DVP&R

DVP&R Methodology @ AVL

Validation of Electrified Powertrain Systems
The AVL-PTE Design Verification Plan & Reporting (DVP&R) unifies in one Workproduct (Master-Document) the Validation and Verification (V&V) test procedures that are to be performed in the context of development projects of mechatronic systems or its subsystems. Additionally it enables progress monitoring and documentation of the execution of the V&V activities within the project development.

In this context the DVP&R combines the validation and verification principles of
- mechanics,
- electric & electronics,
- and software development (including calibration)

to generate a simpler, more economical and reliable validation and verification process.
AGENDA

- DVP challenge and AVL solution
- AVL DVP methodology
  - TARGETS and LOAD PROFILING
  - Test Program
  - Evaluation & Optimization
- Summary & Conclusion
DVP CHALLENGE & AVL SOLUTION
DVP CHALLENGES

"Are the responsibilities aligned?"
"Do we have the right targets?"

Traditional development process & test programs

Target Definition
Concept
Mechanics
SW
EE
Integration
Testing

Workflow ✓
Test targets ✓
Responsibilities ✓
Testing approaches ✓

Specification & Requirements & Milestones ✓

Modified responsibilities
New Worksplit between departments
New Worksplit Supplier & OEM

"Are we testing the right things?"
"Are we testing at the right time?"

New markets/ applications

Verification tasks?
Failure modes?

Economic boundaries
Timeline
Budget
Capacity
AVL DVP&R PROCESS & LOAD MATRIX INTERACTION

Design Verification and Validation Plan & Reporting (DVP&R)

- Function
- Verification
  - Functional issues
- Reliability & Durability
  - Reliability and durability issues
- Validation
- Initial DVP durability test program
- Test program functional development

LOAD MATRIX
- FP-Analysis
- Targets
- Load Analysis
- Optimization

Testing requirements
- Basic DVP
- FMEA
- FP-Database
- Technical specifications
- Others

Testing
- Functional development and reliability & durability testing

Results, failures, measurement, data, new procedures
AVL DVP METHODOLOGY
DVP&R LIFE CYCLE

1. DVP&R Target Definition
2. DVP&R Planning
3. DVP&R Monitoring

System Analysis
Application & Targets
Test Program
Evaluation and Optimization
For each project, the DVP&R Work product (i.e. Deliverable) will be planned and monitor on a level-based approach (similar to the requirement engineering process)

- Level 0 - Vehicle V&V test procedures (Targets)
- Level 1 - Powertrain V&V test procedures
- Level 2 - Powertrain Elements V&V test procedures: ICE System HV Battery System, ...
- Level 3 - Sub-Assemblies V&V test procedures: Mechanical Comp., Hydraulics, ...
- Level 4 - Components V&V test procedures: SW System, ECU (HW), Sensor/Actuators, ...
IDENTIFY VERIFICATION TASKS
FROM VEHICLE LEVEL DOWN TO COMPONENT LEVEL

System analysis
Generate a common understanding of the covered technical elements and their interfaces
VISUALIZE VERIFICATION TASKS & FAILURE MODES

Example

Component failure mode combinations

Verification tasks

Failure modes with unknown impact

Tasks with unknown impact

Failure modes relevant for verification

Tasks to be executed

Failure modes relevant for verification & validation

System analysis

Generate an overview what needs to be covered by the DVP
Define countermeasures to clarify unknown impacts
AVL DVP METHODOLOGY
TARGETS and LOAD PROFILING
LOAD PROFILING – USAGE SPACE ANALYSIS

Analyze customer driving and vehicle usage patterns

- Develop representative customer vehicle usage cycles
- Profiles which include velocity and gradient

Field driving cycles

- ExtraUrban
- Highway
- Offroad
- Urban

Example: Reference Highway

Analyze ambient conditions

Analysis regarding:
- Different regions
- Different seasons / months
- Representative distributions

Example: Ambient temperature distributions in different areas

Analyze target market

Analysis regarding:
- Geography
- Driving behavior
- Road characteristics
- Market segments
- Population

