Design Optimization of Driver Control and Uncertainty Study on Dynamic Performance of a Robot Vehicle
Dynamic Vehicle Simulation “E-Class Sedan” in CarSim

<table>
<thead>
<tr>
<th>Vehicle Body</th>
<th>Animation Data</th>
<th>Systems</th>
<th>Front Suspension</th>
<th>Rear Suspension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid sprung mass</td>
<td>Vehicle 3D Shape: Vehicle Shape</td>
<td>Powertrain: 4-wheel drive</td>
<td>Generic/Independent</td>
<td>Generic/Independent</td>
</tr>
<tr>
<td>E-Class, Sedan</td>
<td>E-Class, Sedan</td>
<td>250 kW, 7-spdl., 2.65 Ratio</td>
<td>E-Class, Sedan - Front</td>
<td>E-Class, Sedan - Rear</td>
</tr>
<tr>
<td>Aerodynamics</td>
<td>E-Class, Sedan Aero</td>
<td></td>
<td>E-Class, Sedan - Front</td>
<td>E-Class, Sedan - Rear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Springs, Dampers, and Compliance</td>
<td>Springs, Dampers, and Compliance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>E-Class, Sedan - Front</td>
<td>E-Class, Sedan - Rear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tires: Specify all four tires alike</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>All tires</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>225/60 R18</td>
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</tr>
</tbody>
</table>

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Driver Control in Simulink by Co-Simulation with CarSim
Design Automation Workflow in OptiY
Design Parameters of Driver Control

Optimization Ranges

- Driver Sensor Distance \( L_x = 2 - 20 \) [m]
- Gain for Lateral Error \( G_l = 0 - 40 \) [-]
- Gain for Area Error \( G_a = 0 - 40 \) [-]
Multi-Objective Design Goals

Steering wheel angle in time domain

Steering wheel angle in frequency domain

Frequency > 0.1221 Hz
High Frequency (Max. Amplitude)

Design Objectives:
- **Driving road**: Minimize integral of lateral error
- **Driving comfort**: Minimize maximal amplitude of high frequency
Multi-Objective Design Optimization

Driving comfort

Lateral Error

Pareto-optimal Solutions

Lx = 5.7; Ga = 7.4; Gl = 0.03

Lx = 5.8; Ga = 8.9; Gl = 17.5

Best Solution

Lx = 15; Ga = 10; Gl = 30

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Some Selected Uncertainties and Errors of a Passenger Vehicle

- Front Differential
  Stiffness + Damping

- Rear Differential
  Stiffness + Damping

- Aerodynamics

- Steering Wheel
  Hysteresis +
  Stiffness + Damping

- Vehicle Speed

- Distance Sensor

- Front Suspension
  Stiffness + Damping

- Rear Suspension
  Stiffness + Damping

- Road Friction

- Tires: Roll Radius +
  Stiffness + Damping +
  Resistance Moment +
  Transition Factor

Uncertainties and errors are varying depending on weather, temperature and environment
### Uncertainties as Stochastic Parameters in OptiY

<table>
<thead>
<tr>
<th>Name</th>
<th>Nominal</th>
<th>Tolerance</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lx Sensor</td>
<td>15</td>
<td>0.2</td>
<td>Normal Distribution</td>
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<tr>
<td>Gain Area Error</td>
<td>10</td>
<td>0</td>
<td>Normal Distribution</td>
</tr>
<tr>
<td>Gain Lateral Error</td>
<td>30</td>
<td>0</td>
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<tr>
<td>Vehicle Speed</td>
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<tr>
<td>Road Friction</td>
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<tr>
<td>Air Mass Density</td>
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<td>0.12</td>
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<tr>
<td>Transfer Torsional Stiffness</td>
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<td>Normal Distribution</td>
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<tr>
<td>Transfer Torsional Damping</td>
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<tr>
<td>Front Differential Stiffness</td>
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<tr>
<td>Front Differential Damping</td>
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<td>0.1</td>
<td>Normal Distribution</td>
</tr>
<tr>
<td>Rear Differential Stiffness</td>
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<td>8</td>
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</tr>
<tr>
<td>Rear Differential Damping</td>
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<td>0.08</td>
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<tr>
<td>Steering Column Damping</td>
<td>0.002</td>
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<td>Steering Column Hysteresis</td>
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<td>0.03</td>
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<td>Front Steering Damping</td>
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<td>0.4</td>
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<td>Front Steering Hysteresis</td>
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<tr>
<td>Steering Torsional Bar Stiffness</td>
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<td>0.2</td>
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<tr>
<td>Tire Effective Roll Radius</td>
<td>365</td>
<td>5</td>
<td>Normal Distribution</td>
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<tr>
<td>Tire Spring Rate</td>
<td>278</td>
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<td>Tire Rolling Resistance Moment</td>
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<td>3e-06</td>
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<td>Tire Transition Factor</td>
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<td>Front Suspension Spring</td>
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<tr>
<td>Front Suspension Friction</td>
<td>20</td>
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<td>Rear Suspension Spring</td>
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<tr>
<td>Rear Suspension Friction</td>
<td>20</td>
<td>2</td>
<td>Normal Distribution</td>
</tr>
</tbody>
</table>

