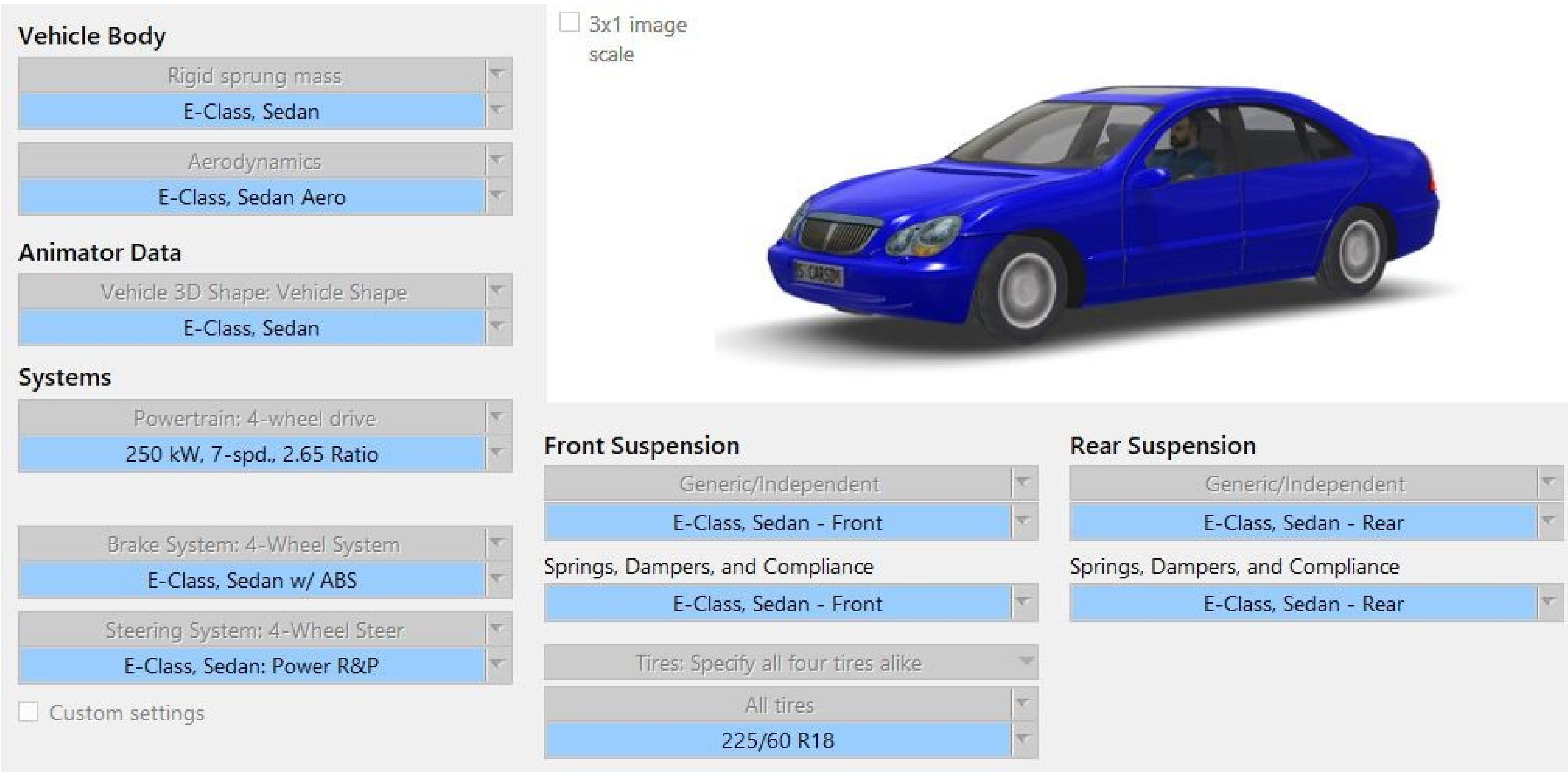
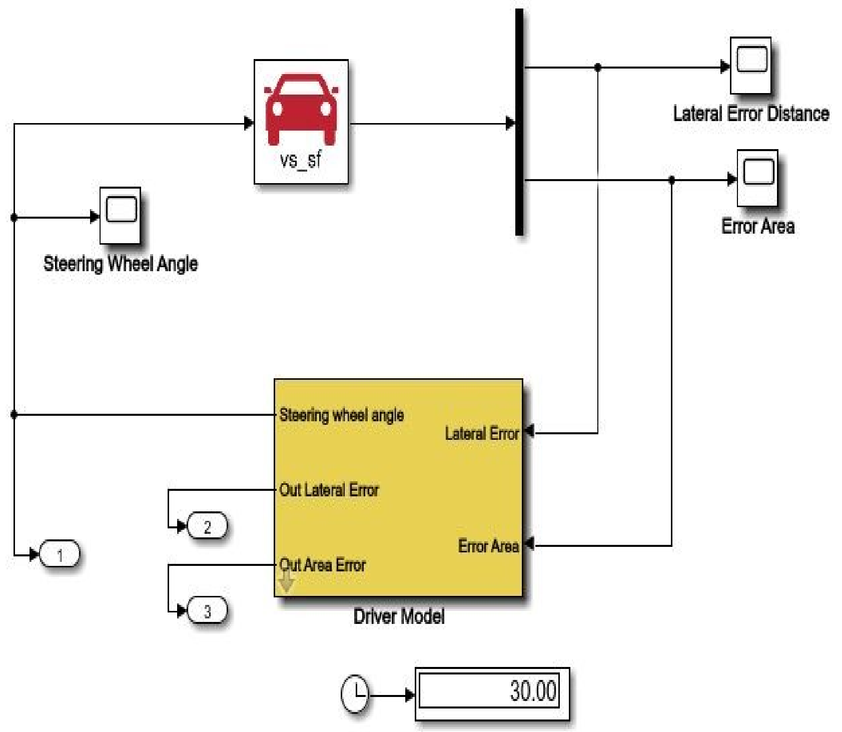
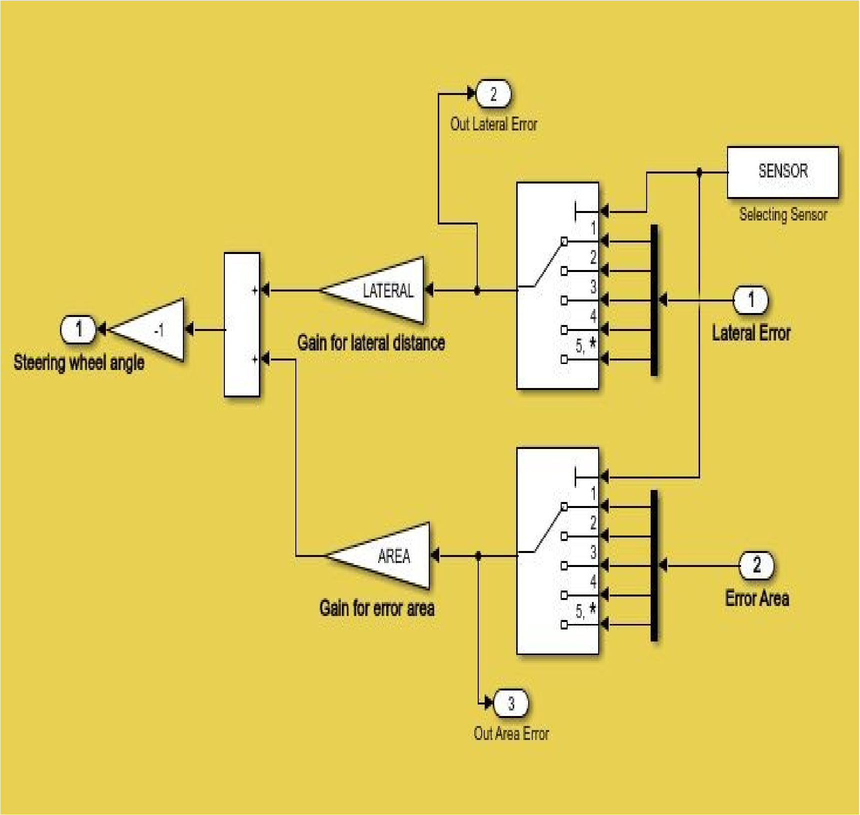
Design Optimization of Driver Control and Uncertainty Study on Dynamic Performance of a Robot Vehicle

