Market segmentation and duty cycles

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Deep Dive to Support Heavy-Duty Vehicle Efficiency Labeling and Standards Meeting #4
Introduction

- Vehicle simulation and component certification procedures can be easily adapted to the other regions.

- On the other hand, the definition of the heavy-duty vehicle segments and duty cycles are market-specific.

- This presentation aims at providing examples from different regions, and the solutions adopted for addressing the variety of heavy-duty vehicle types and uses.
ICCT market studies for HDVs

- European vehicle market statistics, 2017/2018
  https://www.theicct.org/publications/european-vehicle-market-statistics-20172018

- Market analysis and fuel efficiency technology potential of heavy-duty vehicles in China

- Market Penetration of Fuel Efficiency Technologies for Heavy-Duty Vehicles in the EU, US and China
  http://www.theicct.org/market-penetration-HDV-fuel-efficiency-technologies

- Market analysis of heavy-duty commercial trailers in Canada
  http://www.theicct.org/market-analysis-heavy-duty-commercial-trailers-canada

- Overview of the heavy-duty vehicle market and CO2 emissions in the European Union
  http://www.theicct.org/overview-heavy-duty-vehicle-market-and-co2-emissions-european-union

- Market analysis of heavy-duty vehicles in India
Key differences between the major markets

A comparison of China, India, the U.S. and the EU.
The market consolidation differs significantly between regions (2016)

GVW and vehicle type composition for different HDV markets (2014)

Engine displacement distribution for HDVs in four large markets (2014)

Examples of market segmentation

Complete vehicles
Objectives of the market segmentation

- Separate vehicles and components in groups with similar usage and fuel consumption.
- Enable the use of specific duty cycles and CO₂ emissions targets for each segment.
- Identify the vehicle segments with high fuel consumption. The vehicle segment with the highest market share is not necessarily the same as the one with the highest fuel consumption.
- Segmentation of engines and trailers is necessary in the case of separate policy measures addressing this components.
US HDV segmentation for GHG regulation

Class 2: 6,001 to 10,000 lbs
- Minivan
- Cargo van
- Full-size pickup
- Step van

Class 3: 10,001 to 14,000 lbs
- Walk-in
- Box truck
- City delivery
- Heavy-duty pickup

Class 4: 14,001 to 16,000 lbs
- Large walk-in
- Box truck
- City delivery

Class 5: 16,001 to 19,500 lbs
- Bucket truck
- Large walk-in
- City delivery

Class 6: 19,501 to 26,000 lbs
- Beverage truck
- Single-axle
- School bus
- Rack truck

Class 7: 26,001 to 33,000 lbs
- Refuse
- Furniture
- City transit bus
- Truck tractor

Class 8: 33,001 to REALLY HUGE
- Cement truck
- Truck tractor
- Dump truck
- Sleeper cab

Vocational vehicles (Rigid, classes 2b to 8)

LHD (Class 2-5)
- Urban Multipurpose Regional
- SI CI

MHD (Class 6-7)
- Urban Multipurpose Regional
- SI CI

HHD (Class 8)
- Urban Multipurpose Regional

Class 7, day cab
- High roof
- Mid roof
- Low roof

Class 8, day cab
- High roof
- Mid roof
- Low roof

Class 8, sleeper cab
- High roof
- Mid roof
- Low roof

Heavy haul

Source: https://jalopnik.com/truck-sizes-classification-explained-from-tacomas-to-1613958192
### EU HDV segmentation for CO₂ certification

