Global sensitivity analysis of GDI nozzle design parameters using ANSYS workbench & OptisLang

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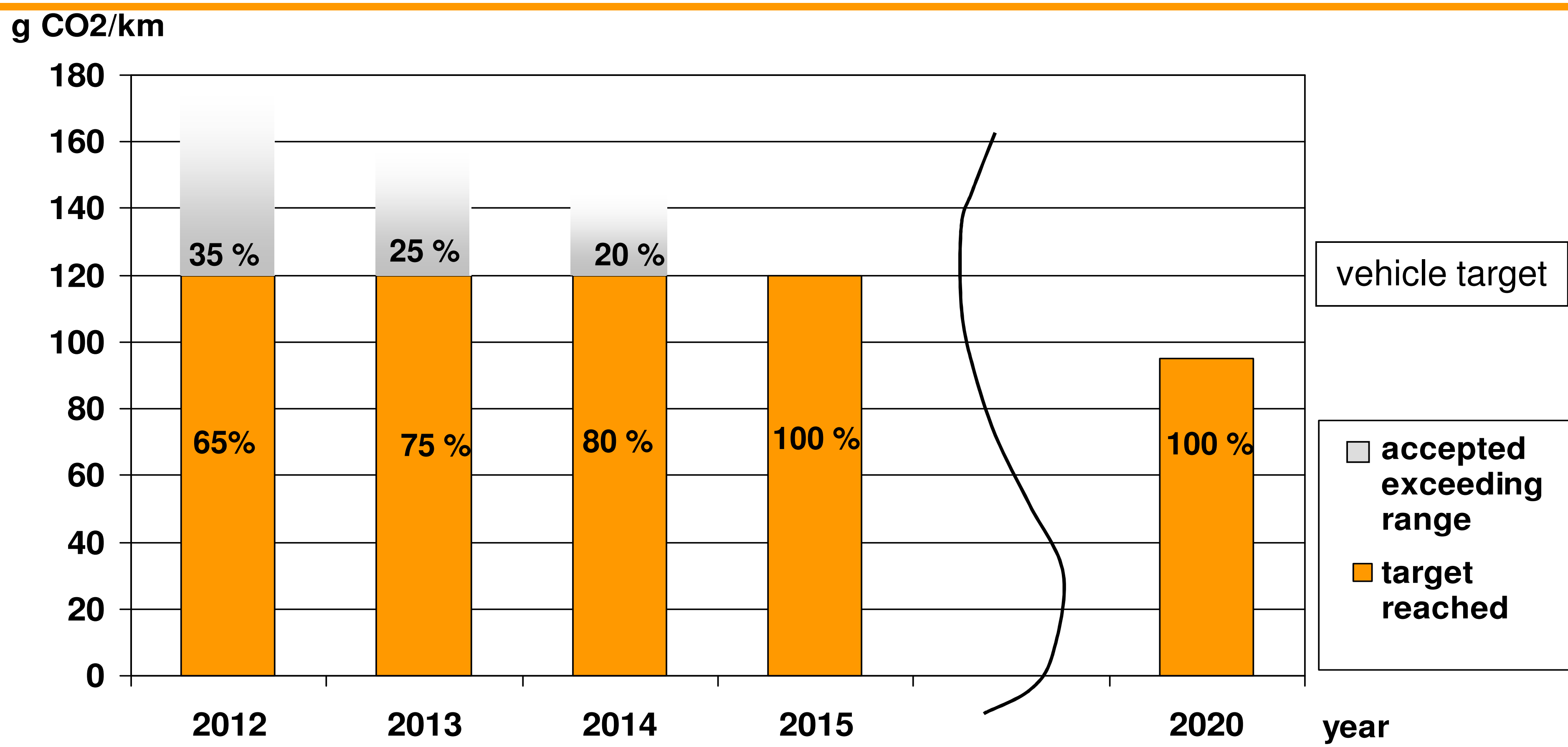
Agenda

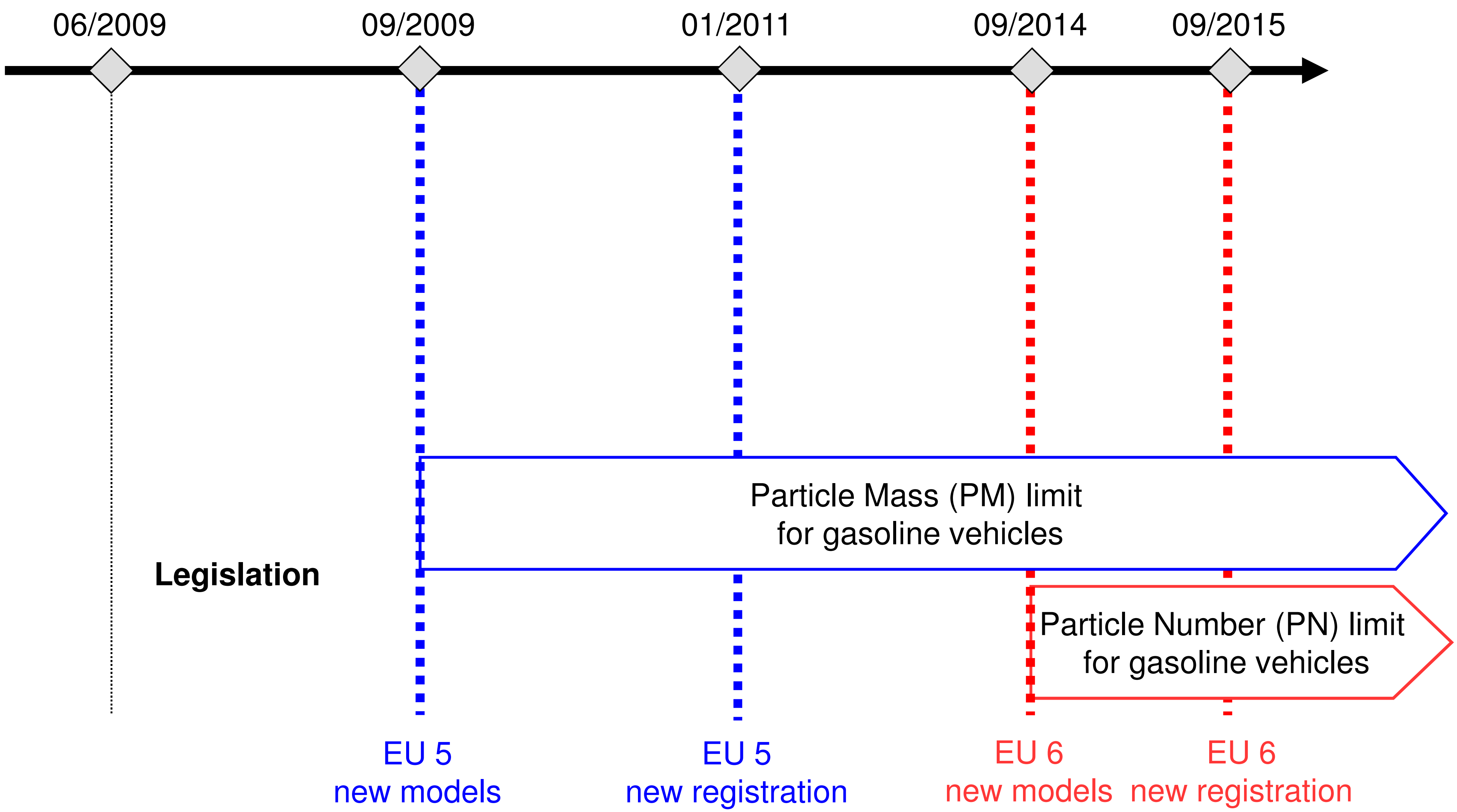
- Motivation: GDI injection system for low emission
- Mathematical model & Simulation approach
- Workflow
- Results
- Summary