Dynamic Vehicle Simulation "E-Class Sedan" in CarSim

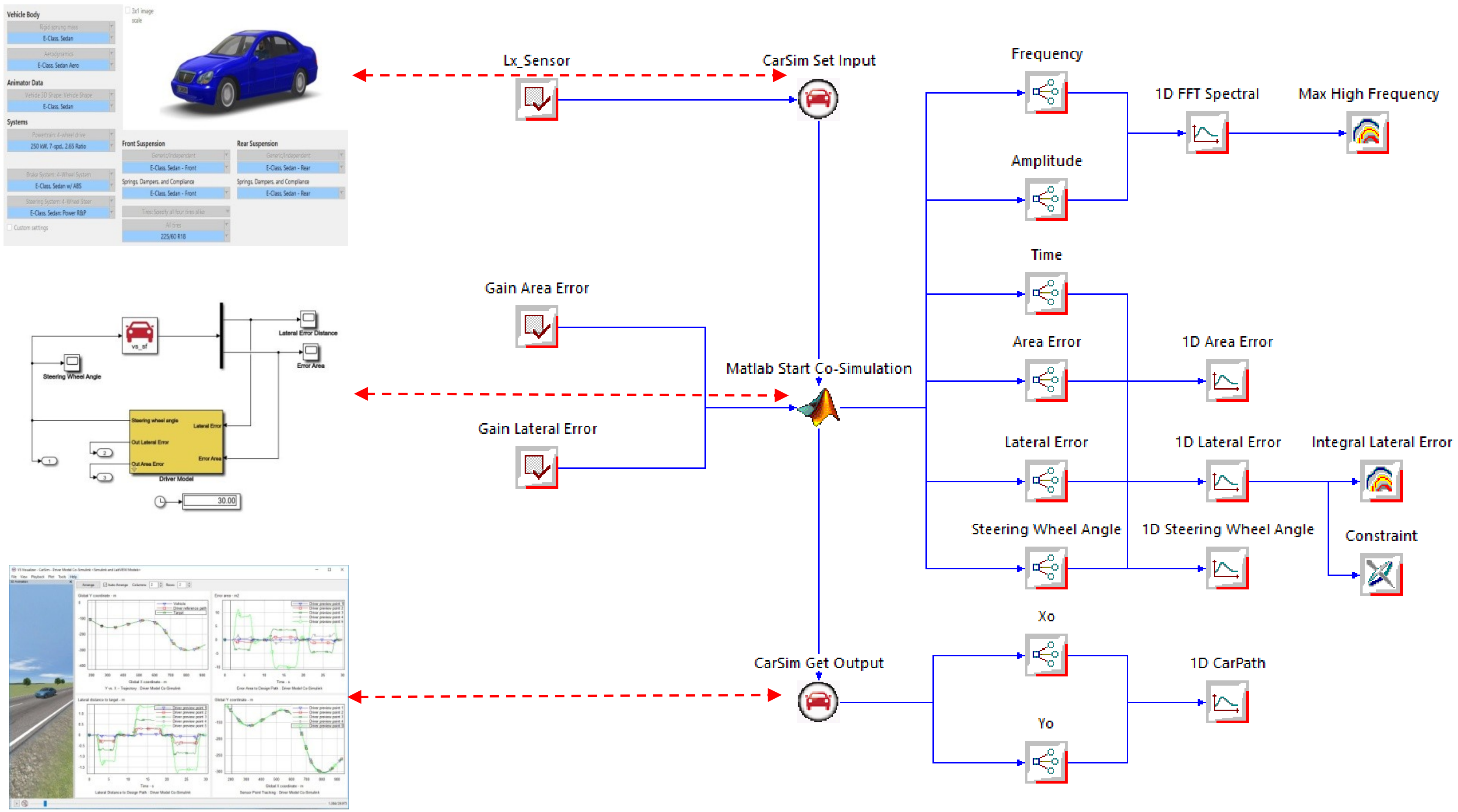


Driver Control in Simulink by Co-Simulation with CarSim

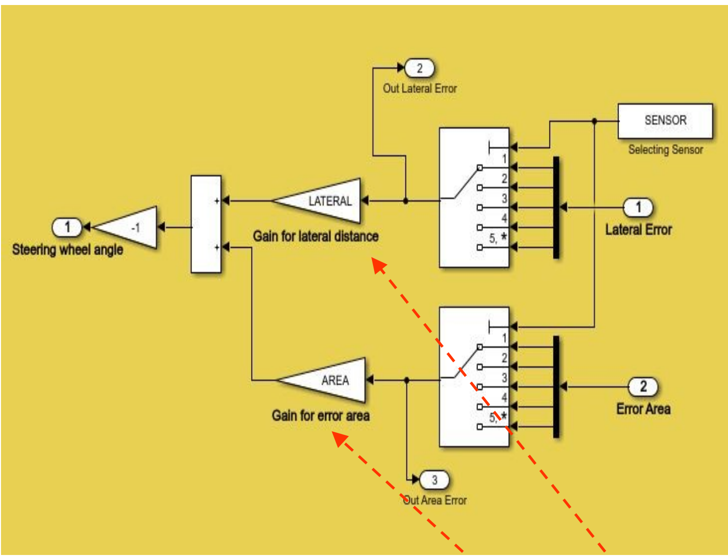


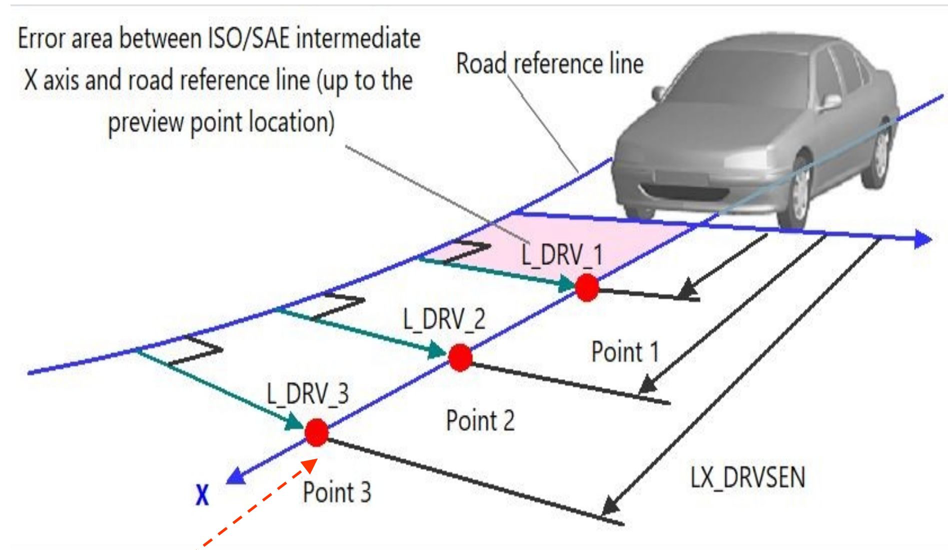


Design Automation Workflow in OptiY



Design Parameters of Driver Control

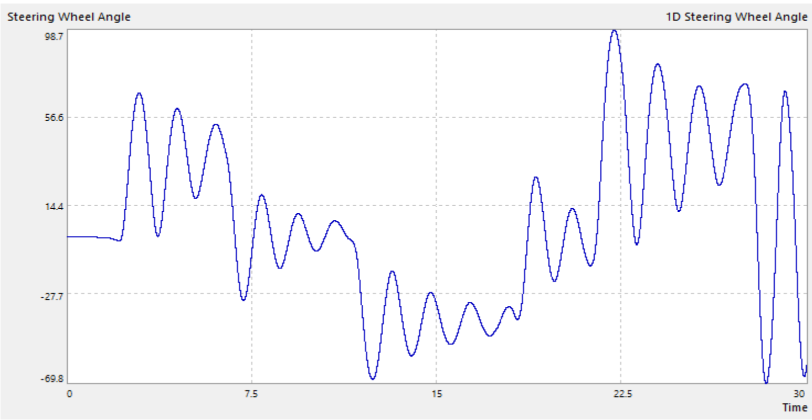




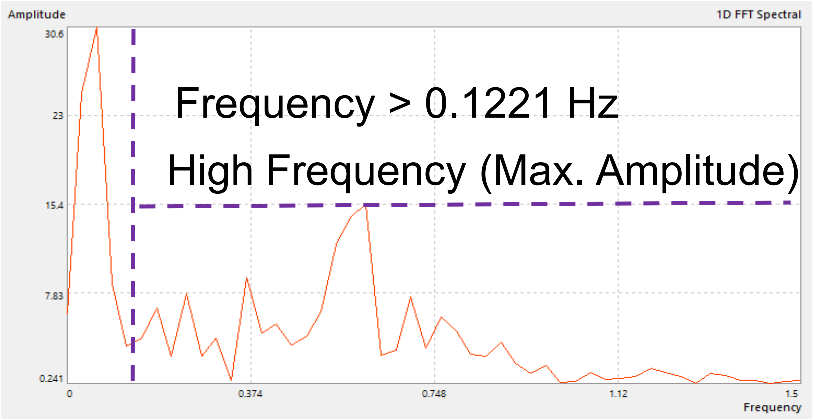
Optimization Ranges

- Driver Sensor Distance **Lx** = 2 – 20 [m]
- Gain for Lateral Error **Gl** = 0 – 40 [-]
