Design in the Loop

Bridging the gap between subjective perception and objective evaluation to achieve desired handling characteristics

"apply & innovate 2012" - IPG Technology Conference, September 18-19, 2012
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Prof. Dr.-Ing. Günther Prokop, Dept. of Vehicle Engineering, TU Dresden
Bernhard Schick, Managing Director, IPG Automotive GmbH, Karlsruhe
David Golloch, TU Dresden
The Problem:
Customer is slightly displeased with your car
The Problem:
Consumer tests compare and criticize your car
The Challenge:
You need to improve but can't get a handle on “how“ and “where“!
The Reason:
The consumer's perception is subjective!
But as an engineer, you need objective criteria
The Solution:
“Design in the Loop” for cars that customers want
Design in the Loop

undefined customer  Design in the Loop  target car
Design in the Loop

undefined customer

Subjective Evaluation

Chassis Guide

Objective Evaluation

Simulation

Characteristic Curves

Multi Body Simulation

Fine-tune vehicle DNA

Customer Needs

target car
Design in the Loop

House of Quality

Chassis Guide

Simulation

Subjective Evaluation

Objective Evaluation

Customer Needs

Fine tuning vehicle DNA

Characteristic Curves

Multi Body Simulation
Design in the Loop

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Fine tune vehicle DNA

Multi Body Simulation

Characteristic Curves

Karlsruhe, 18.09.2012
Design in the Loop

House of Quality

Chassis Guide

Simulation

Subjective Evaluation

Objective Evaluation

Customer Needs

Fine-tune vehicle DNA

Characteristic Curves

Multi Body Simulation

Karlsruhe, 18.09.2012
**Customer Needs**
Knowing and meeting the consumer’s real wishes

### House of Quality (HoQ)

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>5</th>
<th>2</th>
<th>3</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Customer / media target group, market</strong></td>
<td><strong>Customer / media wishes</strong></td>
<td><strong>Link between technical specification and customer wishes</strong></td>
<td><strong>Rating</strong></td>
<td><strong>Subjective benchmarking</strong></td>
<td><strong>Target line</strong></td>
</tr>
<tr>
<td><strong>Customer language</strong></td>
<td><strong>Media language</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Engineering language</td>
<td>4</td>
<td>Technical specifications</td>
<td>7</td>
<td>Benchmarking</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>Tech. targets</td>
</tr>
</tbody>
</table>

**Translating consumer speech into designable engineering language**

Source: TÜV SÜD Automotive GmbH
Subjective Evaluation
Reduction of motion and road excitation on standardized maneuvers

Driving Dynamics
- ISO Maneuver
  - ISO Slalom 18m

Comfort
- "Bertrandt" Maneuver
  - Vertical dynamics
    - Ditch
    - Curb
    - Different speed levels
  - "Vibration DNA"
  - 1 [Bertrandt/Hubbel]
Subjective Evaluation

Criteria: ride harshness

Problem of subjective evaluation

Maneuver: slalom @ 30km/h
## Subjective Evaluation

### Describing driving emotions / experiences

#### Subjective evaluation onroad-comfort

<table>
<thead>
<tr>
<th>Fahrzeug</th>
<th>Fahrzeugtyp</th>
<th>Beladung</th>
<th>km-Mi/age</th>
<th>Bewertung</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Customer</td>
<td>Vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Competitor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Benchmark</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Ergonomie und Akustik

<table>
<thead>
<tr>
<th>1.</th>
<th>2.</th>
<th>3.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funktionelle Übersicht</td>
<td>8,0</td>
<td></td>
</tr>
<tr>
<td>Boden- und akustischer Komfort</td>
<td>7,5</td>
<td></td>
</tr>
<tr>
<td>Komfort und akustischer Eindruck</td>
<td>7,5</td>
<td></td>
</tr>
</tbody>
</table>

#### Decomposing into:

- **Longitudinal Acc.**
- **Lateral Acc.**
- **Head Position**
- **Acc. Gradient**

Gaining **quasi-objective** ratings in highly decomposed test procedures
Subjective Evaluation
Disintegrated subjective driving impressions

Driving Dynamics
- Acceleration
- Ride Comfort
- Braking
- Handling
- Transmission Behavior
- Pitch ‘n’ Roll Behavior
- Steering Behavior
- NVH
- Lateral Torso Support
- Head Shake
- Roll Steer
- Copying

Relevant to consumer and car magazine
Only subjectively ratable
Quasi-objectively perceptible + objectively measurable

Resolution of evaluation criteria into measurable quantities
Objective Evaluation
Measuring the way a human being feels

Road Test

- Steering Robot
- IMU / DGPS
- Data acquisition device
- Correvit
- Measurement steering wheel
- A sensors
- Strain gauge sensors
- CAN signals

