Analysis of the WLTP in-use driving behaviour database with respect to acceleration and deceleration phases

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Description of the WLTP Database

- The WLTP in-use driving behaviour database consists of driving behaviour data from five different regions in the world (see Table 1).

- The data from Europe and the major part of the US data is customer data and thus reflects the practical use of the vehicles in real traffic.

- The data from India, Japan and Korea is not customer data. Vehicles, routes and driving times were chosen in order to reflect representative driving in these countries.
### Overview of the WLTP in-use driving behaviour database

<table>
<thead>
<tr>
<th>Region</th>
<th>Mileage in km</th>
<th>Duration in h</th>
<th>No of short trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>432,572</td>
<td>8,003</td>
<td>200,813</td>
</tr>
<tr>
<td>India</td>
<td>73,694</td>
<td>1,824</td>
<td>17,358</td>
</tr>
<tr>
<td>Japan</td>
<td>49,868</td>
<td>1,255</td>
<td>55,944</td>
</tr>
<tr>
<td>Korea</td>
<td>32,399</td>
<td>790</td>
<td>26,972</td>
</tr>
<tr>
<td>USA</td>
<td>155,160</td>
<td>2,557</td>
<td>65,551</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>743,694</strong></td>
<td><strong>14,430</strong></td>
<td><strong>366,638</strong></td>
</tr>
</tbody>
</table>

Table 1
The European data was collected in Belgium, France, Germany, Italy, Poland, Slovenia, Spain, Sweden and UK.

The US customer data was collected in Atlanta, Denver, Los Angeles, San Diego and San Francisco.

Number of vehicles/vehicle models:

Europe: 126 M1 vehicles, 20 N1 vehicles,

USA: 5 SUV

Japan: 11 M1 vehicles, 13 N1 vehicles,

Korea: 4 M1 vehicles, 4 N1 vehicles,

India: 20 M1 vehicles, 11 N1 vehicles.
Measured/monitored data

• The data consists of vehicle speed, engine speed (not for all vehicles), date and time of the day and trip number with a sample rate of 1 Hz.

• The acceleration was calculated using the following two approaches:
  
  - \( a_i = \frac{(v_{i+1} - v_i)}{3.6} \),
  
  - \( a_i = \frac{(v_{i+1} - v_{i-1})}{2/3.6} \),

• The second approach was used for the further analysis within the WLTP development work.
Analysis approach

The following indicators were assigned to the datasets:

- **trip number,**
- **short trip number within a trip** (a short trip consists of consecutive datasets with $v \geq 1$ km/h)
- **acceleration** (consecutive datasets with $a > 0.1389$ m/s² or 0.5 km/h/s),
- **deceleration** (consecutive datasets with $a < -0.1389$ m/s²),
- **cruise** (consecutive datasets with $-0.1389$ m/s² $\leq a \leq 0.1389$ m/s²).
Structure of the report

1. Explanations for the ACCESS databases
2. Description of the WLTP database
3. Mileage statistics, number of monitoring days etc.
4. Vehicle speeds – average speeds and distributions
5. Vehicle speeds in Europe, urban, rural, motorway
6. Short trip and stop phase analysis
   6.1 Stop phases
   6.2 Short trips
7. Acceleration phases
   7.1 Duration distributions
   7.2 Distance distributions
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Deceleration phases</td>
</tr>
<tr>
<td>8.1</td>
<td>Duration distributions</td>
</tr>
<tr>
<td>8.2</td>
<td>Distance distributions</td>
</tr>
<tr>
<td>9</td>
<td>Phases with brake engaged</td>
</tr>
<tr>
<td>9.1</td>
<td>Determination of a speed dependent deceleration threshold curve</td>
</tr>
<tr>
<td>9.2</td>
<td>Results for the WLTP database</td>
</tr>
<tr>
<td>9.2.1</td>
<td>Brake phase duration distributions</td>
</tr>
<tr>
<td>9.2.2</td>
<td>Brake phase distance distributions</td>
</tr>
<tr>
<td>9.2.3</td>
<td>Number of brake phases per km</td>
</tr>
</tbody>
</table>
Structure of the report

