Multi-Objective Optimization Method for Exhaust System Development

ESTECO USERS MEETING INDIA 2023

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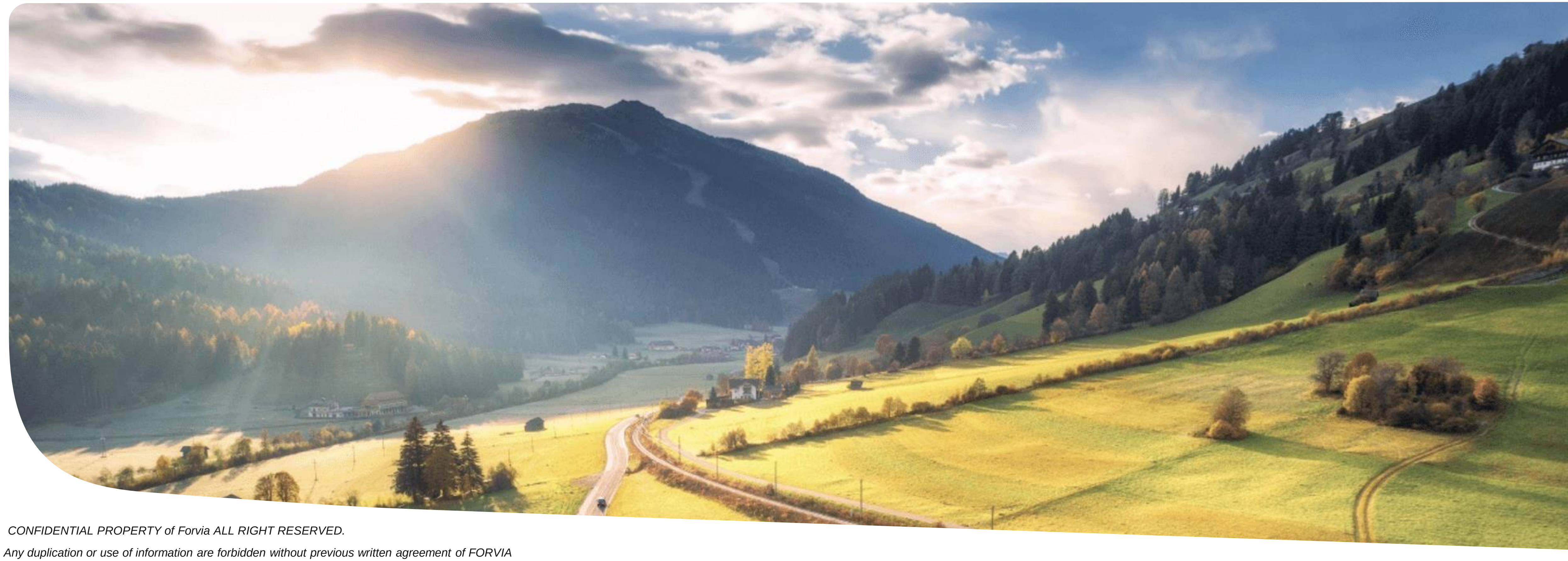
FORVIA

23 August 2023



Agenda

Faurecia transformation
A Leading Automotive Technology Company

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Becoming the 7th global automotive supplier

faurecia
Emissions Control Technologies

2018

faurecia
CLEAN MOBILITY

2022

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HELLA

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6 business groups

Portfolio aligned with automotive “megatrends”

Seating

- Complete Seats
- Mechanisms & Frames
- Safety & Comfort Solutions

45,000+ employees
77 sites
13 R&D centers

Interiors

- Instrument Panels
- Door Panels
- Center Consoles
- Sustainable Materials
- Interior Modules

38,000+ employees
89 sites
31 R&D centers

Clean Mobility

- Ultra-low emissions solutions for passenger & commercial vehicles
- Zero-emission hydrogen solutions

20,000 employees
84 sites
18 R&D centers

Electronics

- Sensors & Actuators
- Automated Driving
- Lighting/Body Electronics
- Energy Management
- Cockpit Electronics
- HMI/Displays

6,000+/13000+ employees
11/18 sites
19/19 R&D centers

Lighting

- Headlamps
- Rear Lamps
- Interior Lighting
- Car Body Lighting

22,000+ employees
22 sites
12 R&D centers

Lifecycle Solutions

- Independent Aftermarket**
- Workshop Solutions
- Special Original Equipment

4,000+ employees
6 sites
8 R&D centers

** Including Clarion Electronics Commercial Solutions

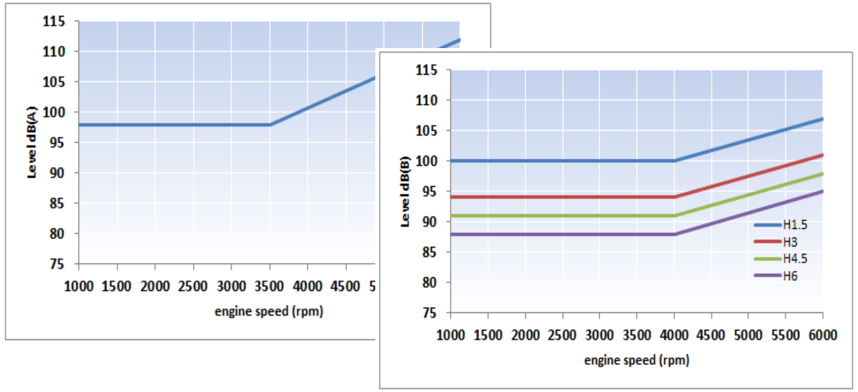
Activities Faurecia — Activities HELLA — Activities Faurecia & HELLA