CO_2 Emission Targets for New Registrations – Automotive Industry

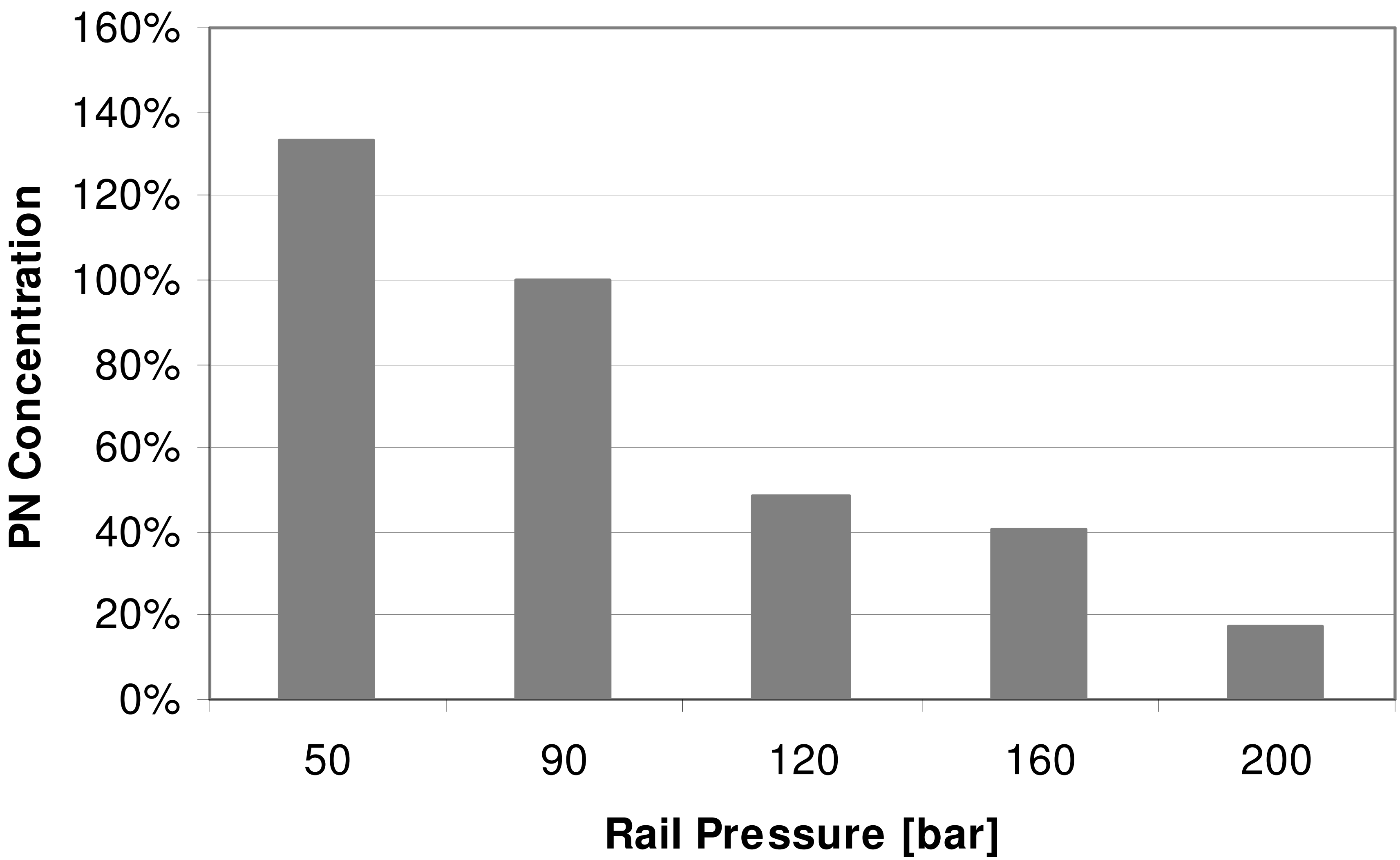


- According to the European policy for CO_2 regarding new car registrations, the CO_2 targets have to be reached step by step on average from 2012 until 2015 as shown in the graph.
- The policy accepts an exceeding range in average of 35 % in 2012, 25 % in 2013 and 20 % in 2014.
- In 2015 first time the target of 120 g CO_2 has to be reached for new car registrations.
- In 2020 the standard will be reduced to 95 g CO_2.

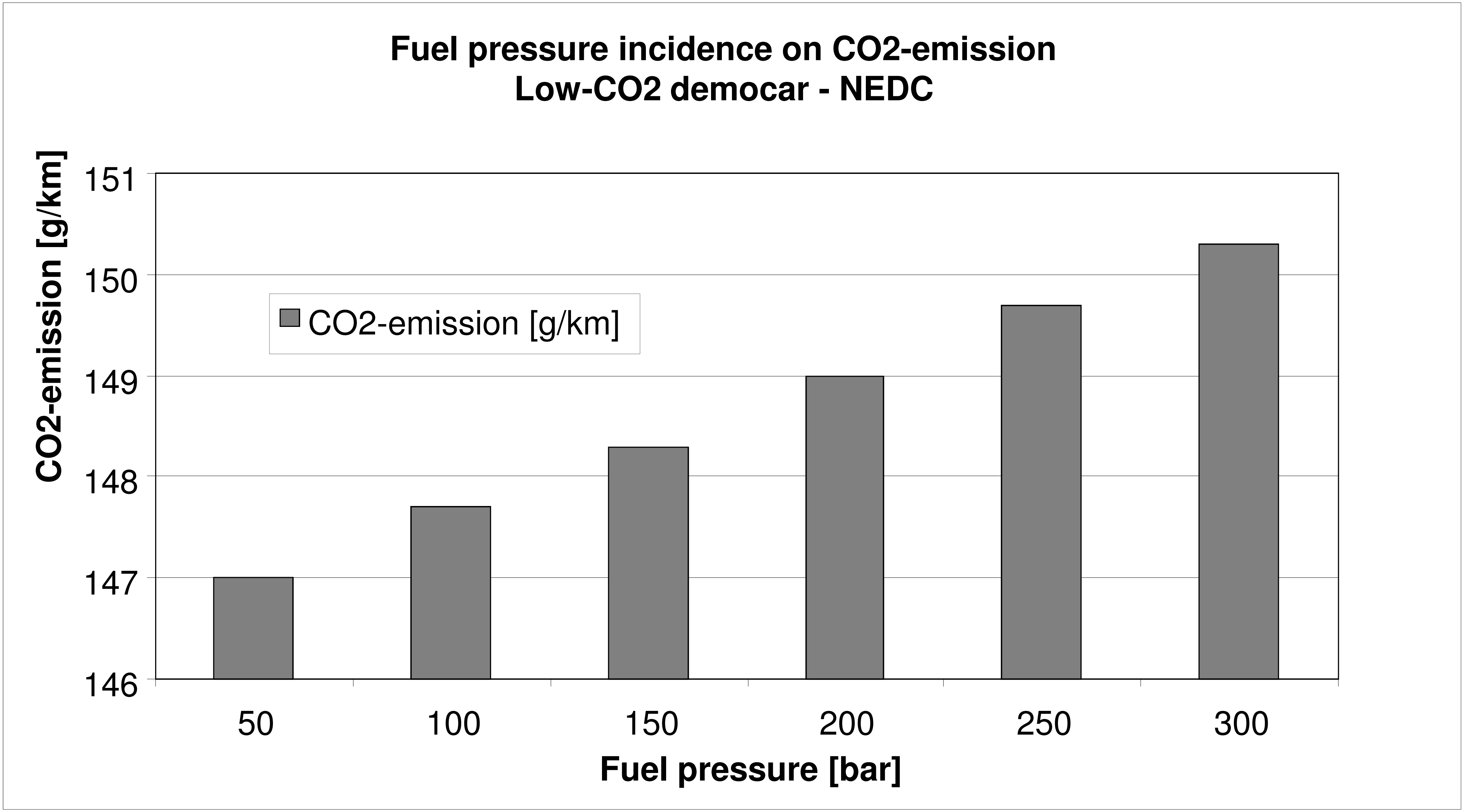
Particle Emission Legislation
EU 5/ EU 6 EU Time Scheduling