10 Joint vehicle speed acceleration distributions
10.1 Time weighted
10.2 Distance weighted
11 Acceleration distributions, acceleration > 0.15 m/s²
11.1 Time weighted
11.2 Distance weighted
12 Deceleration distributions, deceleration < -0.15 m/s²
12.1 Time weighted
12.2 Distance weighted
Structure of the report

13 Vehicle specific acceleration distributions, EU database
   13.1 Time weighted
   13.2 Distance weighted

14 Vehicle specific deceleration distributions, EU database
   14.1 Time weighted
   14.2 Distance weighted

15 $v^\star a_{negative}$ distributions, $v^\star a < -1 \text{ m}^2/\text{s}^3$
   15.1 Time weighted
   15.2 Distance weighted
Structure of the report

Annex 1: Distance weighted joint average speed - maximum speed distributions of short trips

Annex 2: Time weighted joint vehicle speed - acceleration distributions

Annex 3: Distance weighted joint vehicle speed - acceleration distributions
Mileage statistics

- The total mileage of the data is almost 800 000 km.
- 4.7% of this mileage is related to trips below 3000 m. These trips were disregarded for the analysis of acceleration and deceleration distributions.
- Another 5.8% of the total mileage belongs to trips with faulty sections (jumps in vehicle speed etc.). This data was also excluded from the analysis.
- The remaining total mileage is 714 198 km. The distribution to the different countries, measurement campaigns and vehicles are shown in tables 8 to 26 in the report.
Mileage statistics

- The number of monitoring days and the key parameters of the daily travelled distances are summarised in Table 27 to Table 31 of the report.
- More detailed information can be found in table “TB_daily_distance” in the Access database.
- There are big differences between the countries as well as between different measurement campaigns.
- The lowest average daily distance was found for Poland (30 km), the highest for the UK (188 km, N1 vehicle).
Driving statistics

- The key parameters (duration, distance driven, stop duration, average and maximum speeds) for all vehicles are shown in tables 32 to 38 of the report.
- There are significant differences between the individual vehicles (drivers) within a country, but there are also significant differences between the countries, even within Europe.
- The measurement campaigns in Poland and Spain are dominated by urban traffic conditions, while the campaign in Italy has a high influence of rural and motorway traffic.
- This is also reflected in the country related vehicle speed distributions, shown in Figure 1 and Figure 2.
Vehicle speed distributions

Figure 1
Vehicle speed distributions

Figure 2
Vehicle speeds, urban, rural, mot

- The customer datasets Belgium 1, France 1, France 2, Germany, Italy, Slovenia, UK M1, Poland and Spain came along with road category indicators for urban, rural and motorway.
- The key parameters of these datasets with respect to mileage, driving time and average speeds per vehicle are summarised in Table 39 to 47 of the report.
- Examples per dataset are shown in the following figures.
v distributions, urban, rural, mot

Figure 3a
v distributions, urban, rural, mot

Figure 3b
v distributions, urban, rural, mot

Figure 3c
v distributions, urban, rural, mot

Figure 3d
v distributions, urban, rural, mot

Figure 3e
v distributions, urban, rural, mot

Figure 3f
v distributions, urban, rural, mot

Figure 3g
v distributions, urban, rural, mot

Figure 3h
v distributions, urban, rural, mot

Figure 3i

cum frequency

vehicle speed in km/h

with standstill
Stop phases

• For the further analysis the data was separated into stop periods and short trips. Stop periods are defined as connected time sequences with vehicle speeds below 1 km/h, short trips are connected time sequences with vehicle speeds >= 1 km/h.

• Figure 4 to Figure 7 show the stop phase duration distributions for different regions and different countries within Europe, number weighted and duration weighted.

• Number weighted means that the percentages on the y-axis indicate the percentage of the whole number of stop phases with a duration of the corresponding x-axis value.
Stop phases

• Duration weighted means that the percentages on the y-axis indicate the percentage of the whole stop duration with a duration of the corresponding x-axis value.