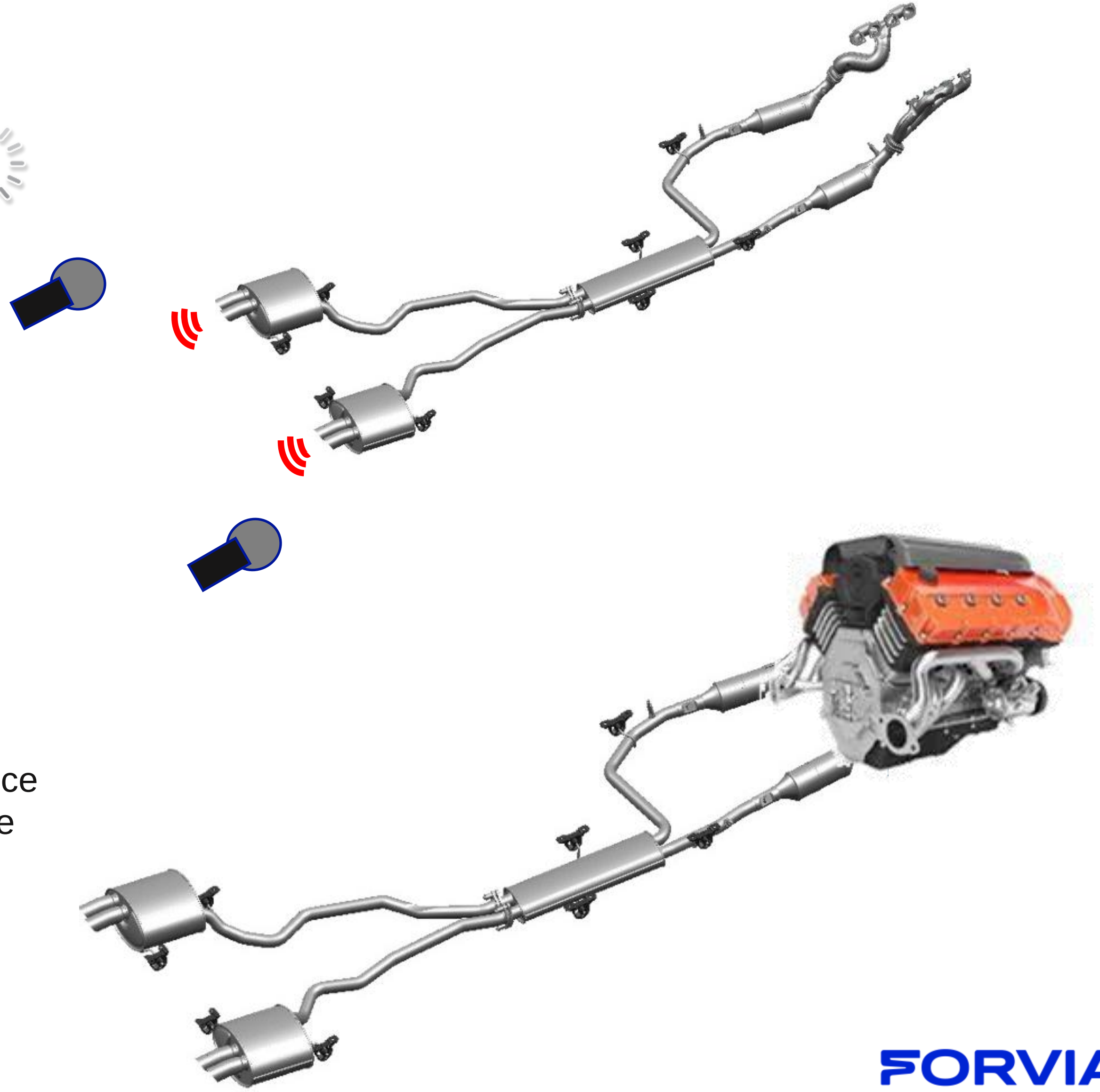
Optimization Approach for Exhaust System Development

Exhaust System in a nutshell

Tailpipe Noise

Run-up/Run down, full or partial load
Target: Overall + Order





Backpressure

Low backpressure → High Noise level → Good Engine performance
High backpressure → Low Noise level → Bad Engine performance

Hence a Cold End system is designed to bring a trade-off
Backpressure under control → Reduced Noise Level