Injection pressure effect on soot emission



Injection pressure effect on CO2 emission



Mixture preparation is the key for emission reduction

Mixture formation dependence

- Chamber geometry
- Charge motion
- Injection system
- Spray targeting
- Operating conditions

The key component is injector & nozzle

Precise injection quantity metering

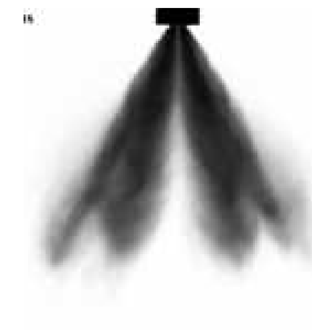
Fast needle dynamic

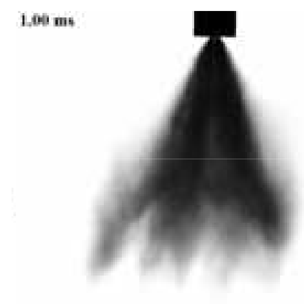
Suitable penetration

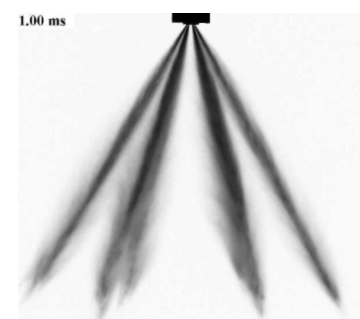
Good atomization

Starting points & Approach

- What are the most significant design parameters?
- How do they affect atomization & spray penetration?
- How much improvement potential does the current design have?
- What design concept can be useful for good atomization?
- How to deliver tailed nozzle for each individual engine?
- Systematic approach: global sensitivity analysis
- Physical understanding: local sensitivity analysis
- Virtual engineering: > 200 virtual nozzle prototypes analyzed
- Cross check: spray characterization, engine experiment vs. CFD

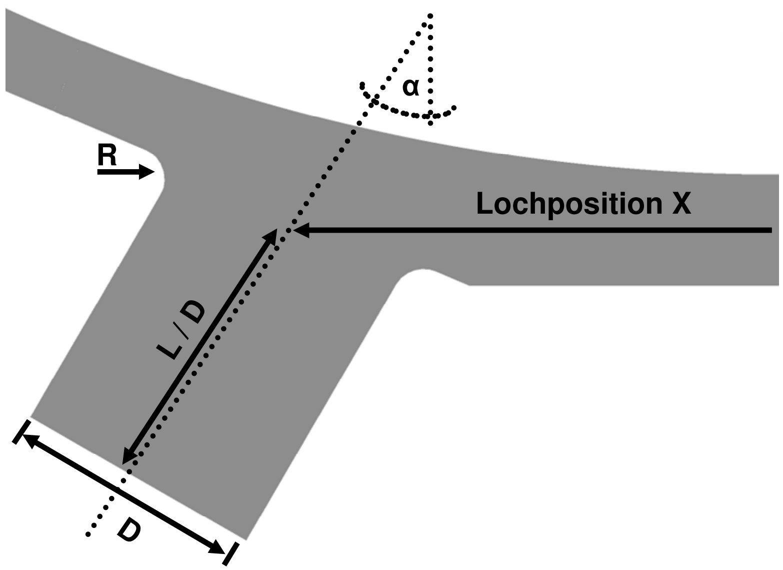


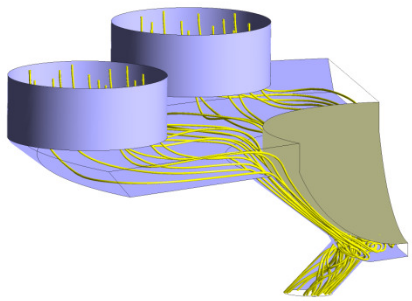




Design parameters investigation

Sensitivity analysis





Design benchmark:

- L/D
- Sac height effect
- Injection hole position
- Injection hole diameter
- Inlet rounding
- Seat-sac variation
- Injection hole shape
- Needle shape

Design parameter	Unit	Range
SPL X-position	[mm]	
SPL Angle α	[°]	
Rounding radius R	[µm]	
Hole diameter D	[mm]	
L over D	[-]	

Evaluation criteria is still a research area

Examples of evaluation quantities:

-Turbulence energy

- Injection velocity

- Vapour volume fraction

- Mass flow rate

- Discharge Coefficient

- Energy efficiency

- Needle force

- … … … …

Spray measurement and engine validation important !

Global sensitivity analysis model

- Global sensitivity analysis allows to change all the input parameters simultaneously.

- Stochastic sampling method: Latin Hypercube sampling for each design parameter over the total design space

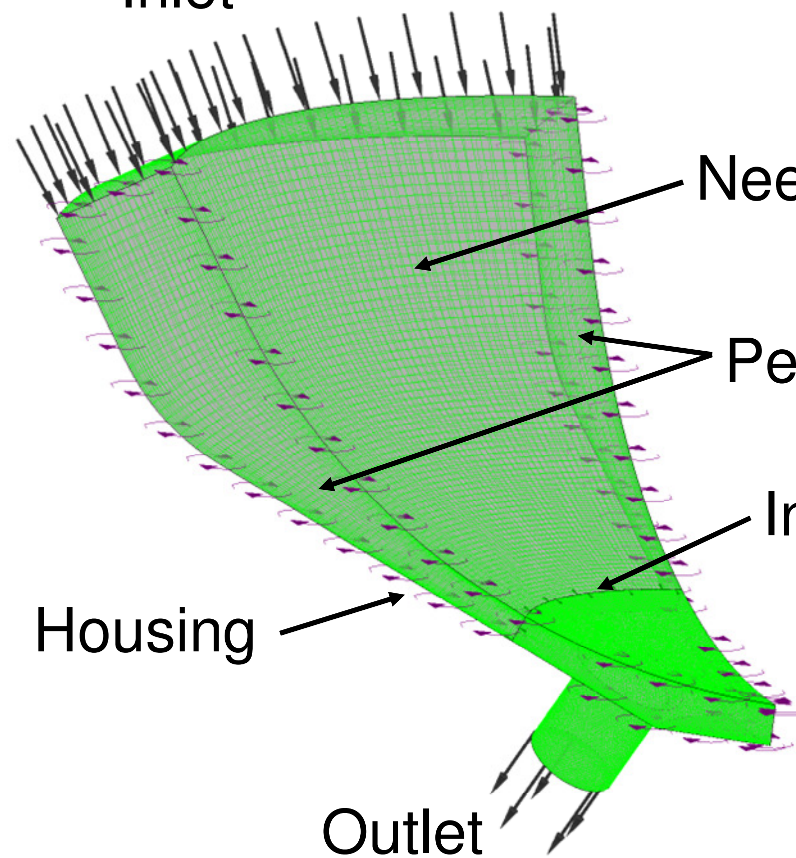
- Sensitivity analysis model: optiSLang Metal Model of Optimal Prognosis (MOP) for correlation analysis.