Tailored measuring in the right places
Objective Evaluation
Head shake

Video
### Characteristic Curves

#### Subjektive Beurteilung Fahrkomfort
**Subjective evaluation onroad-comfort**

<table>
<thead>
<tr>
<th>Fahrzeug Vehicle</th>
<th>Fahrzeugtyp Vehicle Type</th>
<th>Beladung Load</th>
<th>km-Stand Mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Customer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Competitor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Benchmark</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bewertung</th>
<th>Evaluator / Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 excellent (state of the art)</td>
<td>expert / not detectible</td>
</tr>
<tr>
<td>9 very good</td>
<td>expert / hardly detectible</td>
</tr>
<tr>
<td>8 good</td>
<td>expert / nominal complaint</td>
</tr>
<tr>
<td>7 not satisfying</td>
<td>critical consumer / slightly detectible</td>
</tr>
<tr>
<td>6 minimum acceptable</td>
<td>critical consumer / detectible</td>
</tr>
<tr>
<td>5 not satisfying</td>
<td>borderline</td>
</tr>
<tr>
<td>4 poor</td>
<td>regular consumer / inacceptable (claim)</td>
</tr>
<tr>
<td>3 insufficient</td>
<td>consumer / unacceptable (corrupt component)</td>
</tr>
<tr>
<td>2 bad</td>
<td>consumer / unacceptable (limited activity)</td>
</tr>
<tr>
<td>1 very bad</td>
<td>consumer / unacceptable (without activity)</td>
</tr>
</tbody>
</table>

#### Ergonomie und Akustik
**Ergonomics and NVH**

<table>
<thead>
<tr>
<th>Bewertung</th>
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</tbody>
</table>

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<thead>
<tr>
<th>Ergonomie und Akustik</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Übersichtlichkeit und Funktionalität (Overview and functionality)</td>
<td>8,0</td>
<td>7,0</td>
<td>8,0</td>
</tr>
<tr>
<td>Stützkomfort und Isolierung</td>
<td>7,5</td>
<td>6,5</td>
<td>9,0</td>
</tr>
<tr>
<td>Sitzaufliegerung</td>
<td>7,0</td>
<td>8,5</td>
<td>9,0</td>
</tr>
<tr>
<td>Abrollgeräusch</td>
<td>8,0</td>
<td>7,0</td>
<td>9,0</td>
</tr>
<tr>
<td>Schluckvermögen akustisch</td>
<td>8,0</td>
<td>7,5</td>
<td>8,5</td>
</tr>
<tr>
<td>Dröhnen</td>
<td>7,5</td>
<td>7,0</td>
<td>9,0</td>
</tr>
</tbody>
</table>

### Chassis Guide

- **Subjective Evaluation**
- **House of Quality**
- **Multi Body Simulation**
- **Characteristic Curves**

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Folie 19 von 36
### Characteristic Curves

#### Subjective Evaluation

**Subjective Evaluation**: "Fahrkomfort" (Fahrkomfort: onroad comfort)

**Evaluator / Comment**
- Expert / not detectable
- Expert / hardly detectable
- Expert / nominal complaint
- Critical consumer / slightly detectable
- Critical consumer / detectable
- Regular consumer / explicit detectable
- Consumer / unacceptable (corrupt component)
- Consumer / unacceptable (limited activity)
- Consumer / unacceptable (without activity)

### Subjective Beurteilung Fahrkomfort

**Subjective evaluation: onroad comfort**

<table>
<thead>
<tr>
<th>Fachwerk</th>
<th>Fahrzeugtyp</th>
<th>Belästigung</th>
<th>k-Boden</th>
<th>Bewertung</th>
<th>Funktion / Komfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Customer</td>
<td>1. 2. 3.</td>
<td>8.0 6.5 6.0</td>
<td>6.5 8.5 10.0</td>
<td>7.0 8.5 10.0</td>
<td>8.5 8.5 8.5</td>
</tr>
<tr>
<td>2. Competitor</td>
<td>1. 2. 3.</td>
<td>8.0 7.0 9.0</td>
<td>7.5 6.5 9.0</td>
<td>7.0 8.5 8.5</td>
<td>8.0 7.0 9.0</td>
</tr>
<tr>
<td>3. Benchmark</td>
<td>1. 2. 3.</td>
<td>8.0 8.5 9.0</td>
<td>7.0 7.5 9.0</td>
<td>7.5 7.0 9.0</td>
<td>8.0 7.5 9.0</td>
</tr>
</tbody>
</table>

### Overview and Functionality

- Schlickvermögen akustisch (Absorbing capacity (acoustical))
- Abrollgeräusch (Road noise)
- Sitzkomfort und Isolation (Seat comfort and insulation)
- Sitzseitenführung (Seat lateral traction)
- Dröhnen (Drone)
- Nickfederverhalten (Pitch behaviour)
- Wankfederverhalten (Roll behaviour)
- Abrollkomfort (Rolling comfort)
- Schlickvermögen mechanisch (Absorbing capacity (mechanical))
- Aufbaucharakteristik (Body characteristic)
- Pendelbeine (Bump stop working)
- Sturzene (Stuttering)
- Unterbauvibrationen (Body vibration)
- Querschütteln (Transversal shaking)

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Design in the Loop
Characteristic Curves

