ÷ 2 km (1,5 kWh)

Available Electric Charging:
- Power: 2,7 – 3,7 – 7,4 – 11 – 22 – 120 kW
- Current: 16 – 32 A
- Voltage: 230 – 400 V

Averaged Charging Time:
- BEV
  - 100 kWh: 37 h (slow) - 0,8 h (very fast)
  - 7,2 kWh: 3 h (slow) - 0,1 h (very fast)
- PHEV
  - 17,3 kWh: 6 h (slow) - 0,1 h (very fast)
  - 6 kWh: 2 h (slow) – 0,05 h (very fast)

Daily Travelled Length (from data analysis):
- Urban environment: 99,9 % of days per users travel up to 50 km/day
- All trips each other: 99 % of days per users travel up to 400 km/day

Daily Travelled Time (from data analysis):
- Urban environment: 99 % of days per users travel up to 107 minutes/day
- All trips each other: 99 % of days per users travel up to 5,2 h/day

- PHEVs and BEVs could help to reduce pollution in cities
- When necessary, PHEVs could use ICE engine (range extender)
- BEVs need recharging points also outside cities (for long journeys)
Final considerations [2]

The right compromise between higher battery capacity and higher power of charge is to make a versatile vehicle, both for longer distances and for less time to recharge.

One of the possible solutions is a PHEV that would cover short distances with the electric motor (e.g. urban and extra-urban environments) and longer trips with ICE.