- Coefficient of Prognosis: $$\mathrm{COP} = \left(\frac{\mathrm{E}[Y_{Test} \cdot \hat{Y}_{Test}]}{\sigma_{Y_{Test}} \sigma_{\hat{Y}_{Test}}} \right)^2; \quad 0 \leq \mathrm{COP} \leq 1.$$

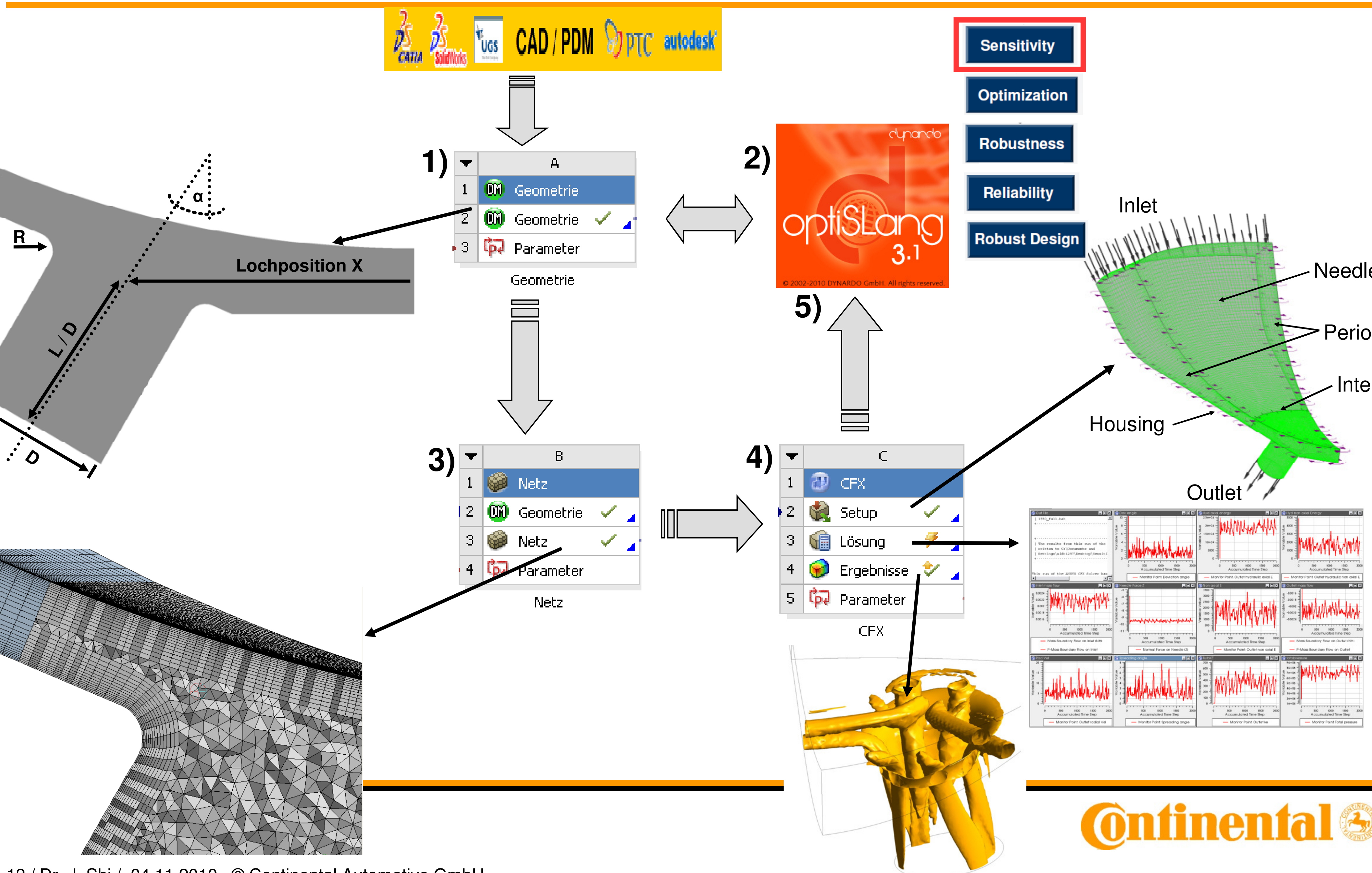
CFD model

- Inlet total pressure 101 bar
- Outlet static pressure 1 bar
- n-heptane:

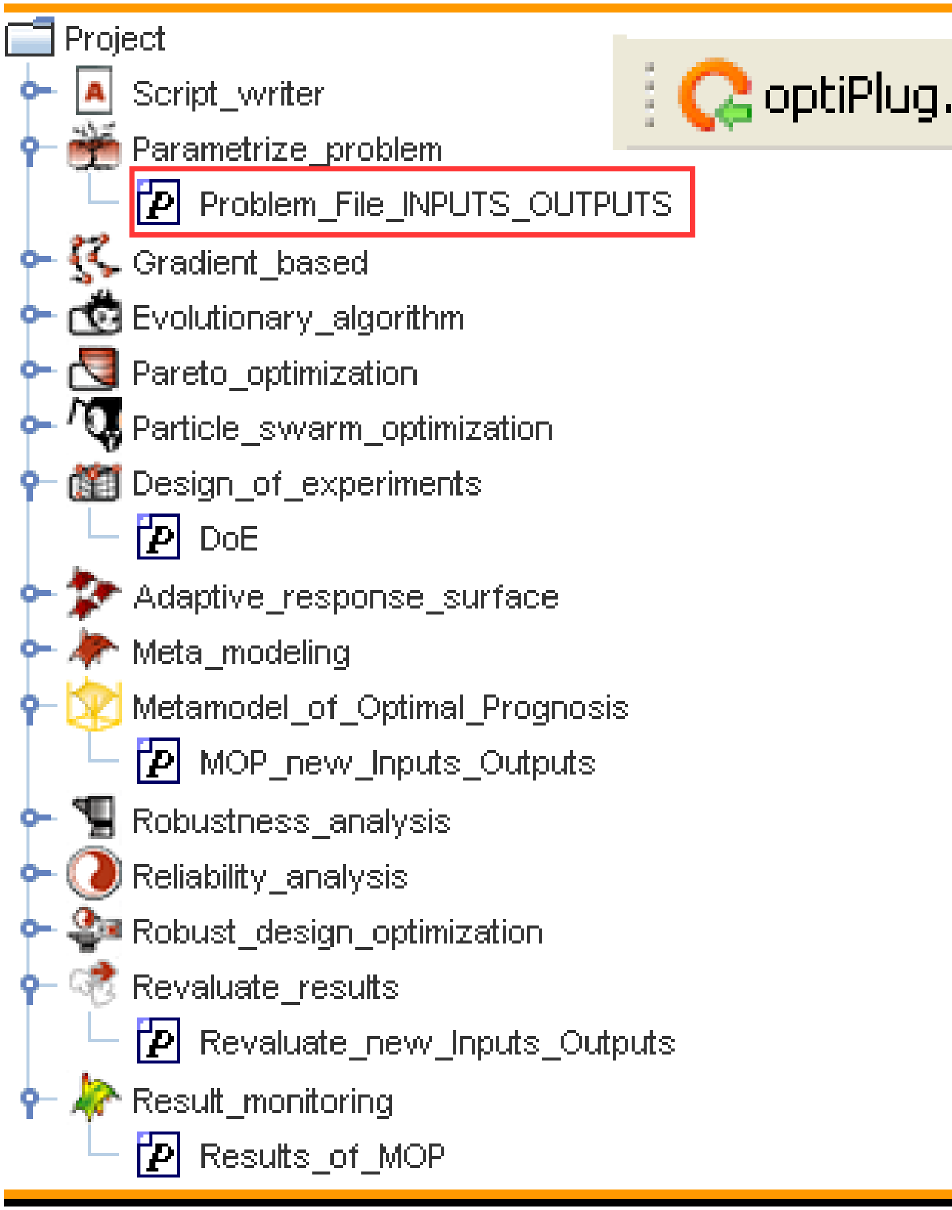
  ρ= 680 [kg/m3], μ = 3.885e-4 [Pa.s]
- Rayleigh-Plesset cavitation model
- k-omega SST turbulence model
- 2nd order spatial discretization
- 2nd time discretization