• Figure 8 shows the number weighted stop duration distributions for Europe, separated into three road categories.
Stop duration distribution

![Graph showing stop duration distribution for different regions: Europe, India class 1, India class 2, India class 3, Japan, Korea, USA. The x-axis represents stop duration in seconds, and the y-axis represents the number of weighted cumulative frequency. The graph includes stop phases box.]
Stop duration distribution

![Graph showing stop duration distribution for different regions and countries with duration weighted in the center of the graph.](image)
Stop duration distribution

Figure 6
Stop duration distribution

Figure 7
Stop duration distribution

Figure 8
Short trips

• Figure 9 to Figure 12 show the short trip distance distributions for different regions and different countries within Europe, number weighted and distance weighted.

• Figure 13 and Figure 14 show number and distance weighted short trip distance distributions for Europe, separated for different road categories.

• In order to assess the occurrence of creeping situations the short trips were binned with respect to $v_{\text{max}}$ and the distances were summed up per $v_{\text{max}}$ bin and related to the total distance per road category.

• The results are shown for different road categories for some European countries in Table 53 to 60 of the report.
Short trips

- Distance weighted joint frequency distributions of average speed / maximum speed for short trips are shown in annex 1.
Short trip distribution

Figure 9
Short trip distribution

Figure 10
Short trip distribution

Figure 11
Short trip distribution

Figure 12
Short trip distribution

Figure 13

Europe, number weighted

- motorway
- rural
- urban
Short trip distribution

Figure 14
Acceleration duration distributions

- Acceleration phases are specified as consecutive time samples with $a > 0.5 \text{ km/h/s}$ or $0.1389 \text{ m/s}^2$. The following key parameters of such phases were collected in a separate table ($TB_{acc}$) per vehicle and trip:
  - Date, Time, Duration, Distance,
  - $v_{\text{min}}$, $v_{\text{ave}}$, $v_{\text{max}}$, stddev$_v$,
  - $a_{\text{min}}$, $a_{\text{ave}}$, $a_{\text{max}}$,
  - $v^*a_{\text{min}}$, $v^*a_{\text{ave}}$, $v^*a_{\text{max}}$.

- In order to ease the calculation of duration and distance related distributions the results were binned for both values ($2 \text{ s}$ for the duration and $5 \text{ m}$ for the distance). The analysis was performed for $v_{\text{max}} \leq 60 \text{ km/h}$, $60 \text{ km/h} < v_{\text{max}} \leq 80 \text{ km/h}$ and $v_{\text{max}} > 80 \text{ km/h}$ separately.
The following figures show the duration distributions for individual vehicles in Europe and for the different regions for the lowest $v_{\text{max}}$ class.

The distributions for the two other $v_{\text{max}}$ classes are shown in the report.

The distance distributions are also included in the report and show similar trends within the three $v_{\text{max}}$ classes.

Figure 17 shows the average duration distributions for the EU and the three $v_{\text{max}}$ classes.

Figure 18 shows the corresponding results for the average distance distributions.
Acceleration distributions

Figure 15

EU database, $v_{\text{max}} \leq 60$ km/h
Acceleration distributions

$v_{\text{max}} \leq 60 \text{ km/h}$

Figure 16
Acceleration distributions

Figure 17
Acceleration distributions

![Graph showing acceleration distributions with different speed limits (average EU v_max ≤ 60 km/h, average EU 60 km/h < v_max ≤ 80 km/h, average EU v_max > 80 km/h). The x-axis represents the acceleration phase distance in m, and the y-axis represents the cumulative frequency.]

Figure 18
Deceleration duration distributions

- Deceleration phases are specified as consecutive time samples with $a < -0.5 \text{ km/h/s}$ or $-0.1389 \text{ m/s}^2$. The following key parameters of such phases were collected in a separate table (TB_acc) per vehicle and trip:
  - Date, Time, Duration, Distance,
  - $v_{\text{min}}, v_{\text{ave}}, v_{\text{max}}, \text{stddev}_v$,
  - $a_{\text{min}}, a_{\text{ave}}, a_{\max}$,
  - $v^*a_{\text{min}}, v^*a_{\text{ave}}, v^*a_{\max}$.