Example: Population of China
### Lifetime distribution matrix

- No pre-existing data
- Market researches
- Varying boundaries (vehicle loading, vehicle gradients, ambient conditions, vehicle modes)

#### Example: Lifetime distribution matrix

<table>
<thead>
<tr>
<th>Profile Slope Weight</th>
<th>Urban</th>
<th>Rural</th>
<th>Highway</th>
<th>Offroad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>20.0%</td>
<td>68.0%</td>
<td>12.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Vehicle Loading: Full</td>
<td>10.0%</td>
<td>30.0%</td>
<td>12.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Vehicle Loading: Lite</td>
<td>11.0%</td>
<td>22.0%</td>
<td>0.0%</td>
<td>6.0%</td>
</tr>
<tr>
<td>Vehicle Loading: Std.</td>
<td>30.0%</td>
<td>20.0%</td>
<td>2.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Vehicle Speed: Flat</td>
<td>5.0%</td>
<td>5.0%</td>
<td>3.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Vehicle Speed: Hilly</td>
<td>4.0%</td>
<td>1.0%</td>
<td>2.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Ambient Temperature (Very Low)</td>
<td>5.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Ambient Temperature (Normal)</td>
<td>5.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Ambient Temperature (Very Hot)</td>
<td>5.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

### Generate larger data base

- Design of experiments
- Variations included

#### Example:

Full variation of cycles & parameters would lead to a high number of cycles

### Reduction step

- Set up weighting tables
- Calculate lifetime mileage proportion
- Consider variations which fulfill target

#### Example: Reduction step
DEFINITION OF COMPONENT LOAD PROFILES DERIVED FROM REAL WORLD VEHICLE DATA

Usage space analysis

- Fleet data
- Reference cycle(s)

Simulation model

- Results:
  - Time based component load data
  - Parameter variation covering different ambient conditions or control strategies

Damage modeling & statistical analysis

- Results:
  - Lifetime load profiles
  - Lifetime load collectives for components

Targets & responsibilities

Utilize customer fleet data efficiently to generate load profiles for new systems and components

Results:

- Reference cycles based on actual end customer usage
- Market related analysis report
AVL DVP METHODOLOGY

TEST PROGRAM
DVP&R: GENERATION OF V&V PLANS

System

Software

Design

... Categories

PROPOSED TARGET/DVP V&V CATEGORIES

- 10 Functional System Development and Integration
  - Performance and range
  - Core functions (driving features incl. operation strategy, activation/deactivation features, support features, external charging...)
  - Diagnostics
  - Communication
  - Life time and operation conditions
  - Service concept
  - Consumption System
  - Emission System
  - OBD
- (Operation Strategy)

- 20 Geometrical Integration
  - Geometrical Targets
  - Weight
  - Tolerance management

- 30 Mechanical System Development and Integration
  - Durability
  - Mechanical Function
  - Robustness/Misuse
  - Vibration/Stiffness/Strength/Torsion
  - Shock/crash/crush
  - Additional mechanical loads e.g. jack load...
  - Tightness

- 40 Thermal System Development and Integration
  - Condensation and pressure handling
  - Cooling/heating
  - Thermal Protection/Component temperature
  - Comfort (NVHAC)

- 50 Electrical System Development and Integration
  - Electrical safety (creep age and clearance, short circuit protection,)
  - HV architecture

- 60 System Safety and Security
  - Vehicle Safety (active and functional passive safety)
  - Functional Safety (incl. torque safety)
  - HV Safety
  - Safety of Use (e.g. touch protection, transport,...)
  - Safety of Components (e.g. venting,...)
  - Cyber Security

- 70 Material and Environment
  - Recycling
  - Prohibited substances

- 80 Production, Serviceability and Product Costs
  - Product Costs
  - Assembly accessibility
DVP&R
MAIN TEST CATEGORIES