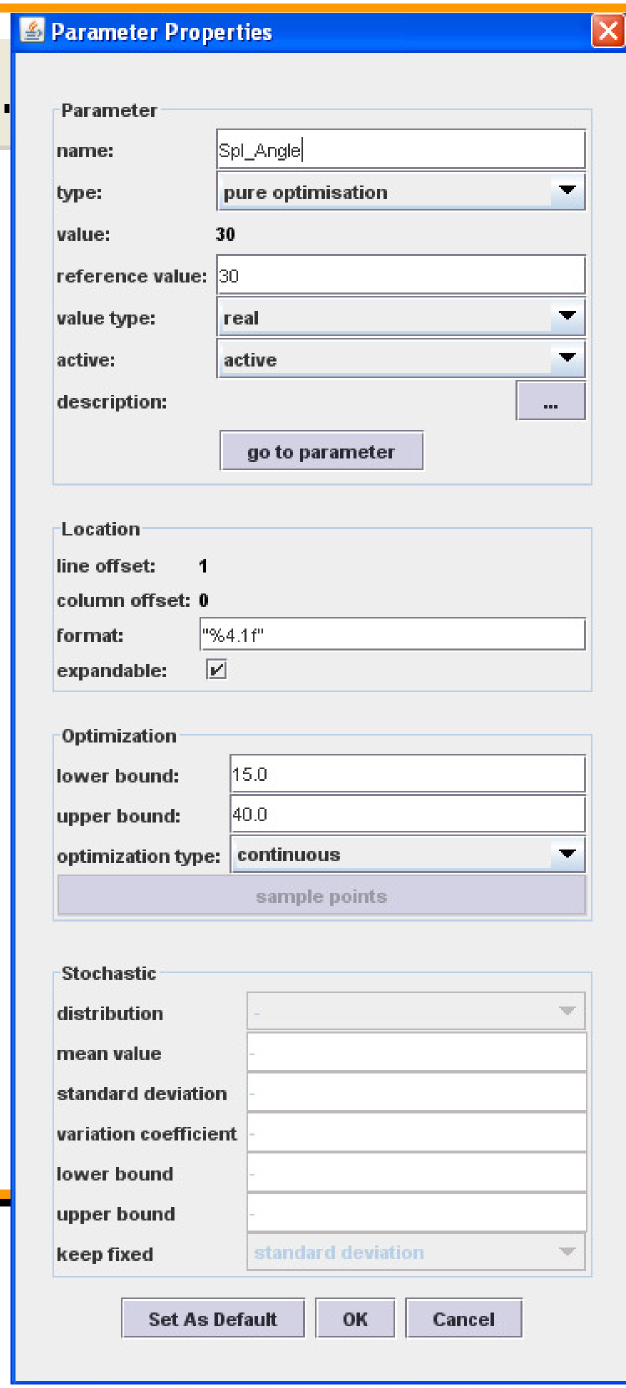


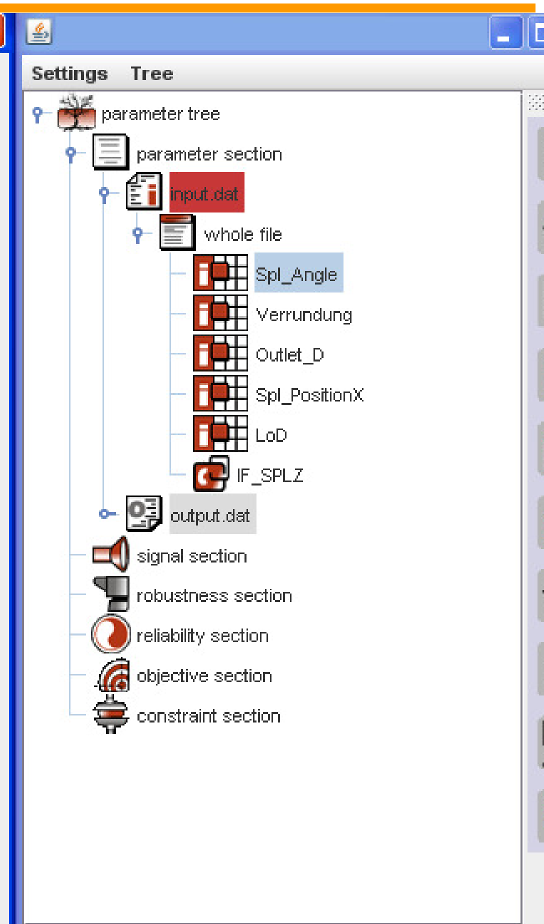
Workflow: CAE tool integration & process automation