- In order to ease the calculation of duration and distance related distributions the results were binned for both values (2 $s$ for the duration and 5 $m$ for the distance). The analysis was performed for $v_{\text{max}} \leq 60 \text{ km/h}$, $60 \text{ km/h} < v_{\text{max}} \leq 80 \text{ km/h}$ and $v_{\text{max}} > 80 \text{ km/h}$ separately.
Deceleration duration distributions

• The following figures show the duration distributions for individual vehicles in Europe and for the different regions for the lowest $v_{\text{max}}$ class.

• The distributions for the two other $v_{\text{max}}$ classes are shown in the report.

• The distance distributions are also included in the report and show similar trends within the three $v_{\text{max}}$ classes.

• Figure 21 shows the average duration distributions for the EU and the three $v_{\text{max}}$ classes.

• Figure 22 shows the corresponding results for the average distance distributions.
Deceleration distributions

EU database, $v_{\text{max}} \leq 60$ km/h

Figure 19
Deceleration distributions

v_{max} \leq 60 \text{ km/h}
Deceleration distributions

Figure 21
Deceleration distributions

Figure 22

- average EU $v_{\text{max}} \leq 60$ km/h
- average EU $60$ km/h < $v_{\text{max}} \leq 80$ km/h
- average EU $v_{\text{max}} > 80$ km/h

EU database
Phases with brake engaged

• Another task within this analysis was the determination of brake use duration and distance distributions. The brake use during deceleration phases should be determined by expert guess thresholds for the deceleration or for $v^*a$ respectively.

• Fortunately, an alternative method could be used, because the author could analyse in-use driving behaviour data from a former research project of the German Environment Agency, dedicated to the improvement of the type approval noise measurement method for light duty vehicles.
Phases with brake engaged

• Within this project in-use driving behaviour measurements were performed with 11 cars in Aachen and the surroundings, where vehicle speed, engine speed and drive axle torque, but also clutch and brake engagement was measured.
• Several threshold curves were tested and the resulting brake use duration and distance distributions were compared with the measured ones.
Phases with brake engaged

- The best fit was achieved for the following vehicle speed dependent deceleration threshold curve:
  \[ a_{\text{threshold}} = -0.098468 \times \ln(v) - 0.30439 \]

- This results in the following polynomial function for a corresponding \( v^a \) threshold curve:
  \[ v^a_{\text{threshold}} = 7.83392 \times 10^{-7} v^3 - 4.10447 \times 10^{-4} v^2 - 1.80147 \times 10^{-1} v + 3.35105 \times 10^{-1} \]

- Both curves are shown in figure 23.

- When vehicles with automatic transmissions are disregarded, the calculated distributions are in sufficiently good agreement with the measured distributions.
Threshold curves for brake use

\[ y = 7.83392E-07x^3 - 4.10447E-04x^2 - 1.80147E-01x + 3.35105E-01 \]

\[ R^2 = 9.99982E-01 \]

\[ y = -9.84680E-02\ln(x) - 3.04390E-01 \]

\[ R^2 = 1.00000E+00 \]
The following figures show the duration distributions for individual vehicles in Europe and for the different regions for the lowest \( \text{vmax} \) class.

The distributions for the two other \( \text{vmax} \) classes are shown in the report.

The distance distributions are also included in the report and show similar trends within the three \( \text{vmax} \) classes.

Figure 26 shows the average duration distributions for the EU and the three \( \text{vmax} \) classes.