- Gain for Area Error **Ga** = 0 – 40 [-]

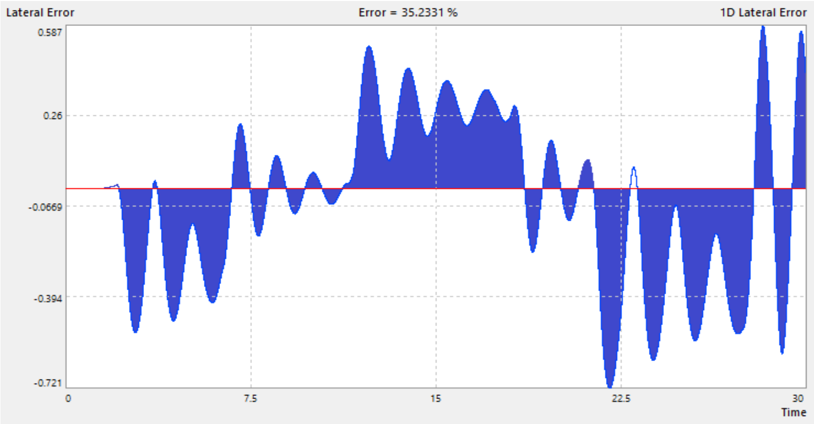
Multi-Objective Design Goals



Steering wheel angle in time domain



Steering wheel angle in frequency domain

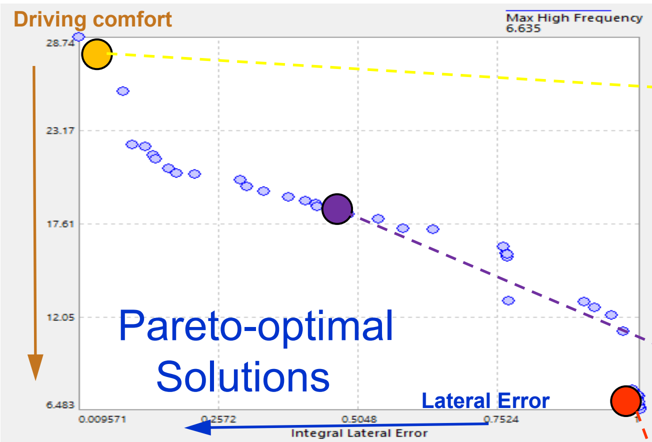


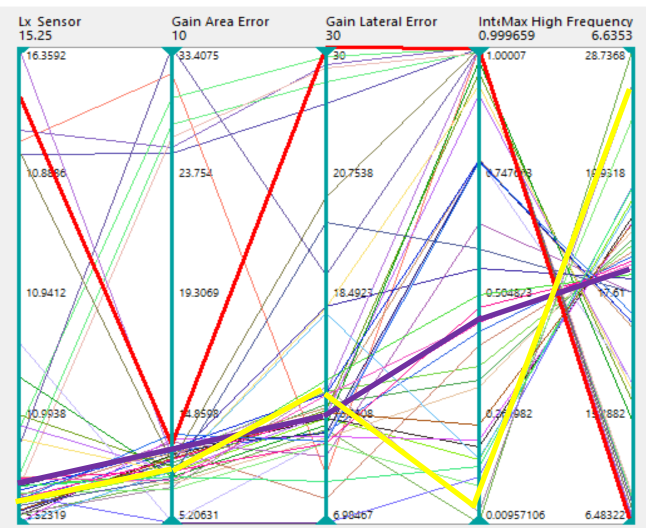
Integral of Lateral Distance Error

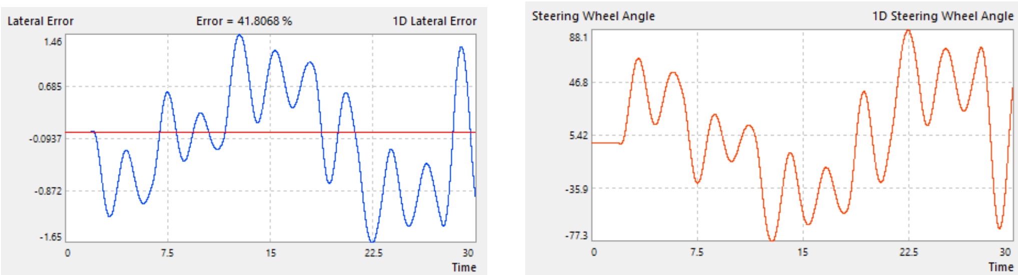
Design Objectives:

- Driving road: Minimize integral of lateral error
- Driving comfort: Minimize maximal amplitude of high frequency