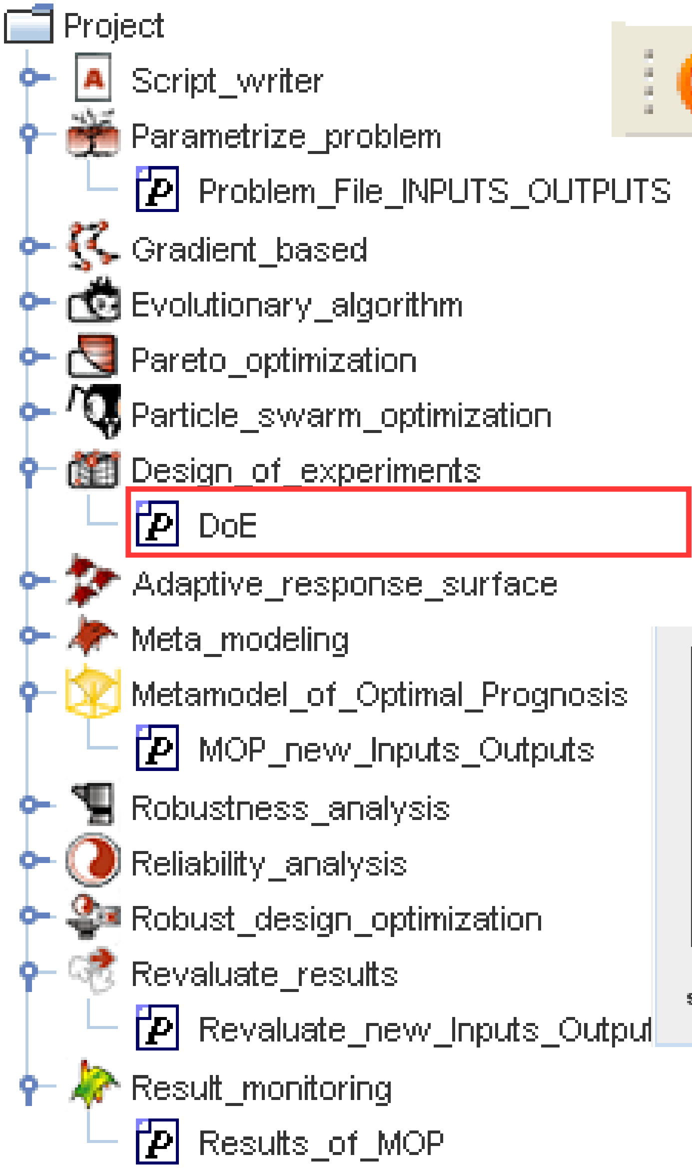
Coupling optiSLang – ANSYS Workbench

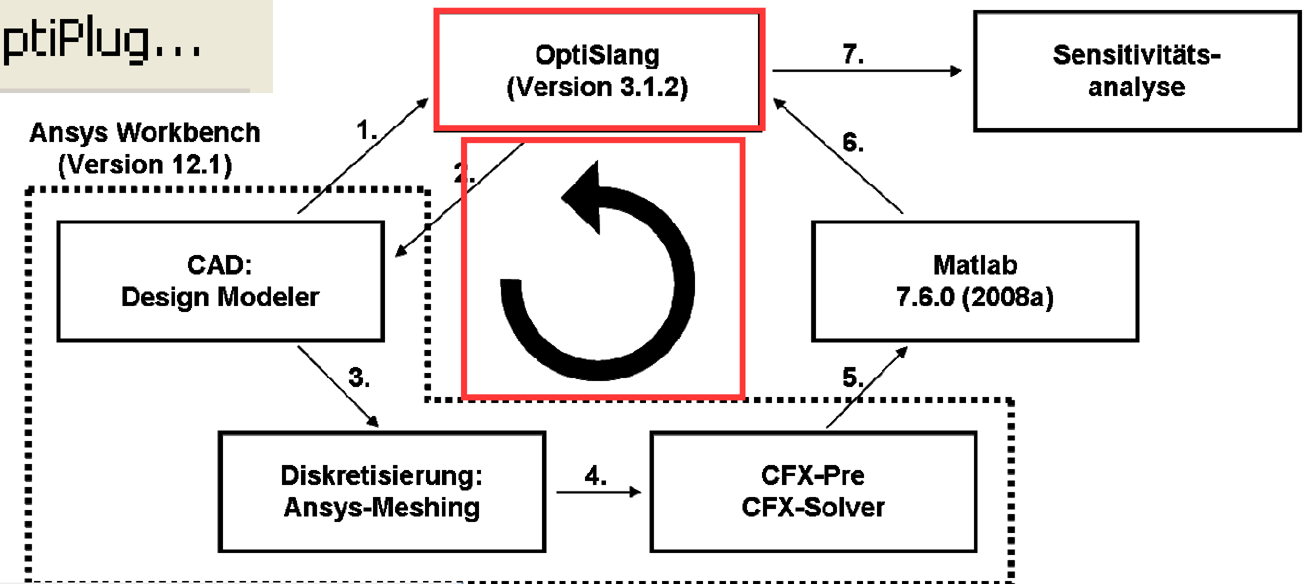


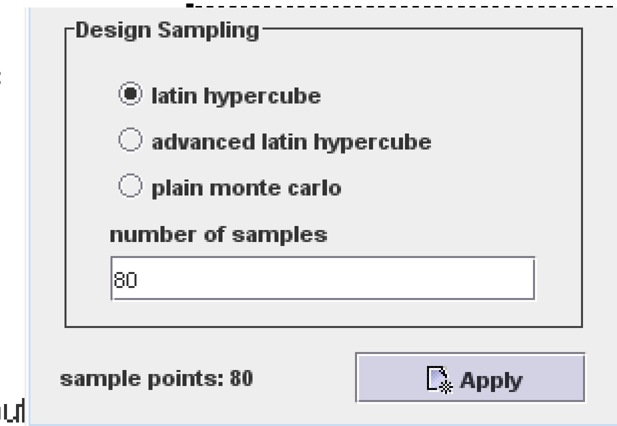




Coupling optiSLang – ANSYS Workbench

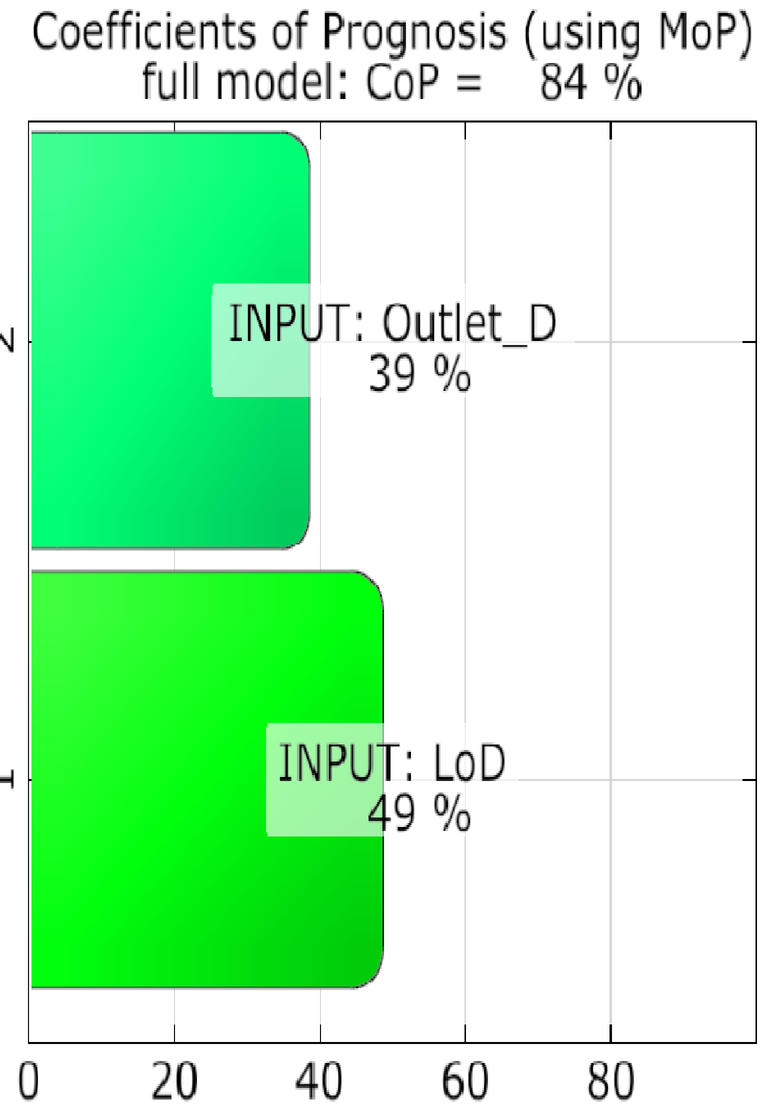


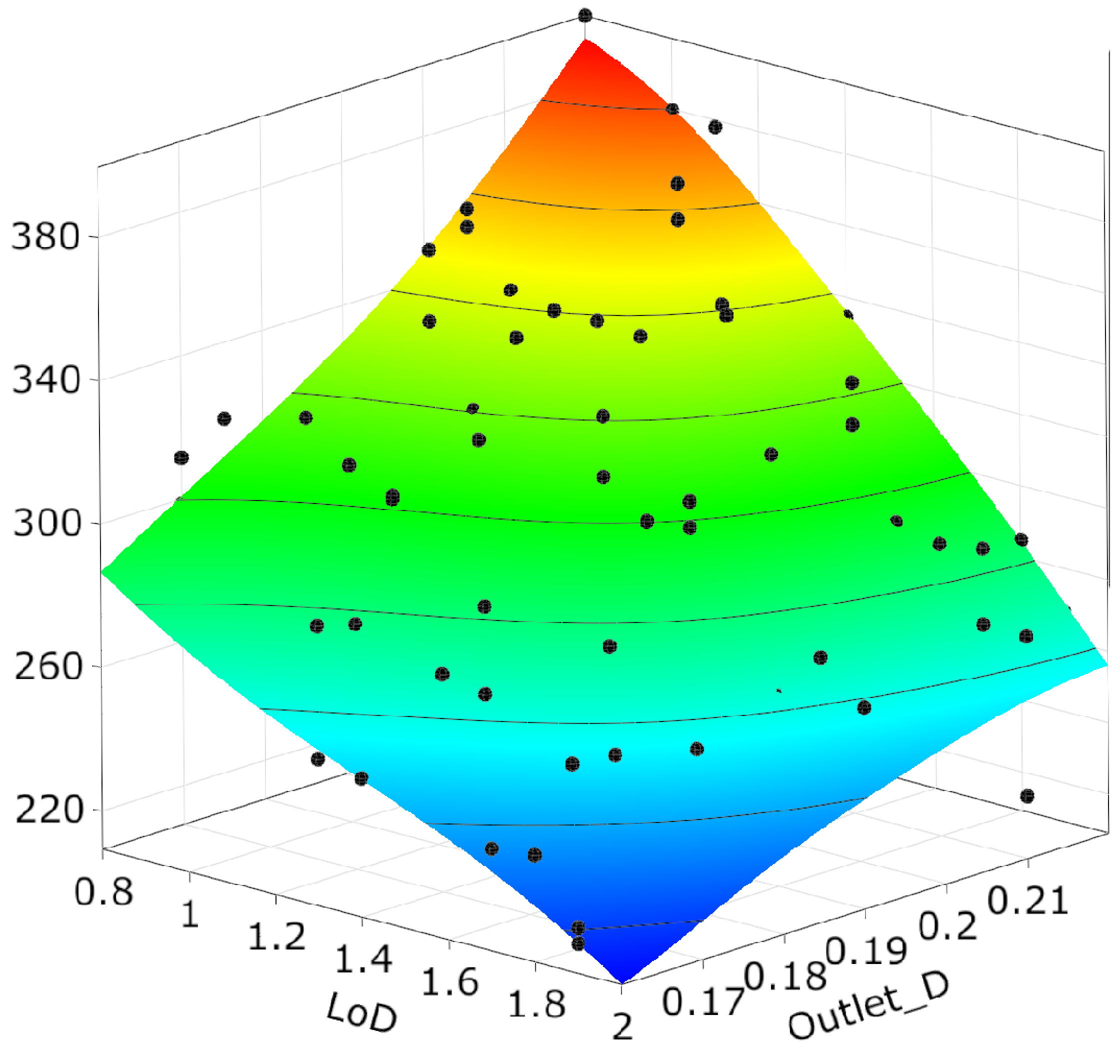




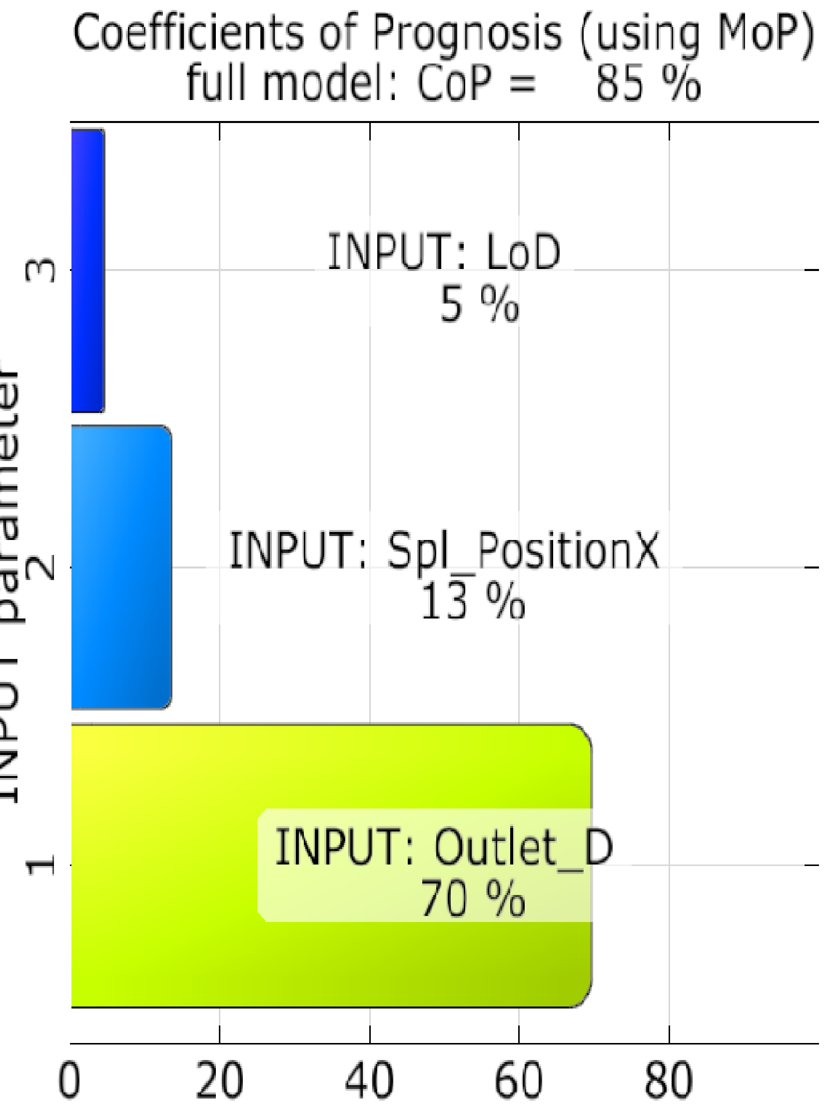
#	SELECT	Source	Design Number	Spl_Angle	Verrundung	Outlet_D	Spl_PositionX	I
1	✔	SAMPLIN...	1	36.09375	0.0240874...	0.209125	0.395687499...	1.317
2	✔	SAMPLIN...	2	38.59375	0.0212375	0.201625	0.3871875	1.272
3	✔	SAMPLIN...	3	32.34375	0.0103125...	0.203875	0.3978125	1.047
4	✔	SAMPLIN...	4	24.84375	0.0145875...	0.164875	0.4148125	0.822
5	✔	SAMPLIN...	5	21.09375	0.0326375	0.165625	0.3616875	1.647