Figure 27 shows the corresponding results for the average distance distributions.
Brake phase distributions

Figure 24
Brake phase distributions

Figure 25

\[ v_{\text{max}} \leq 60 \text{ km/h} \]
Brake phase distributions

Figure 26
Brake phase distributions

Figure 27
Number of brake phases per km

- The following table shows the average number of brake phases per kilometer for the different regions and different short trip $v_{\text{max}}$ classes and for different road categories.
- Tables for individual vehicles are included in the report.
## Number of brake phases per km

<table>
<thead>
<tr>
<th>region</th>
<th>average</th>
<th># of brake phases per km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Short trips with v_max</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;= 60 km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 km/h &lt; and &lt;= 80 km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80 km/h &lt; and &lt;= 110 km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 110 km/h</td>
</tr>
<tr>
<td>Europe</td>
<td>1.56</td>
<td>5.3</td>
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<tr>
<td></td>
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<td>2.1</td>
</tr>
<tr>
<td></td>
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<td>1.0</td>
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<td></td>
<td></td>
<td>0.4</td>
</tr>
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<td>India, class 1</td>
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<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>India, class 2</td>
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<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>India, class 3</td>
<td>1.84</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.9</td>
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<tr>
<td></td>
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<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>Japan</td>
<td>3.00</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.1</td>
</tr>
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<td>Korea</td>
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<td>1.5</td>
</tr>
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<td>USA</td>
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<td></td>
<td>1.3</td>
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<tr>
<td></td>
<td></td>
<td>0.3</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>region</th>
<th># of brake phases per km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>urban</td>
</tr>
<tr>
<td>Europe</td>
<td>3.8</td>
</tr>
<tr>
<td>India, class 1</td>
<td>3.2</td>
</tr>
<tr>
<td>India, class 2</td>
<td>2.3</td>
</tr>
<tr>
<td>India, class 3</td>
<td>2.8</td>
</tr>
<tr>
<td>Japan</td>
<td>4.5</td>
</tr>
<tr>
<td>Korea</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Joint v, a distributions

- Joint vehicle speed/acceleration distributions are shown in annex 2 (time weighted) and annex 3 (distance weighted) of the report.
The following figures show acceleration distributions for accelerations > 0.15 m/s² (acceleration bins >= 0.2 m/s², bin distance 0.1 m/s²)

- Figure 28: Europe per road category, time weighted,
- Figure 29: Europe per vehicle speed bin, time weighted
- Figure 30: Europe per vehicle speed bin, distance weighted.

Corresponding figures for the different datasets also from other regions are provided in the report.

Vehicle specific distributions for different speed bins are provided in paragraph 13 of the report for the EU part.

An example is shown in figure 31.
Acceleration distributions

![Graph showing acceleration distributions in Europe, time weighted. The graph includes three curves representing motorway, rural, and urban conditions.]
Acceleration distributions

Figure 29

EU database, time weighted, Europe
Acceleration distributions

Figure 30

EU database, distance weighted, Europe
Acceleration distributions

WLTP EU database, $v = 10$ km/h

Figure 31
Deceleration distributions

• The following figures show deceleration distributions for accelerations $< -0.15 \text{ m/s}^2$ (acceleration bins $\leq -0.2 \text{ m/s}^2$, bin distance 0.1 m/s²)

• Figure 32: Europe per road category, time weighted,

• Figure 33: Europe per vehicle speed bin, time weighted

• Figure 34: Europe per vehicle speed bin, distance weighted.

• Corresponding figures for the different datasets also from other regions are provided in the report.

• Vehicle specific distributions for different speed bins are provided in paragraph 14 of the report for the EU part.

• An example is shown in figure 35.
Deceleration distributions

Europe, time weighted

- Cumulative frequency
- Acceleration in m/s²
- Motorway
- Rural
- Urban

Figure 32
Deceleration distributions

Figure 33
Deceleration distributions

EU database, distance weighted, Europe
Deceleration distributions

Figure 35
v*a_neg distributions

• Paragraph 15 of the report contains distributions of v*a for decelerations for v*a < -1 m³/s² in v*a bins of 2 m³/s² distance for different speed bins and datasets in the EU, time and distance weighted.

• Figure 36 shows a time weighted example.
v*a distributions

EU database, time weighted, Europe

Figure 36
Thank you for your attention