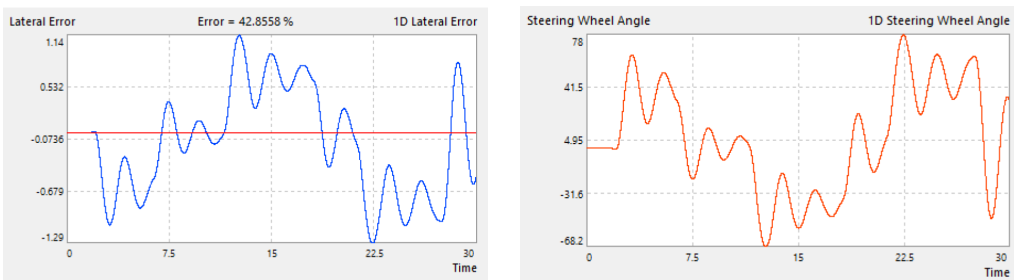
Multi-Objective Design Optimization



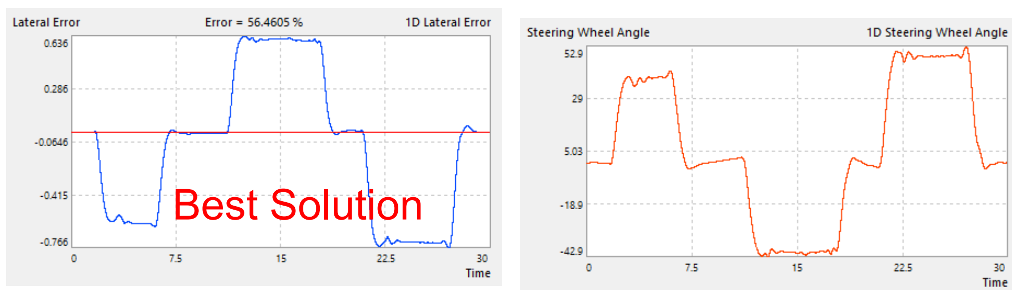




Lx = 5.7; Ga = 7.4; Gl = 0.03



Lx = 5.8; Ga = 8.9; Gl = 17.5



Lx = 15; Ga = 10; Gl = 30

Some Selected Uncertainties and Errors of a Passenger Vehicle

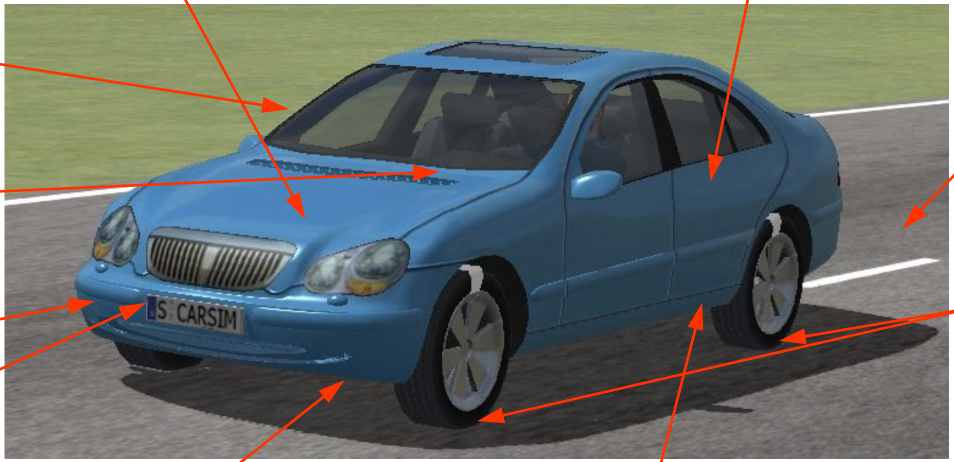
Front Differential
Stiffness + Damping

Rear Differential
Stiffness + Damping

Aerodynamics

Road Friction

Steering Wheel
Hysteresis +
Stiffness + Damping



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

Vehicle Speed

Distance Sensor

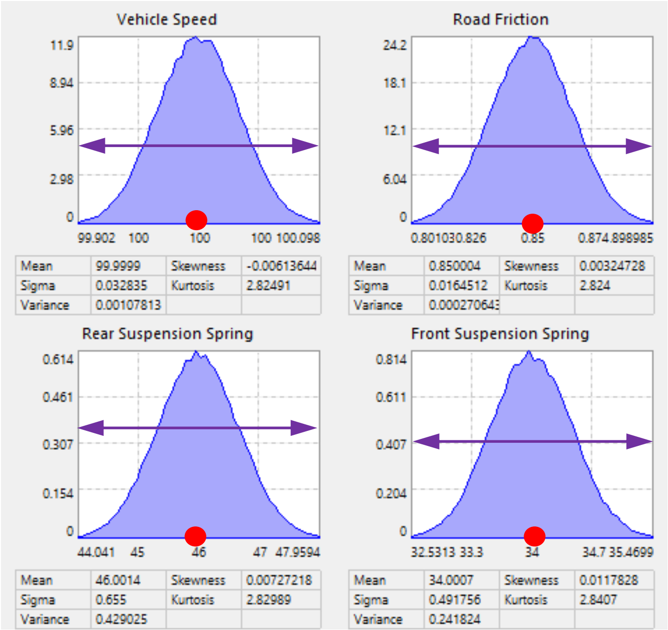
Front Suspension
Stiffness + Damping

Rear Suspension
Stiffness + Damping

Uncertainties and errors are varying depending on weather, temperature and environment

Uncertainties as Stochastic Parameters in OptiY

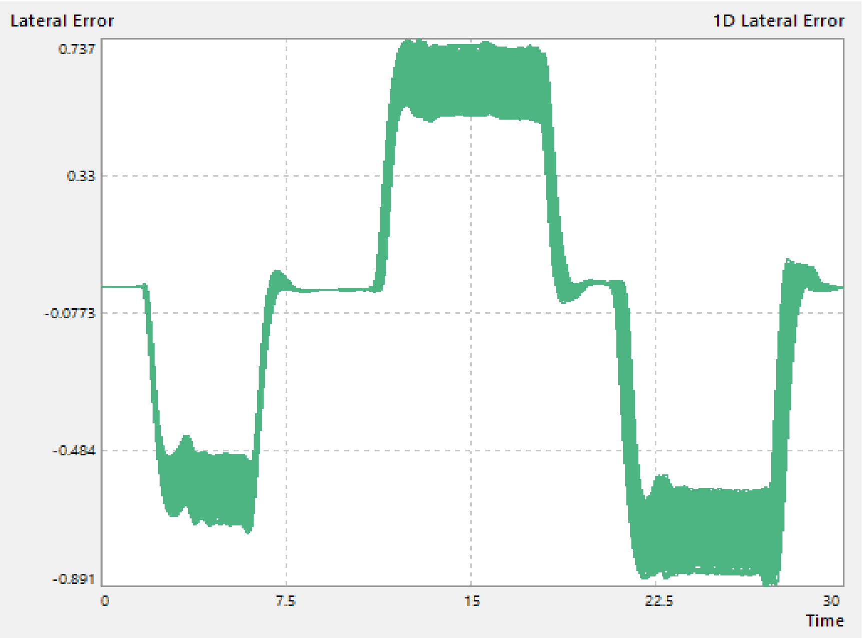
Name	Nominal	Tolerance	Distribution
Lx_Sensor	15	0.2	Normal Distribution
Gain Area Error	10	0	Normal Distribution
Gain Lateral Error	30	0	Normal Distribution
Vehicle Speed	100	0.2	Normal Distribution
Road Friction	0.85	0.1	Normal Distribution
Air Mass Density	1.206	0.12	Normal Distribution
Transfer Torsional Stiffness	80	8	Normal Distribution
Transfer Torsional Damping	0.8	0.08	Normal Distribution
Front Differantial Stiffness	100	10	Normal Distribution
Front Differantial Damping	1	0.1	Normal Distribution
Rear Differantial Stiffness	80	8	Normal Distribution
Rear Differantial Daping	0.8	0.08	Normal Distribution
Steering Column Damping	0.002	0.0002	Normal Distribution
Steering Column Hysteresis	0.3	0.03	Normal Distribution
Front Steering Damping	4	0.4	Normal Distribution
Front Steering Hysteresis	200	20	Normal Distribution
Steering Torsion Bar Stiffness	2	0.2	Normal Distribution
Tire Effective Roll Radius	365	5	Normal Distribution
Tire Spring Rate	278	27	Normal Distribution
Tire Rolling Resistance Moment	3e-005	3e-006	Normal Distribution
Tire Transition Factor	1.1	0.11	Normal Distribution
Front Suspension Spring	34	3	Normal Distribution
Front Suspension Friction	20	2	Normal Distribution
Rear Suspension Spring	46	4	Normal Distribution
Rear Suspension Friction	20	2	Normal Distribution