6	✔	SAMPLIN...	6	27.03125	0.0155375	0.212125	0.4466875	1.932
7	✔	SAMPLIN...	7	22.03125	0.0150625...	0.176125	0.4615625	1.662
8	✔	SAMPLIN...	8	28.90625	0.0364375	0.203125	0.4254375	1.347
9	✔	SAMPLIN...	9	31.09375	0.0283625	0.205375	0.368062499...	0.882
10	✔	SAMPLIN...	10	19.53125	0.0354875	0.170875	0.416937499...	1.422
11	✔	SAMPLIN...	11	15.46875...	0.0321625	0.199375	0.4339375	1.527
12	✔	SAMPLIN...	12	17.34375	0.0269375	0.182875	0.444562499...	1.887
13	✔	SAMPLIN...	13	26.40625	0.0378625	0.217374999...	0.4211875	1.677
14	✔	SAMPLIN...	14	23.59375	0.0307375	0.173125	0.4318125	1.467
15	✔	SAMPLIN...	15	37.96875	0.0036625...	0.175375	0.4849375	1.167

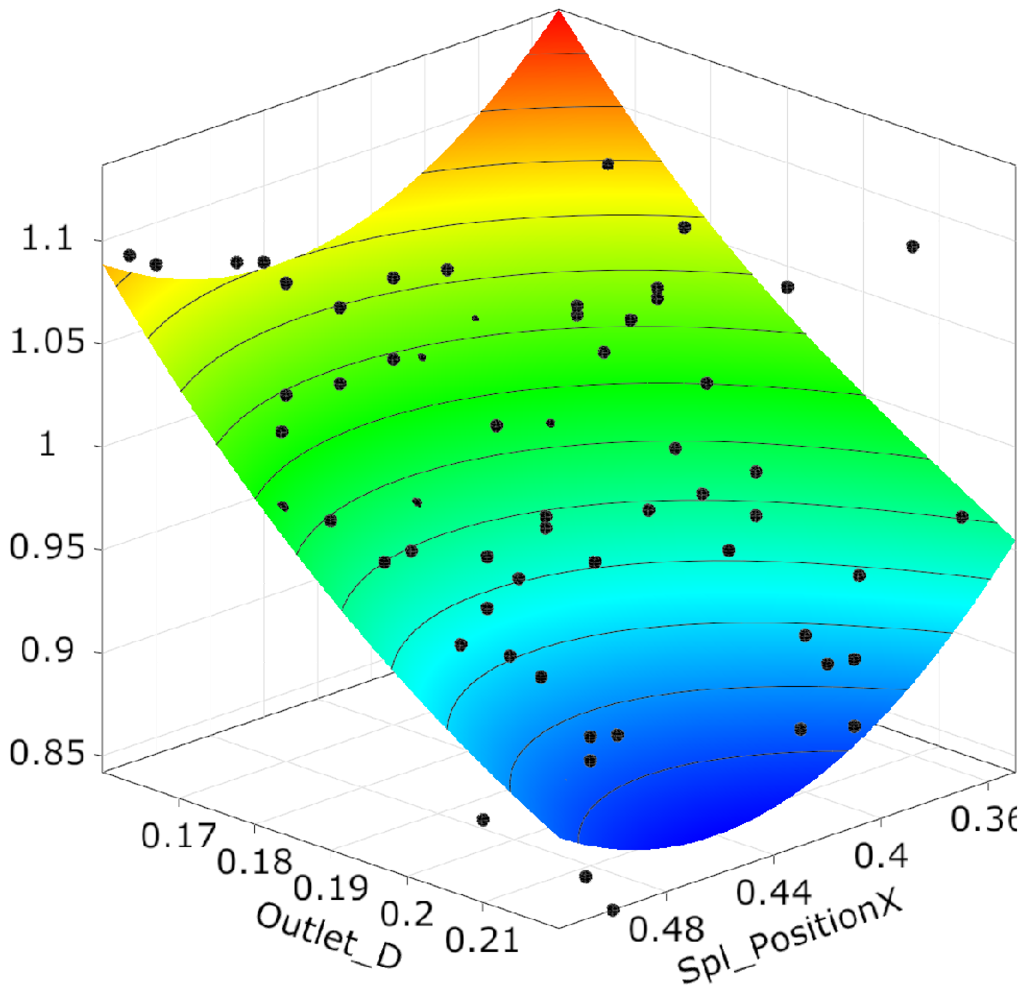
Turbulence kinetic energy @outlet [J/kg]