<table>
<thead>
<tr>
<th>Axle type</th>
<th>Chassis configuration</th>
<th>Gross vehicle weight (tonnes)</th>
<th>Vehicle group</th>
<th>Regulatory cycles* and payloads* used in VECTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>4x2</td>
<td>Rigid</td>
<td>&gt;3.5 – &lt;7.5</td>
<td>0</td>
<td>Not considered by the regulation</td>
</tr>
<tr>
<td></td>
<td>Rigid (or tractor)</td>
<td>7.5 – 10</td>
<td>1</td>
<td>RD (50%), UD (50%)</td>
</tr>
<tr>
<td></td>
<td>Rigid (or tractor)</td>
<td>&gt;10 – 12</td>
<td>2</td>
<td>LH (75%), RD (50%), UD (50%)</td>
</tr>
<tr>
<td></td>
<td>Rigid (or tractor)</td>
<td>&gt;12 – 16</td>
<td>3</td>
<td>RD (50%), UD (50%)</td>
</tr>
<tr>
<td></td>
<td>Rigid</td>
<td>&gt;16</td>
<td>4</td>
<td>LH (14.0t), RD (4.4t), MU (4.4t)</td>
</tr>
<tr>
<td></td>
<td>Tractor</td>
<td>&gt;16</td>
<td>5</td>
<td>LH (19.3t), RD (12.9t)</td>
</tr>
<tr>
<td>4x4</td>
<td>Rigid</td>
<td>7.5 – 16</td>
<td>6</td>
<td>Not considered by the regulation</td>
</tr>
<tr>
<td></td>
<td>Rigid</td>
<td>&gt;16</td>
<td>7</td>
<td>Not considered by the regulation</td>
</tr>
<tr>
<td></td>
<td>Tractor</td>
<td>&gt;16</td>
<td>8</td>
<td>Not considered by the regulation</td>
</tr>
<tr>
<td>6x2</td>
<td>Rigid</td>
<td>all weights</td>
<td>9</td>
<td>LH (19.3t), RD (7.1t), MU (7.1t)</td>
</tr>
<tr>
<td></td>
<td>Tractor</td>
<td>all weights</td>
<td>10</td>
<td>LH (19.3t), RD (12.9t)</td>
</tr>
<tr>
<td>6x4</td>
<td>Rigid</td>
<td>all weights</td>
<td>11</td>
<td>LH (19.3t), RD (7.1t), MU (7.1t), C(7.1t)</td>
</tr>
<tr>
<td></td>
<td>Tractor</td>
<td>all weights</td>
<td>12</td>
<td>LH (19.3t), RD (12.9t), C (12.9t)</td>
</tr>
<tr>
<td>6x6</td>
<td>Rigid</td>
<td>all weights</td>
<td>13</td>
<td>Not considered by the regulation</td>
</tr>
<tr>
<td></td>
<td>Tractor</td>
<td>all weights</td>
<td>14</td>
<td>Not considered by the regulation</td>
</tr>
<tr>
<td>8x2</td>
<td>Rigid</td>
<td>all weights</td>
<td>15</td>
<td>Not considered by the regulation</td>
</tr>
<tr>
<td>8x4</td>
<td>Rigid</td>
<td>all weights</td>
<td>16</td>
<td>C (7.1t)</td>
</tr>
<tr>
<td>8x6 8x8</td>
<td>Rigid</td>
<td>all weights</td>
<td>17</td>
<td>Not considered by the regulation</td>
</tr>
</tbody>
</table>

- **Axle type**: Rigid, Rigid (or tractor).
- **Chassis configuration**: All weights, Rigid (or tractor) 7.5 – 10, Rigid (or tractor) >10 – 12, Rigid (or tractor) >12 – 16, Rigid >16, Tractor >16.
- **Gross vehicle weight (tonnes)**: >3.5 – <7.5, 7.5 – 10, >10 – 12, >12 – 16, >16, all weights.
- **Vehicle group**: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, C (7.1t), not considered by the regulation.
- **Regulatory cycles* and payloads* used in VECTO**: LD, RD, MU, not considered by the regulation.

- **Possible further sub-division of the vehicle groups under development for setting mandatory CO₂ targets.**
- **Possibilities**: Group sub-division based on engine power, or/and cabin type (day or sleeper).

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a. Long-Haul (LH), Regional Delivery (RD), Urban Delivery (UD), Municipal Utility (MU), Construction (C).

b. Number in brackets is the payload in tonnes. For vehicle groups 1, 2, and 3, the payload is dependent on the GFW; the percentage number in brackets refers the approximate fraction of the maximum payload that is used in the vehicle simulation.

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China HDV segmentation for CO₂ standards

- Tractor: 20.3%
- Dump Truck: 18.7%
- Coach: 6.0%
- City Bus: 4.7%
- Specialized Vocational (Not regulated): 4.6%
- Alternative Fuel HDV (Not regulated): 10.8%