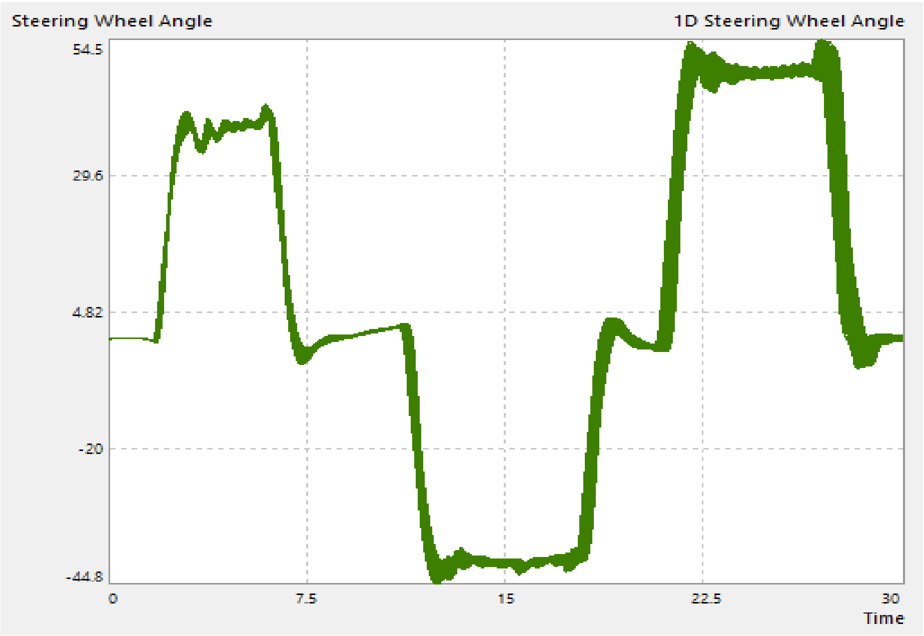


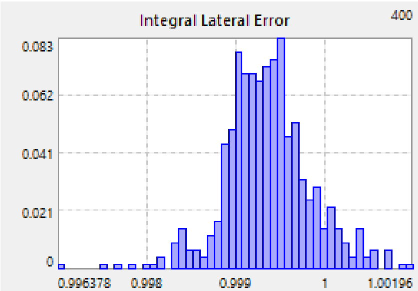
Normal Distribution:

- Nominal
- Tolerance

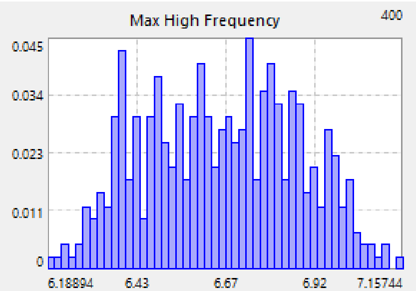
Monte-Carlo Dynamic-Simulation for Meta-Modeling







Mean	0.999737	Skewness	-0.178628
Sigma	0.000727927	Kurtosis	4.84589
Variance	5.29878e-007		



Mean	6.67261	Skewness	-0.00263546
Sigma	0.212432	Kurtosis	2.08935
Variance	0.0451274		

Design of Experiment

- Latin Hypercube Sampling
- 400 Sampled Points

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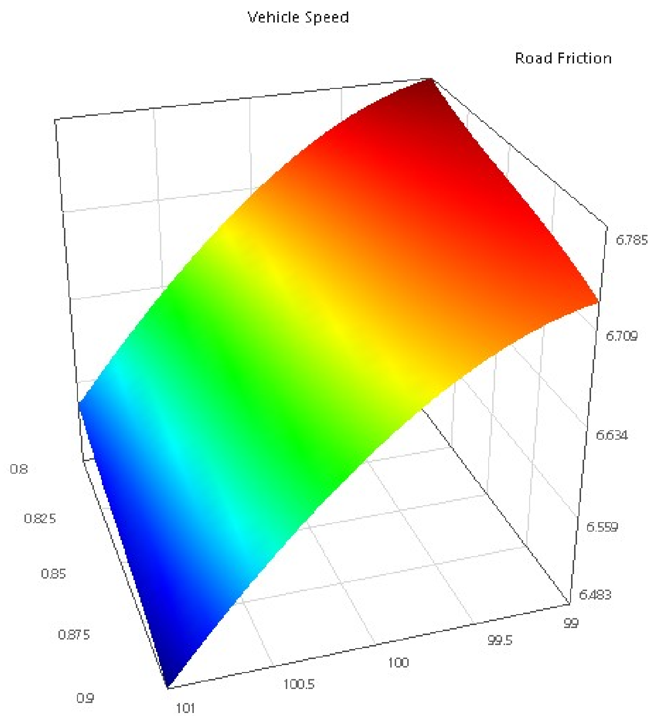
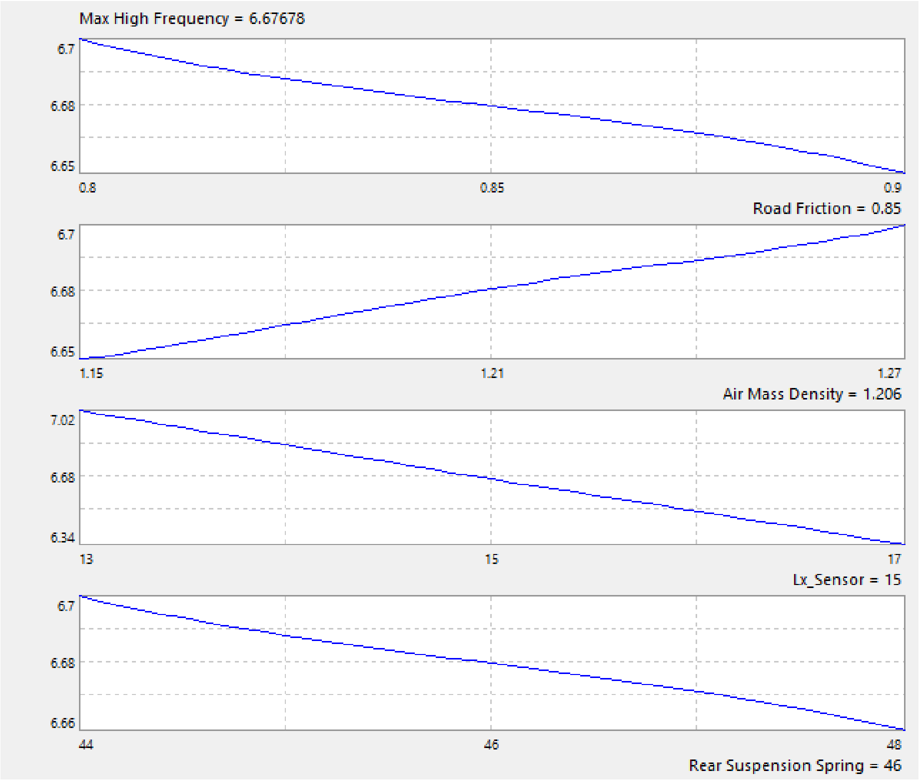
Meta-Model of Driving Comfort on Some Selected Parameters