“Validated” measurement

Linking subjective evaluations with objective measurements

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Design in the Loop
Folie 21 von 36
Comfort-critical phenomenon of the “noisy rear axle” can now be identified and evaluated through high-resolution subjective evaluation.
**Characteristic Curves**

Objectivation of steering behavior

**Validation – Weave test**

- **Criteria: Steering Torque Build-up & Turn-in Feeling**
- **Criteria: Smoothness**
- **Criteria: Steering Effort at Center Point**
- **Criteria: Steering Precision**
- **Overall Criteria: On-Center Feeling**

Source: IPG Automotive GmbH
**Multi-Body Simulation**
Securing / covering consumer requirement in simulation

- **Real vehicle**
- **Virtual vehicle**
- **Virtual benchmark study**

**Systems characteristics**

**Parameterization**

**Vehicle variations**

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**Multi-Body Simulation**
Virtualization of real vehicle

**Sim-Tools:** CarMaker, ADAMS, veDYNA

### Vertical Dynamics

<table>
<thead>
<tr>
<th>Single Events</th>
<th>Public Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ditch</td>
<td>• Uneven cross-country roads</td>
</tr>
<tr>
<td>• Curb</td>
<td>• Different excitation characteristics</td>
</tr>
<tr>
<td>• Different speed levels</td>
<td>• Uneven cross-country roads with curves</td>
</tr>
<tr>
<td></td>
<td>• Different speed levels</td>
</tr>
<tr>
<td></td>
<td>• Closed loop driven</td>
</tr>
</tbody>
</table>

These maneuvers allow efficient reproduction / simulation of the vibration DNA.

Incorporation of “validated measurements” as targets into a virtual vehicle model.
Subjective Ratings:

Benchmark: 9
Customer: 7
Modified: 8.5

Roll Gain vs. Frequency

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Subjective Ratings:

Benchmark: 9
Customer: 7
Modified: 8.5

after digital engineering

Steering Wheel Torque vs. Steering Wheel Angle

Benchmark: 9
Customer: 7
Modified: 8.5
Multi-Body Simulation
Virtual benchmark

Lap time optimization
Multi-Body Simulation
Virtual benchmark

Speed Profile and Steering Effort

Real driver loss 0.5 sec due to risky section
- Mental block

Virtual driver takes car closer to understeer limit
- Perception problem
Finetuning of Vehicle DNA
“Characteristics” optimization

Parameters

<table>
<thead>
<tr>
<th>Target #1</th>
<th>Target-area</th>
<th>Regulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target #2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target #3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target #4</td>
<td></td>
<td></td>
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<tr>
<td>Target #5</td>
<td></td>
<td></td>
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<tr>
<td>Target #6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target #7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Linking component parameters (susension stiffness etc.) with “validated characteristics”. Finding OEM targets / respecting brand or vehicle model philosophy (vehicle DNA)
Design in the Loop
Implementation
Design in the Loop
Implementation

Kick-off

Product
Market Analysis
Concept Car
Final Concept
Construction

Coverage
Virtual Concept
Virtual Prototype
Simulation
1st Prototype
Prototypes / Testing

TIME TO MARKET

House of Quality
Chassis Guide
Simulation

Design in the Loop

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Design in the Loop
Your benefits

- **Target / Objective**
  - “First time right” (before building a physical prototype)
  - Saving precious development time
  - Covering new car concepts
  - “First time right” (90%)
  - Minimize the risk of failing the market

- **Tools**
  - QFD → knowing designable customer wishes

- **Chassis Guide**
  - Standardized test procedure for objective & subjective evaluation
  - Translation of subjective marks into objective scientific values for simulation
Design in the Loop

Summary

Process Description in Chassis Development

- **Customer requirement**
  - Objective e.g. speed
  - Subjective e.g. comfort

- **Objectivation**
  - Intermediate step

- **Physical action chain**
  - Simulation
  - Road test
  - Rig test

- **Developing**
  - Observing
  - Evaluating
  - Understanding

The vehicle dynamics characteristics are key in this context:
- Pitch, yaw, roll
- Dynamic response to driving maneuvers…
<table>
<thead>
<tr>
<th>Package</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Package</td>
<td>Chassis Guide</td>
</tr>
<tr>
<td>Extended Package</td>
<td>Chassis Guide&lt;sup&gt;Plus&lt;/sup&gt; (subjective AND objective evaluation process)</td>
</tr>
<tr>
<td></td>
<td>QFD (customer request)</td>
</tr>
<tr>
<td>Premium Package</td>
<td>Chassis Guide</td>
</tr>
<tr>
<td></td>
<td>QFD (customer wishes)</td>
</tr>
<tr>
<td></td>
<td>Simulation (model building, virtual benchmark and virtual development)</td>
</tr>
</tbody>
</table>
We develop concepts and design suspension systems with the desired handling characteristics for the automotive industry. As concept consultants, we deliver advanced approaches to solutions. As a “co-driver,” we help steer entire development processes and accompany our customers into new markets.

Thank you!

Dieter Scharpe  
Chief Operating Officer

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