## India and Japan’s HDV segmentation for fuel consumption standards

<table>
<thead>
<tr>
<th>Rigid truck</th>
<th>GVW Bin (tonnes)</th>
<th>Axle Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12.0-16.2</td>
<td>4x2</td>
</tr>
<tr>
<td></td>
<td>16.2-25.0</td>
<td>6x2</td>
</tr>
<tr>
<td></td>
<td>16.2-25.0</td>
<td>6x4</td>
</tr>
<tr>
<td></td>
<td>25.0-31.0</td>
<td>8x2</td>
</tr>
<tr>
<td></td>
<td>25.0-31.0</td>
<td>8x4</td>
</tr>
<tr>
<td></td>
<td>31.0-37.0</td>
<td>10x2</td>
</tr>
<tr>
<td>Tractor-trailer</td>
<td>35.2-40.2</td>
<td>4x2</td>
</tr>
<tr>
<td></td>
<td>40.2-49.0</td>
<td>6x2</td>
</tr>
<tr>
<td></td>
<td>40.2-49.0</td>
<td>6x4</td>
</tr>
<tr>
<td>Bus</td>
<td>12.0 and above</td>
<td>All Configuration</td>
</tr>
</tbody>
</table>

### Rigid freight trucks:

<table>
<thead>
<tr>
<th>Pl</th>
<th>GVW Bin (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL ≤ 1.5</td>
<td>3.5 ≤ GVW ≤ 7.5</td>
</tr>
<tr>
<td>1.5 ≤ PL ≤ 2</td>
<td>2 ≤ GVW ≤ 3</td>
</tr>
<tr>
<td>3 ≤ PL</td>
<td>7 ≤ GVW</td>
</tr>
<tr>
<td>8 ≤ GVW ≤ 10</td>
<td>10 ≤ GVW ≤ 12</td>
</tr>
<tr>
<td>12 ≤ GVW ≤ 14</td>
<td>14 ≤ GVW ≤ 16</td>
</tr>
<tr>
<td>16 ≤ GVW ≤ 20</td>
<td>20 ≤ GVW</td>
</tr>
</tbody>
</table>

### Tractor trucks:

<table>
<thead>
<tr>
<th>Tractor trucks</th>
<th>GVW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤ 20</td>
</tr>
<tr>
<td>2</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>
Summary: Segmentation comparison by GVW

1) Further divided into four subsegments by maximum payload,
2) Further divided into six subsegments by roof height and cab type,
3) Further divided into three subsegments by roof height,
4) Each EU segment further divided into two to seven subsegments by axle, chassis, and body configuration and weight.
Examples of market segmentation
Improvements in engine efficiency translate directly into vehicle efficiency improvements.
Engine segmentation in the US for engine GHG standards

- HD engines in the US are segmented based on the type – tractor or non-tractor – and “primary intended service class” of the vehicle in which the engine will be used.
- For diesel engines, “the primary intended service classes” are light heavy-duty (LHD), medium heavy-duty (MHD), and heavy heavy-duty (HHD).
- The U.S. standard considers that tractor engines are more likely to be driven on the highway in a steady state and that non-tractors are more likely to be driven in transient operation. Therefore, the tractor engines are required to meet a CO$_2$ limit over a steady-state engine cycle.

<table>
<thead>
<tr>
<th>Vehicle Type for engine segmentation</th>
<th>GVW (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor</td>
<td>11.8 to 15</td>
</tr>
<tr>
<td></td>
<td>15+</td>
</tr>
<tr>
<td>Non-tractor</td>
<td>3.9 to 8.8</td>
</tr>
<tr>
<td></td>
<td>8.8 to 15</td>
</tr>
<tr>
<td></td>
<td>15+</td>
</tr>
</tbody>
</table>

Alternatives for HD engine segmentation

<table>
<thead>
<tr>
<th>Grouping by</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Vehicle GVWR and type | • Most attractive method for ensuring engines installed in similar types of vehicles are grouped in the same category  
                      | • Unique engine cycles can be utilized to better reflect real-world operations | Could lead to wide ranges of engine size and power ratings in the same regulatory category → inherent efficiency advantage of large engines could incentivize trend towards bigger engines |
| Engine size         | Parameter is very difficult to change without major hardware overalls → virtual eliminates opportunities for gaming | Very little opportunity to choose different test cycles to more closely match in-use operations |
| Engine power        | Parameter directly corresponds to the grams per brake horsepower metric for evaluating engines | Same as above                                                                  |

Correlation between engine power and GVW for non-tractor truck sales in the EU in 2016

www.theicct.org/publications/market-analysis-heavy-duty-vehicles-india

Market dynamics present a challenge for using engine power or displacement for engine segmentation.
Examples of market segmentation

Trailers
Trailers have a large technology potential to reduce CO$_2$ emissions from HDVs. Trailer manufacturers are usually local players.