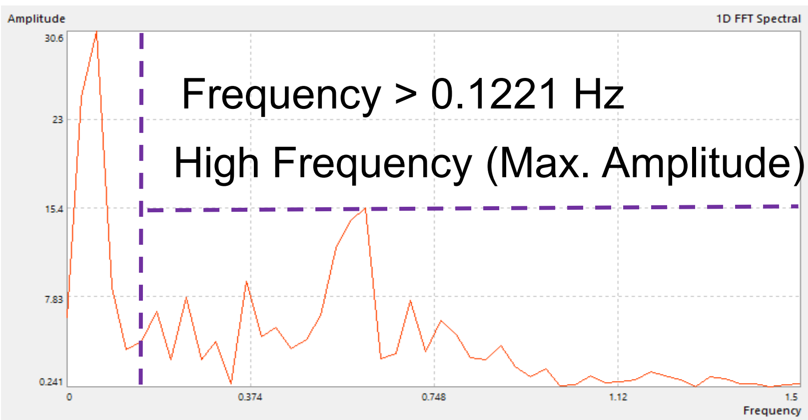
3D- Response Surface



2D- Section Diagram

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

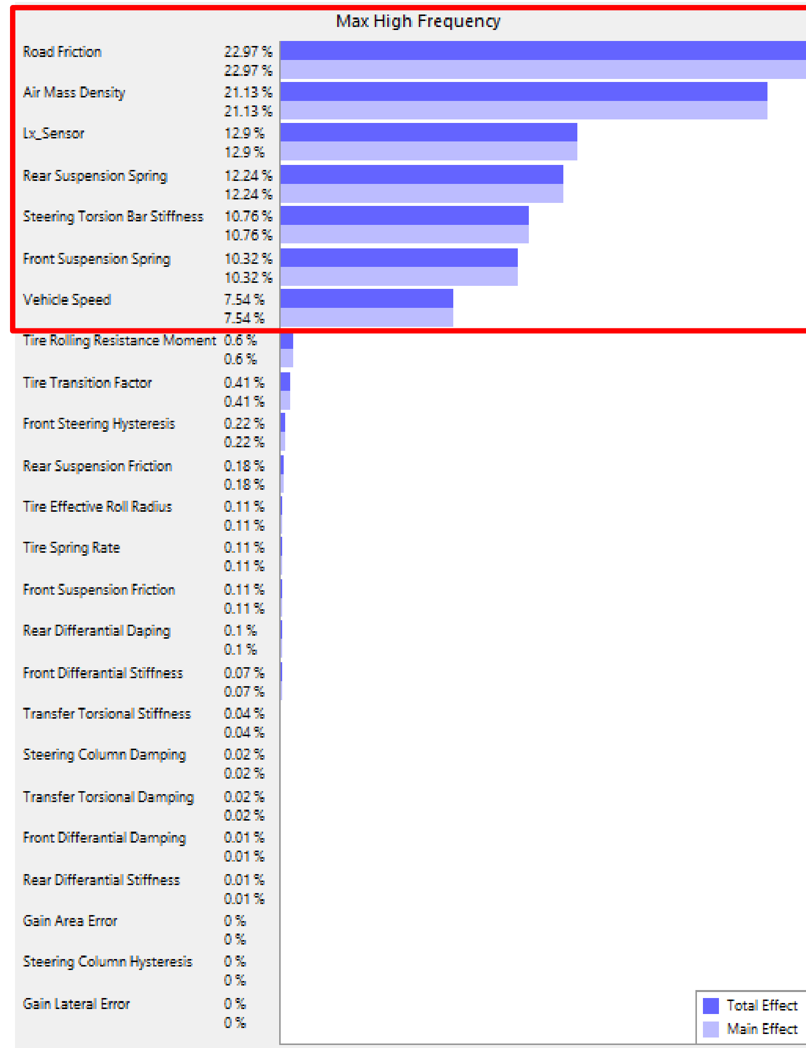
Sensitivity Analysis on Driving Comfort



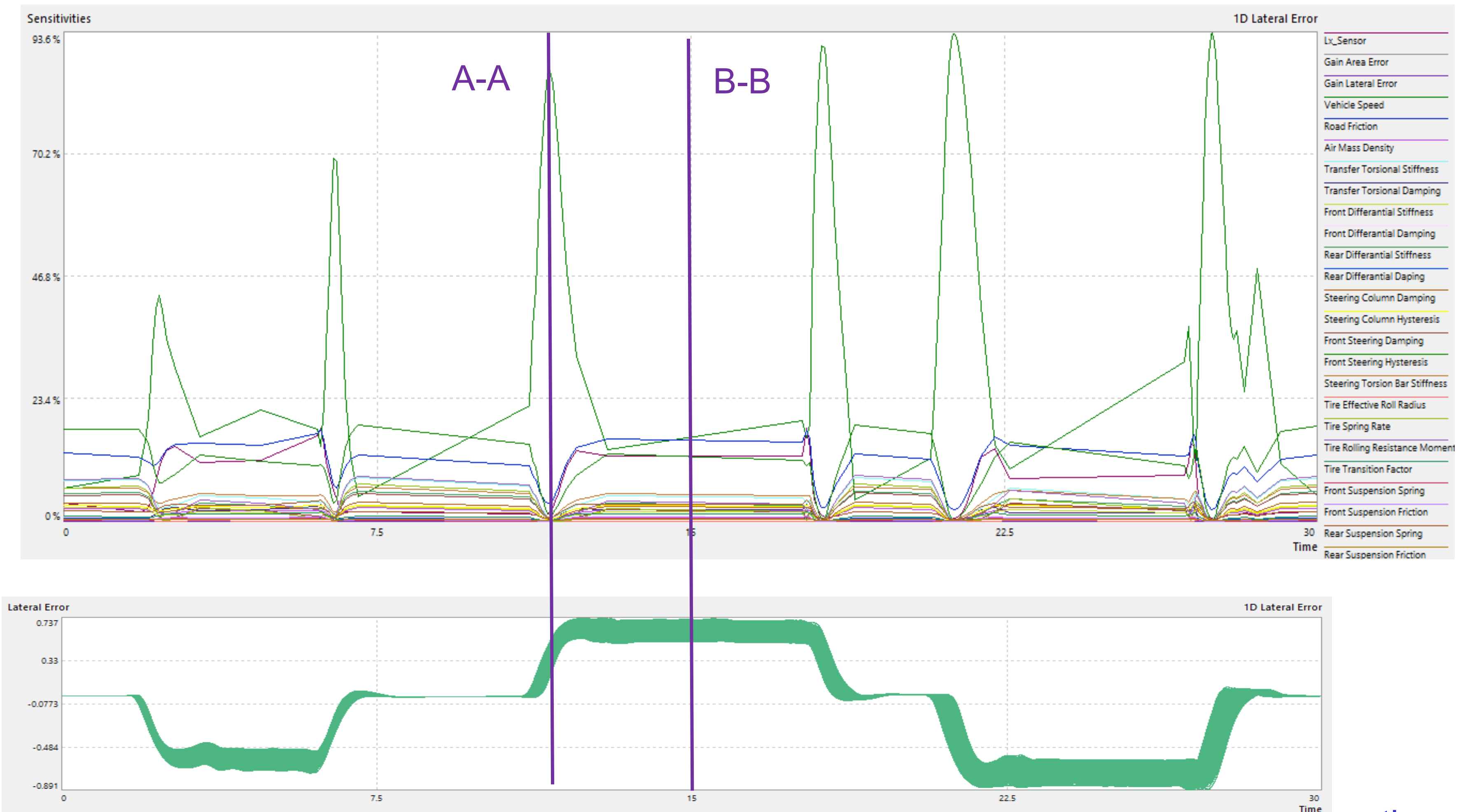
Driving Comfort = min. Amplitude of High Frequency (>0.1221 Hz) for steering wheel angle

