Frontloaded e-AWD development with automated system optimization

EAWD19 - Electrification and All-wheel Drive Congress
Graz / Spielberg May 9. – 10. 5. 2019
Electric vehicles worldwide sales

Cumulative global passenger EV sales, current and forecast

Global-54 Car Sales Full Year Market share by segment

Source: Bloomberg NEF

https://about.bnef.com/blog/cumulative-global-ev-sales-hit-4-million/
1. Customer demands on electric vehicle
Which are the main electrification related vehicle attributes
2. Electric vehicle development requirements

The customer defines the main requirements:

- High acceleration level and \( v_{\text{max}} \)
- High range, short charging time
- High pulling force, big ground clearance
- Low interior noise level
- Jerkless accelerating
- High cornering ability & traction
3. Electric Vehicle Specification
The vehicle requirements set the vehicle specifications

Customer’s demands → Vehicle requirements → Vehicle specification

- Low vehicle mass, high motor power
- Insulation measures
- High battery capacity
- Performance tire, low ride height
- Off-road tire, high ride height
- Driveability Calibration
4. Powertrain System Requirements

The vehicle specification set the powertrain requirements.
4. Powertrain System requirements
Goal of frontloaded development is to gain powertrain requirements

Customer

Requirement

Specification

System level

Vehicle level
Virtual Concept Definition

**Process**

**Benchmarking:**
- Competitive analysis
- Highlights & weaknesses
- Deep dive

**Vehicles:**
- Tesla Model X
- Jaguar I Pace

**Target Setting**
Translating customers vision into technical requirements:
- Performance
- Efficiency
- Handling
- AWD / Off-road
- Driveability
→ Definition of E-AWD vehicle attributes

**Vehicle Simulation**
- Vehicle simulation and virtual calibration
- Simultaneous vehicle attribute assessment

**Improvements**
- Long. torque split
- Torque vectoring
- Slip control
- Regenerative braking
- Efficiency strategy

**Output:**
E-AWD Powertrain according customer’s demands
BENCHMARKING ON VEHICLE LEVEL

- **Tesla Model X** outstanding performance
- The I-Pace outperforms the Tesla in Offroad capability
- The Model X is the more efficient vehicle in terms of consumption and charging

**Attribute Rating**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Tesla</th>
<th>Jaguar</th>
<th>I-Pace</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100 [s]</td>
<td>3.6</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Max. Acceleration [m/s²]</td>
<td>4.8</td>
<td>7.21</td>
<td>7.21</td>
</tr>
<tr>
<td>Max. Speed [kph]</td>
<td>245</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Range [km]</td>
<td>516</td>
<td>467</td>
<td>467</td>
</tr>
<tr>
<td>Real World driving consumption [kWh/100km]</td>
<td>21.2</td>
<td>30.6</td>
<td>30.6</td>
</tr>
<tr>
<td>Charging Efficiency [%]</td>
<td>85</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Gradeability dirt [%]</td>
<td>92</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Control quality HDC [DR]</td>
<td>8.5</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Pulling Force gravel [N]</td>
<td>14,020</td>
<td>12,150</td>
<td>12,150</td>
</tr>
<tr>
<td>Brake in a turn [DR]</td>
<td>3.6</td>
<td>3.3</td>
<td>5</td>
</tr>
<tr>
<td>Acceleration µ-split [m/s²]</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Torque Intervention Cornering [DR]</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**AVL scatter band**

**Tesla:** Very good slip control conservative in stability interventions

**Jaguar:** Very harmonic control system

**5)** no function available
Benchmarking Offroad / AWD

What causes the results and what are findings for the target setting?
Let's have a deeper look
## E-AWD related vehicle criteria

### Benchmark Vehicles Overview

<table>
<thead>
<tr>
<th>E-AWD related criteria</th>
<th>Attribute Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulling Force gravel [N]</td>
<td>4</td>
</tr>
<tr>
<td>Gravelability [%]</td>
<td>5</td>
</tr>
<tr>
<td>Lowspeed Controllability [Pa]</td>
<td>3</td>
</tr>
<tr>
<td>Acceleration μ-split [m/s²]</td>
<td>6</td>
</tr>
<tr>
<td>Deceleration μ-split [m/s²]</td>
<td>7</td>
</tr>
<tr>
<td>Average wheel slip [µ-low launch]</td>
<td>8</td>
</tr>
<tr>
<td>Understeer [DR]</td>
<td>9</td>
</tr>
<tr>
<td>Brake in a Turn Stability [DR]</td>
<td>10</td>
</tr>
<tr>
<td>Max. Lateral Acceleration [m/s²]</td>
<td>3</td>
</tr>
<tr>
<td>Turn In Agility [DR]</td>
<td>2</td>
</tr>
</tbody>
</table>

### Model X

- Excellent performance level
- Very good wheel slip control
- Limited off-road capability
- Inert on-road agility
- Very restrictive cornering stability control

### I pace

- Very balanced over all attributes
- Good total control system characteristic
- Satisfying off-road capability (HDC, Hill hold)
- Good on road handling balance
### What are the right system elements?