US trailer segmentation for Phase 2 GHG standards


US trailer market distribution between 2003 and 2011

<table>
<thead>
<tr>
<th>US trailer segmentation</th>
<th>DRY VAN</th>
<th>REFRIGERATED VAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long box trailers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short box trailers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-aero box trailers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-box trailers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The EU has a similar trailer distribution as the US, and a similar market segmentation is possible

Duty cycles  Vehicle
The duty cycles should represent real on-road HDV operation

- The definition of representative duty cycles for HDVs is challenging due to the variety of applications.

- The main objective is of the duty cycle design is to give realistic fuel consumption values for all vehicle variants. The definition of the duty cycles is dependent on, among others: vehicle fleet technical specifications, road type (urban, regional, highway), speed limits, topography, traffic conditions, etc.

- Duty cycles can be categorized in two main categories: Actual speed vs time based and target speed vs. distance
The WHVC was developed under the United Nations Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29).

The WHVC is based on data from trucking operations in a number of countries (Australia, EU, Japan and the US) and is designed to cover a wide range of HDV driving situations.

The WHVC consists of three segments: an urban segment with transient stop-and-go driving, a rural segment that incorporates higher speeds, and a final motorway segment with steady state cruise driving.

The speed, and acceleration trace is fully defined by the cycle.

Some vehicles will have an easy time following the speed trace, while some others won’t be able to follow it.

The set average speeds might not be representative of the local conditions.

Some countries have modified the WHVC to reflect the local lower engine power-to-vehicle weight ratios.
WHVC modifications for China and Korea


Example: Average speeds are lower in India than other major markets

ICCT’s version of a modified WHVC for fuel consumption research in India

- Urban part: 900 seconds $v_{avg} = 21.3$ km/h
- Rural part: 481 seconds $v_{avg} = 37.1$ km/h
- Highway part: 419 seconds $v_{avg} = 52.8$ km/h

* Average speed from surveys of 28 major trucking routes in India
Distance based, target speed cycles in the EU

- Duty cycle is defined as routes. That is, road grade profiles and a desired target speed as a function of distance.
- The actual driven speed profile is a function of the vehicle technical specifications and the driver model.
EU’s Regional Delivery and Long Haul cycles

ACEA’s validation for the Long Haul cycle for the EU

1. Derive representative routes for European long-haul road network based on statistical “goods flow” data

2. Measurement of slopes and speed profiles on representative routes (>10,000 km)

3. Compare speed and slope characteristics with long-haul cycle. Make adaptations if needed.

The GEM Phase 2 cycles are a combination of distance and time based cycles.

ICCT has developed a work-flow for developing duty cycles based on in-use vehicle data

**Duty Cycle Development:**
6 steps:
1. Generates microtrips.
2. Generates N candidate cycles by adding randomly selected microtrips until minimum cycle time is achieved.
3. Calculates candidate cycles’ metrics.
5. Compares candidates with in-use database.
6. Selects and save the 10 candidate cycles that best match the database.
Duty cycles | Engine cycles
The duty-cycles for engine CO$_2$ certification can be derived directly from those developed for pollutant emission testing.

World Harmonized Transient Cycle (WHTC)
Adaptations of the existing cycles can be necessary

- Tractor engines in the US have limits over the SET steady-state cycle. For Phase 2, the SET weighting were revisited to reflect better low engine speed highway operation.
EU and US duty cycles can be correlated for CO$_2$ emissions

Comparison of 26 different engine maps over a simulated environment were used to estimate the correlation coefficients between the stationary WHSC and SET cycles, as well as between the transient cycles WHTC and FTP.

Takeaway messages

- The market segmentation and definition of duty cycles are country specific exercises. However, experiences and concepts applied in other regions can be adapted.

- There is no perfect segmentation, nor duty cycle. A balance between complexity and representativeness is necessary.

- The market segmentation divides the vehicle fleet into different segments with similar application and fuel consumption. Typical differentiators are vehicle weight, chassis configuration, and axle configuration. Further segmentation can be achieved by cabin type, engine power, intended vehicle use, among others.

- The development of duty cycles for fuel consumption certification must be a data-driven process. A good characterization of the vehicle fleet is necessary. Similarly, the topography and typical traffic conditions of the road network are also required.
Questions? Contact the HDV team at the ICCT

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