Depending on 7 important Parameters/Uncertainties

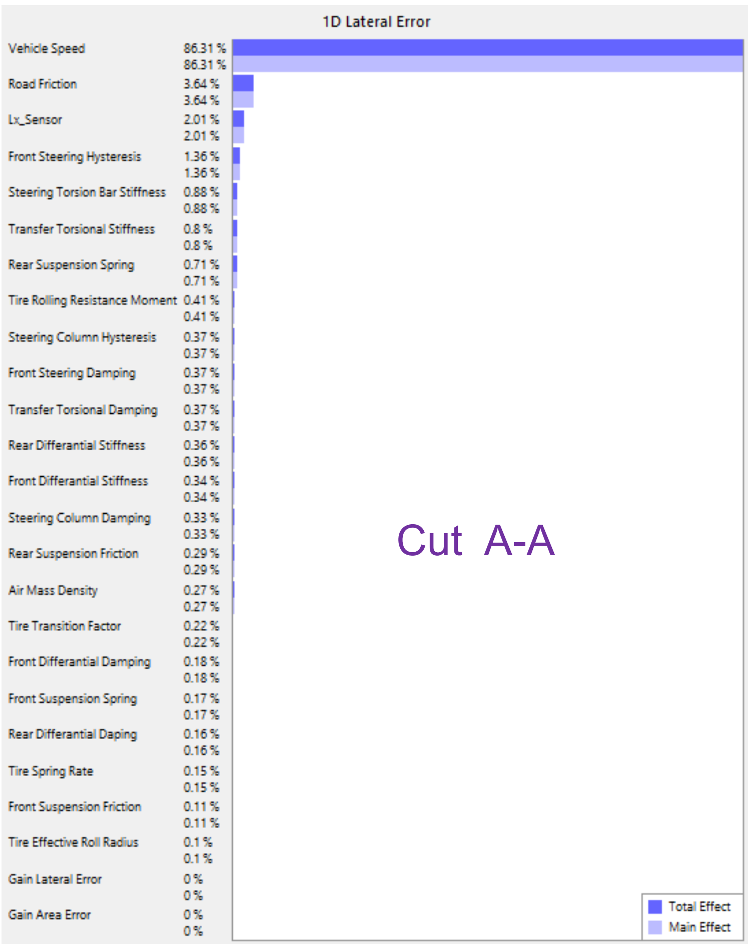
- Road Friction = 22,97%
- Aerodynamics = 21,13%
- Driver Sensor =12,9%
- Rear Suspension Spring = 12,24%
- Steering Torsion Bar Stiffness = 10,76%
- Front Suspension Spring = 10,32%
- Vehicle Speed = 7.54%