10 Functional System Development and Integration
- Performance and range
- Core Functions (e.g. external Charging)
- Emission and Consumption System
- On-Board Diagnostics

20 Geometrical Integration
- Geometrical Targets (Digital Mock-Up)
- Weight monitoring
- Center of gravity and inertia
- Assembly (e.g. accessibility)
- Serviceability
## MAIN TEST CATEGORIES

### 30 Mechanical System Development and Integration

- Durability
- Mechanical Functional Testing (e.g. Efficiency)
- NVH Functional Testing (e.g. NVH Analysis of e-Machine)
- Robustness and Misuse
- Vibration, Stiffness, Strength
- Shock, Crash, Crush

### 40 Thermal System Development and Integration

- Condensation and pressure handling
- Cooling system performance
- Tightness and vacuum test
- Filling and Degassing of cooling circuit
- Wind Tunnel Testing
- Street testing (e.g. uphill towing)
DVP&R
MAIN TEST CATEGORIES

50 Electrical System Development and Integration

- HV Architecture
- Energy Management
- Load Balance
- EMC (e.g. Immunity, Emission, ESD)

60 System Safety

- HV Safety (ISO 26262)
- Functional Safety
- Vehicle Safety (active and functional passive safety)
- Safety of components
ADAS V&V

Develop ADAS functions, control units and vehicle integration

ADAS validation (MIL cloud, MIL office, HIL, VIL, proving ground, public street)

ADAS test and validation tools
AVL DVP METHODOLOGY

EVALUATION & OPTIMIZATION
VISUALIZE STATUS AND RISKS OF ACTUAL DVP

Required tasks from system analysis

Correlation with planned test program

Test program

Connect verification tasks and failure mode with the planned program
Visualize risks and guide team to close gaps
## Definition and Visualization of DVP Improvements

<table>
<thead>
<tr>
<th>Status</th>
<th>DVP-Result</th>
<th>Main Request</th>
<th>Applied Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>First analysis results</td>
<td><img src="chart1.png" alt="Chart" /></td>
<td>“Clarify responsibilities And targets”</td>
<td>Targets &amp; timeline&lt;br&gt; - Specify targets&lt;br&gt; - Improve timing of testing&lt;br&gt; Responsibilities&lt;br&gt; - Align responsibilities</td>
</tr>
<tr>
<td>1st update of analysis</td>
<td><img src="chart2.png" alt="Chart" /></td>
<td>“Achieve best possible task coverage”</td>
<td>Test program&lt;br&gt; - Modify procedures&lt;br&gt; - Define new procedures&lt;br&gt; Risk based task coverage&lt;br&gt; - Decide risk based on tasks in development team</td>
</tr>
<tr>
<td>Final update of analysis</td>
<td><img src="chart3.png" alt="Chart" /></td>
<td>“Visualize effects of changes”</td>
<td>Management and project team&lt;br&gt; - Agree on changes&lt;br&gt; - Highlight &amp; agree on remaining risks</td>
</tr>
</tbody>
</table>
SUMMARY & CONCLUSION
AVL DVP BENEFITS

- Increased technical and economical efficiency of verification and validation test program
- Minimized risk of verification & validation gaps
- Consideration of individual program targets, boundaries and customer processes.

<table>
<thead>
<tr>
<th>System analysis</th>
<th>Test Program</th>
</tr>
</thead>
</table>
| ▪ Identification of verification tasks from vehicle level down to component level
| ▪ Identification of components and failure modes to be covered by testing in one document |
| ▪ Clear definition of project specific verification & validation targets |
| ▪ Alignment of responsibilities for complete test program |
| ▪ Highlight needed missing information |
| ▪ Collection of all required testing activities in one document |
| ▪ Correlation of verification tasks and failure modes with planned testing program |

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<tbody>
<tr>
<td>▪ Clear visibility of the verification &amp; validation risks for all relevant components</td>
</tr>
<tr>
<td>▪ Structured approach to make progress &amp; improvements visible</td>
</tr>
</tbody>
</table>
THANK YOU

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