<table>
<thead>
<tr>
<th>Category</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric machines</strong></td>
<td>Induction / PSM type</td>
</tr>
<tr>
<td></td>
<td>Power</td>
</tr>
<tr>
<td><strong>E/E components</strong></td>
<td>Inverter</td>
</tr>
<tr>
<td></td>
<td>Charger</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>Cell technology</td>
</tr>
<tr>
<td></td>
<td>Capacity</td>
</tr>
<tr>
<td></td>
<td>Size and weight</td>
</tr>
<tr>
<td></td>
<td>Voltage</td>
</tr>
<tr>
<td><strong>Aerodynamics</strong></td>
<td>Drag</td>
</tr>
<tr>
<td></td>
<td>Rideheight</td>
</tr>
<tr>
<td><strong>Body</strong></td>
<td>Weight</td>
</tr>
<tr>
<td></td>
<td>Geometry</td>
</tr>
<tr>
<td><strong>Tyre</strong></td>
<td>Off-road capability</td>
</tr>
<tr>
<td></td>
<td>Resistance / Grip</td>
</tr>
<tr>
<td><strong>Powertrain Controls</strong></td>
<td>E-AWD torque split</td>
</tr>
<tr>
<td></td>
<td>Slip control</td>
</tr>
<tr>
<td></td>
<td>Regenerative braking</td>
</tr>
<tr>
<td></td>
<td>Operation strategy</td>
</tr>
</tbody>
</table>
### Vehicle positioning

**Performance**
- **High**
- **Moderate**

**Energy Efficiency**
- **High**
- **Low**

**Offroad e-AWD**
- **Among the best**
- **Average**

**Control System**
- **Among the best**
- **Average**

**Handling**
- **Engaging**
- **Relaxed**

**Further attributes: NVH, Driveability**
- **High**
- **Low**

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Translating customers vision into technical requirements down to a very detailed level.
**Off-road capability:**
- Acceptable allover off-road capability
- Good low speed controllability
- Very good $\mu$-split acceleration level

**Performance**
- Performance level close to Model X
- Very good overall traction

**Handling**
- Low understeer
- Good oversteer stability
- Acceptable turning agility
Set Up of Virtual Calibration Toolchain

**Automatized Optimization Toolchain**

**AVL Cameo:**
DOE approach
- calibration parameter variation

**AVL VSM:**
- Vehicle dynamic simulation + e-AWD controller model embedded

**AVL-DRIVE™:**
- Objective evaluation of driving attributes
# E-AWD Functions Definition

## E-AWD Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Torque split</th>
<th>Slip Control</th>
<th>Torque vectoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical equivalent</td>
<td>Center Differential</td>
<td>E-LSD (electronic-limited slip differential)</td>
<td>TV-Differential</td>
</tr>
</tbody>
</table>

### Description

- **Torque split**: Torque split between front and rear axle to maximize traction and vehicle dynamics.
- **Slip Control**: Axle / wheel selective torque reduction in case of the spinning wheels.
- **Torque vectoring**: Torque split between left and right side to generate a yaw moment.
Virtual Calibration and Optimization

**Optimization**

**AWD CONTROLS**
Parameter variation

**SIMULATION**
Vehicle, driver, road

**PARAMETER & VARIANTS ITERSATIONS**

**ATTRIBUTES ASSESSMENT**
Offroad, Handling, Performance, WLTP

**SPECIFIC MANEUVERS**
Traction, Gradeability, Pulling force

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Graz/Spielberg, May 9 to 10, 2019
Electrification & All-Wheel Drive Congress
Capability of vehicle dynamic calibration

Methodology for DOE optimization of AWD to achieve targets

Benchmarking & competitor analysis

Optimized AWD characteristic

Target definition by KPIs

<table>
<thead>
<tr>
<th>18% gradient µ-split</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPI</td>
<td>max. long acc.</td>
</tr>
<tr>
<td>wheel slip level</td>
<td>n-nn [%]</td>
</tr>
</tbody>
</table>

Target Area

DoE-based calibration closed-loop optimization

Simulation

Obj. Evaluation

Optimized AWD function parameter-set

Graz/Spielberg, May 9 to 10, 2019
Electrification & All-Wheel Drive Congress
Optimization Result Video e-AWD
Optimization Result Video
Torque Vectoring – ISO T2 Lane Change
Optimized results:
- Target band could be met for all criteria
- Very good on road handling due to torque vectoring
- Good Performance due to low vehicle weight
Optimization Result Video
Nürburgring Nordschleife
Thank You

www.avl.com