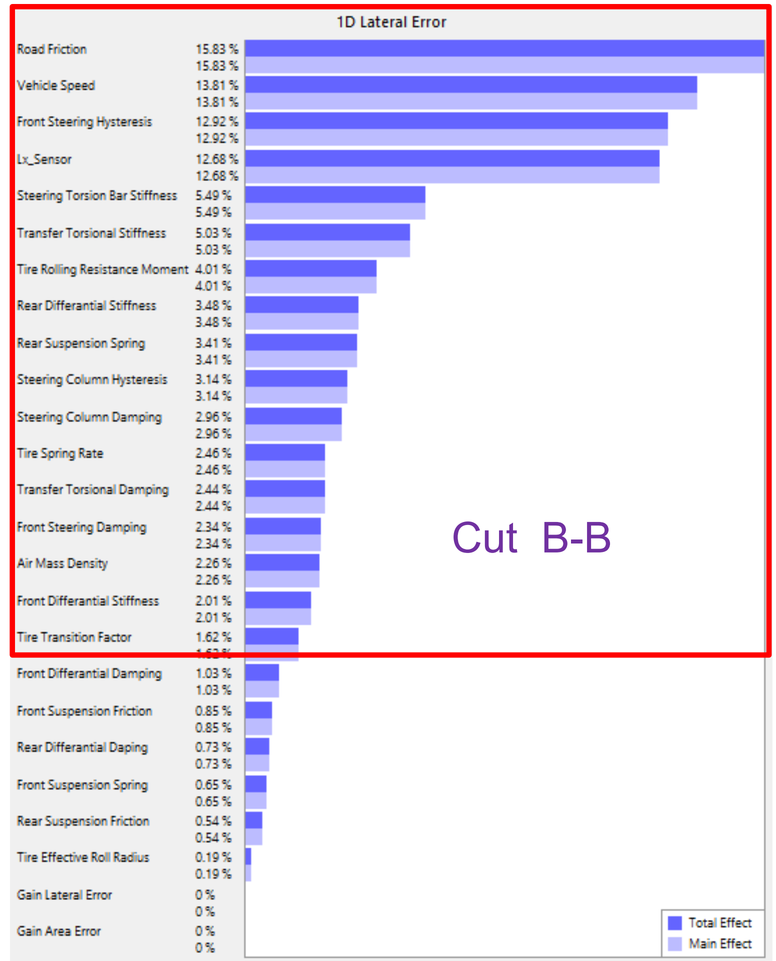


Dynamic Sensitivity on Lateral Error

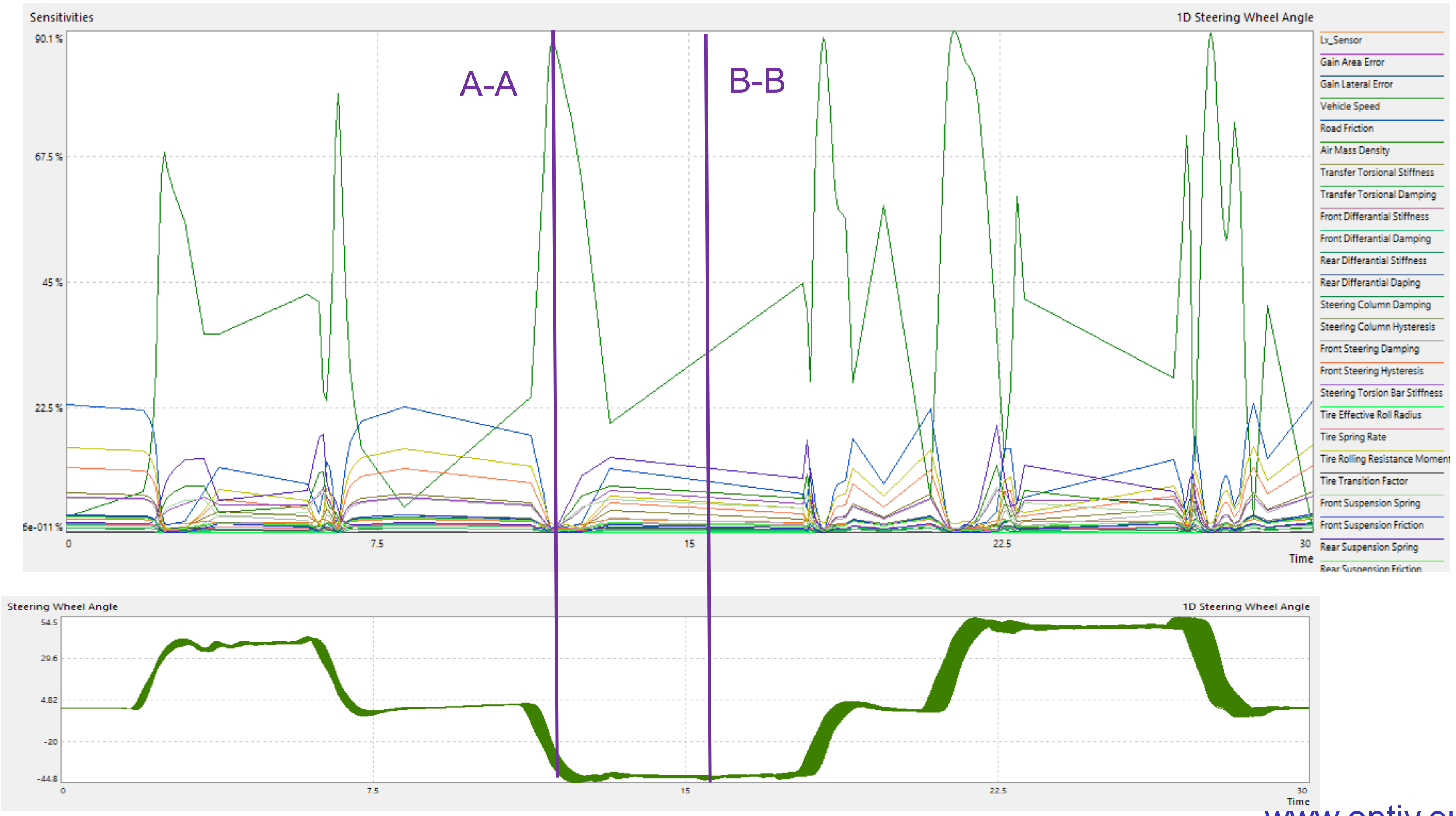


Cut-Sensitivities on Lateral Error

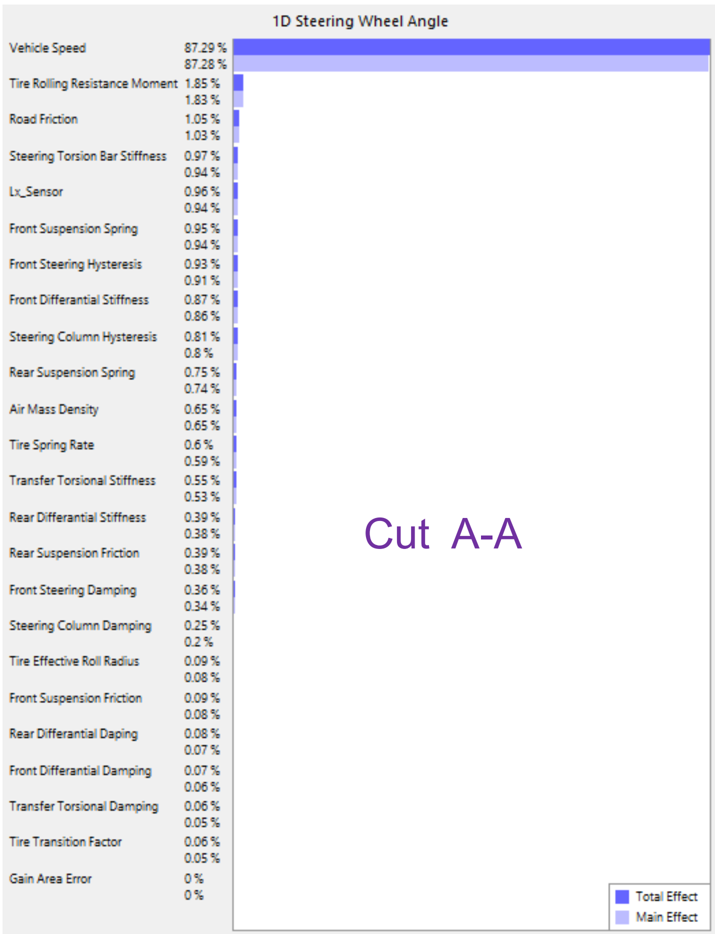


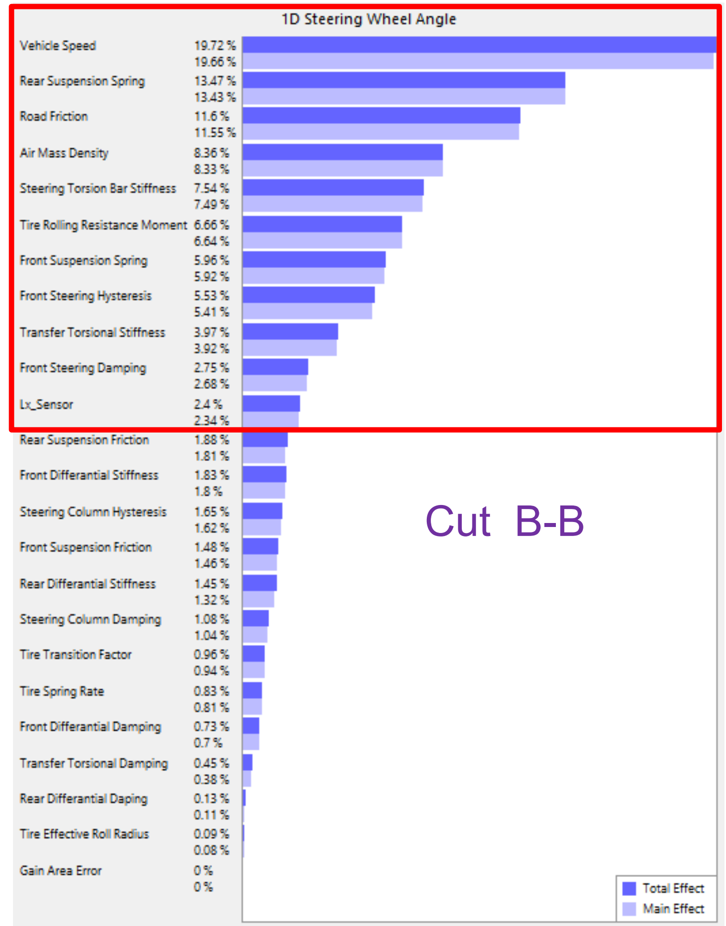


Dynamic Sensitivity on Steering Wheel Angle



Cut-Sensitivities on Steering Wheel Angle





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.