**Normal Distribution:**
- Nominal
- Tolerance
Monte-Carlo Dynamic-Simulation for Meta-Modeling

Design of Experiment
- Latin Hypercube Sampling
- 400 Sampled Points
Meta-Model of Driving Comfort on Some Selected Parameters

3D- Response Surface

2D- Section Diagram

Meta-Model = mathematical relationship between driving comfort and uncertainty parameters

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Sensitivity Analysis on Driving Comfort

Driving Comfort = min. Amplitude of High Frequency (>0.1221 Hz) for steering wheel angle

Depending on 7 important Parameters/Uncertainties:
- Road Friction = 22.97%
- Aerodynamics = 21.13%
- Driver Sensor = 12.9%
- Rear Suspension Spring = 12.24%
- Steering Torsion Bar Stiffness = 10.76%
- Front Suspension Spring = 10.32%
- Vehicle Speed = 7.54%
Dynamic Sensitivity on Lateral Error

A-A

B-B
Cut-Sensitivities on Lateral Error

Cut A-A

Cut B-B

Parameter | Total Effect | Main Effect
--- | --- | ---
Vehicle Speed | 96.31% | 96.31%
Road Friction | 15.63% | 15.63%
Vehicle Speed | 13.61% | 13.61%
Front Steering Hysteresis | 12.62% | 12.62%
Transfer Torque Hysteresis | 12.62% | 12.62%
Lx Sensor | 12.66% | 12.66%
Steering Tension Bar Stiffness | 5.49% | 5.49%
Transfer Torque Stiffness | 5.03% | 5.03%
Tire Rolling Resistance Moment | 4.01% | 4.01%
Rear Differential Stiffness | 3.84% | 3.84%
Rear Suspension Spring | 3.41% | 3.41%
Steering Column Hysteresis | 3.14% | 3.14%
Steering Column Stiffness | 3.14% | 3.14%
Tire Spring Rate | 2.06% | 2.06%
Rear Differential Stiffness | 2.06% | 2.06%
Front Suspension Spring | 2.06% | 2.06%
Front Differential Stiffness | 1.02% | 1.02%
Front Differential Stiffness | 1.02% | 1.02%
Front Suspension Friction | 0.83% | 0.83%
Front Suspension Friction | 0.83% | 0.83%
Front Suspension Spring | 0.73% | 0.73%
Front Suspension Spring | 0.73% | 0.73%
Front Differential Stiffness | 0.72% | 0.72%
Front Differential Stiffness | 0.72% | 0.72%
Front Suspension Spring | 0.65% | 0.65%
Front Suspension Spring | 0.65% | 0.65%
Front Suspension Friction | 0.34% | 0.34%
Front Suspension Friction | 0.34% | 0.34%
Tire Spring Rate | 0.34% | 0.34%
Tire Spring Rate | 0.34% | 0.34%
Tire Transition Factor | 0.18% | 0.18%
Gain Lateral Error | 0% | 0%
Gain Lateral Error | 0% | 0%
Gain Area Error | 0% | 0%
Gain Area Error | 0% | 0%

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Dynamic Sensitivity on Steering Wheel Angle
Cut-Sensitivities on Steering Wheel Angle

Cut A-A

Cut B-B
Summary

- Detailed simulation of dynamic performance of a robot vehicle is performed in CarSim and the driver control by co-simulation in Matlab/Simulink. The design workflow for both processes is build in OptiY for automation and optimization.

- Finding optimal control parameters of the driver model automatically, a multi-objective optimization is used to increasing the driving comfort and minimize the lateral error of driving road.

- The dynamic performance of a passenger vehicle is affected by many uncertainties and errors as friction, stiffness, damping of components etc.. They are varying depending on weather, temperature and environment. The uncertainty study takes these uncertainties and errors into consideration. It uncovers the relationships between driving comfort, lateral error on these uncertainty parameters. With sensitivity analysis, almost important parameters can be identified for driving comfort and lateral error.