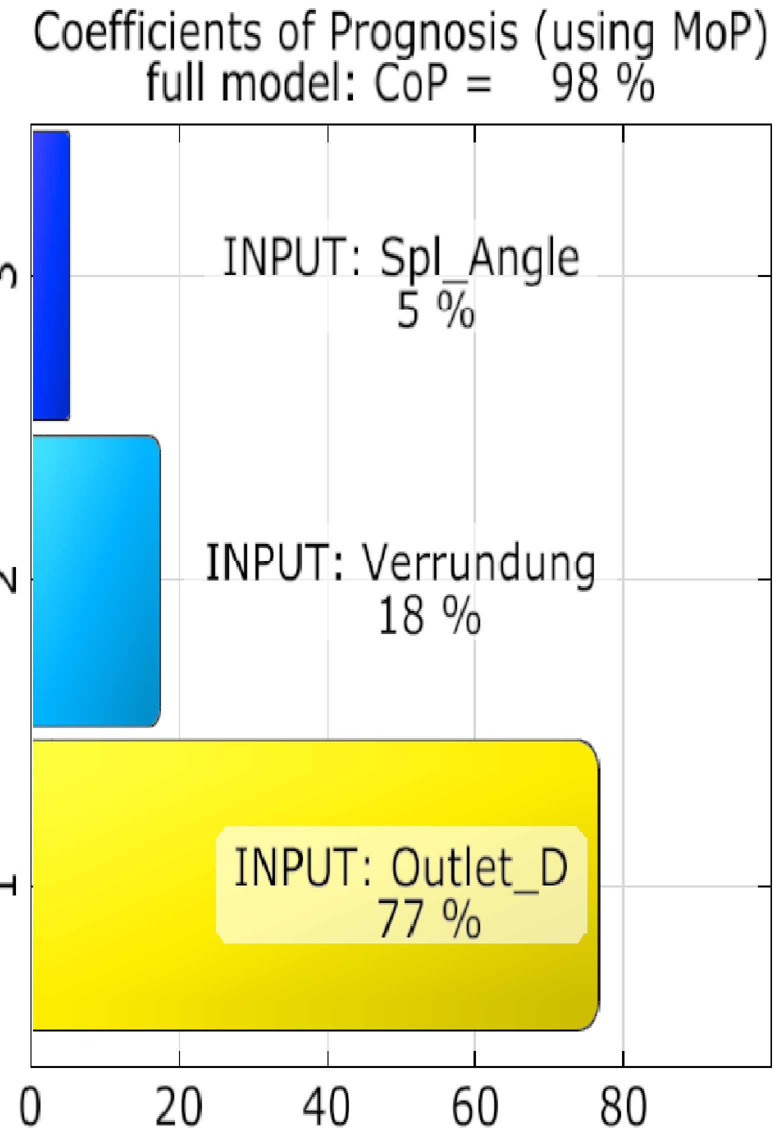


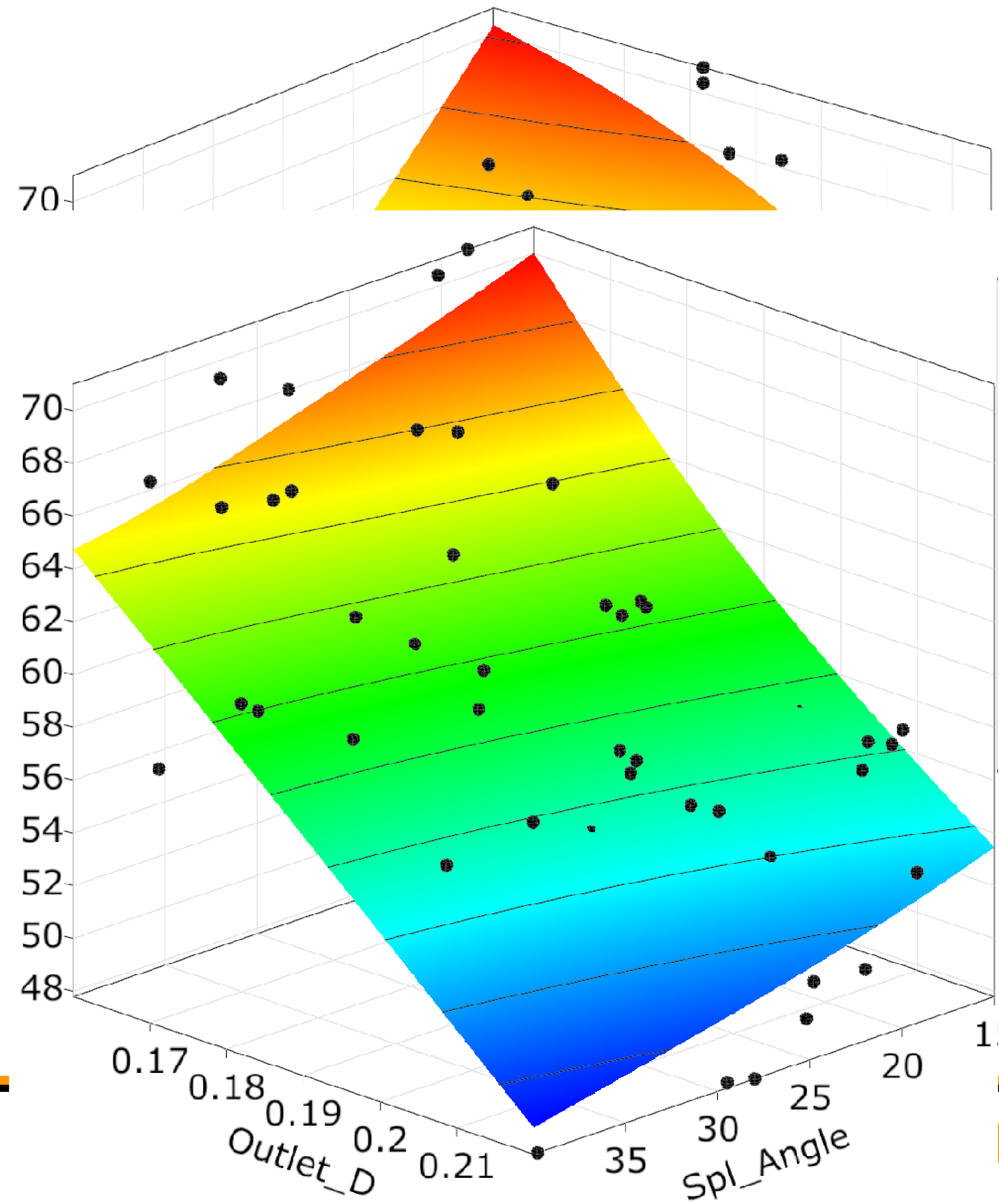
Injection velocity





Discharge Coefficient





Summary

- ANSYS workbench + optiSLang have been applied to design sensitivity analysis.
- Workflow has been successfully proved.
- The global sensitivity analysis has reached the following results:
  - **Identified the most important influencing parameters**
  - **Worked out the improvement potential and direction**
  - **Significant product imporvement confirmed by OEMs & a number of inventions**
- The predicted trends have been confirmed by spray and engine experiment results.
- A predictive methodology (trend) for GDI nozzle design analysis developed
- Understanding of atomization mechanism improved.