Tailpipe Noise $\propto$ 1 / Backpressure

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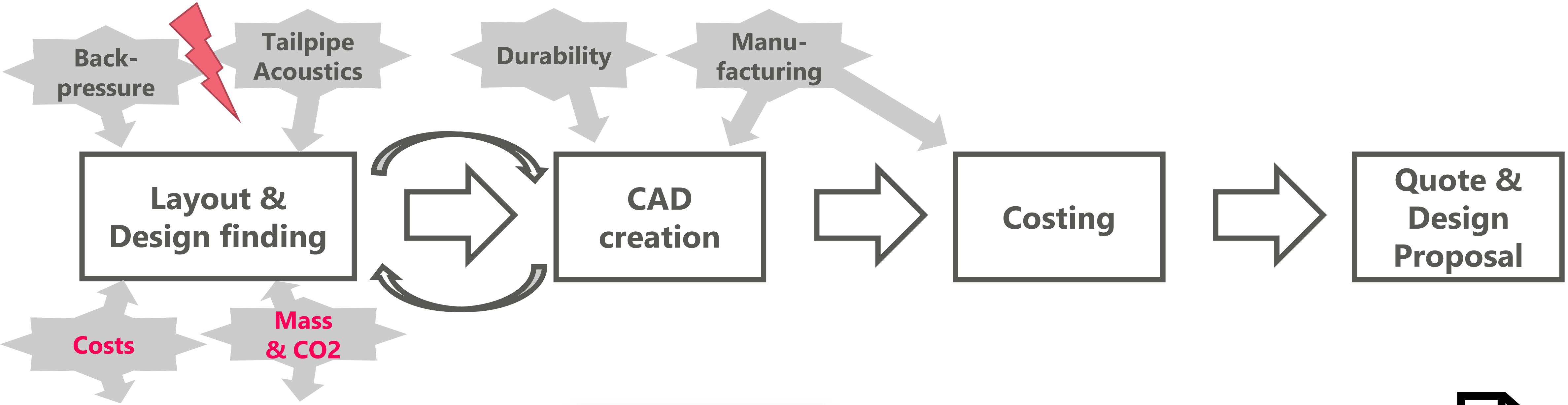
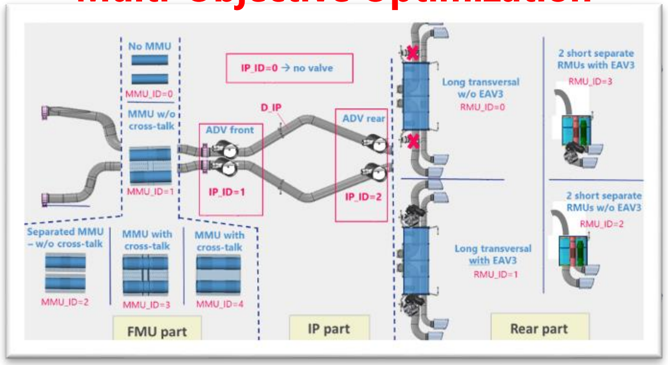
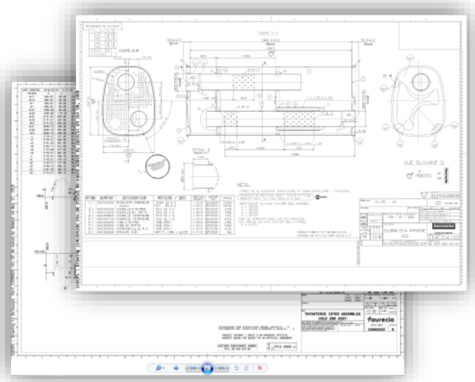
Optimization Approach for Exhaust System Development

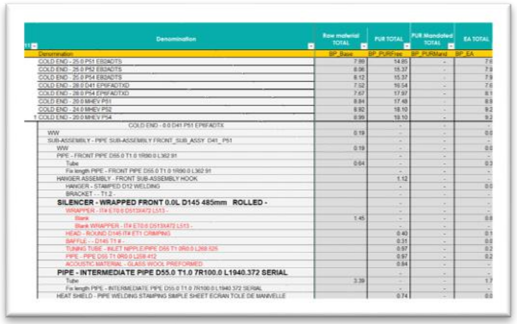
Exhaust System Development Work Flow



Multi-Objective Optimization







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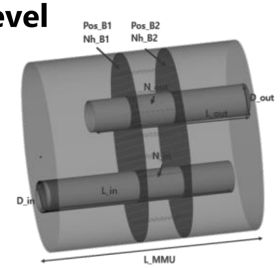
Optimization Approach for Exhaust System Development

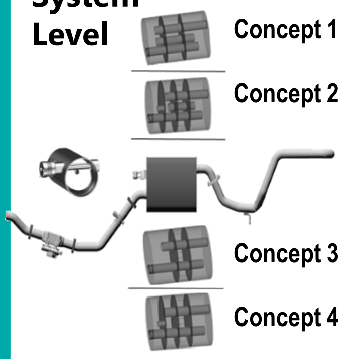
Workflow of Exhaust System Optimization

Design Space at

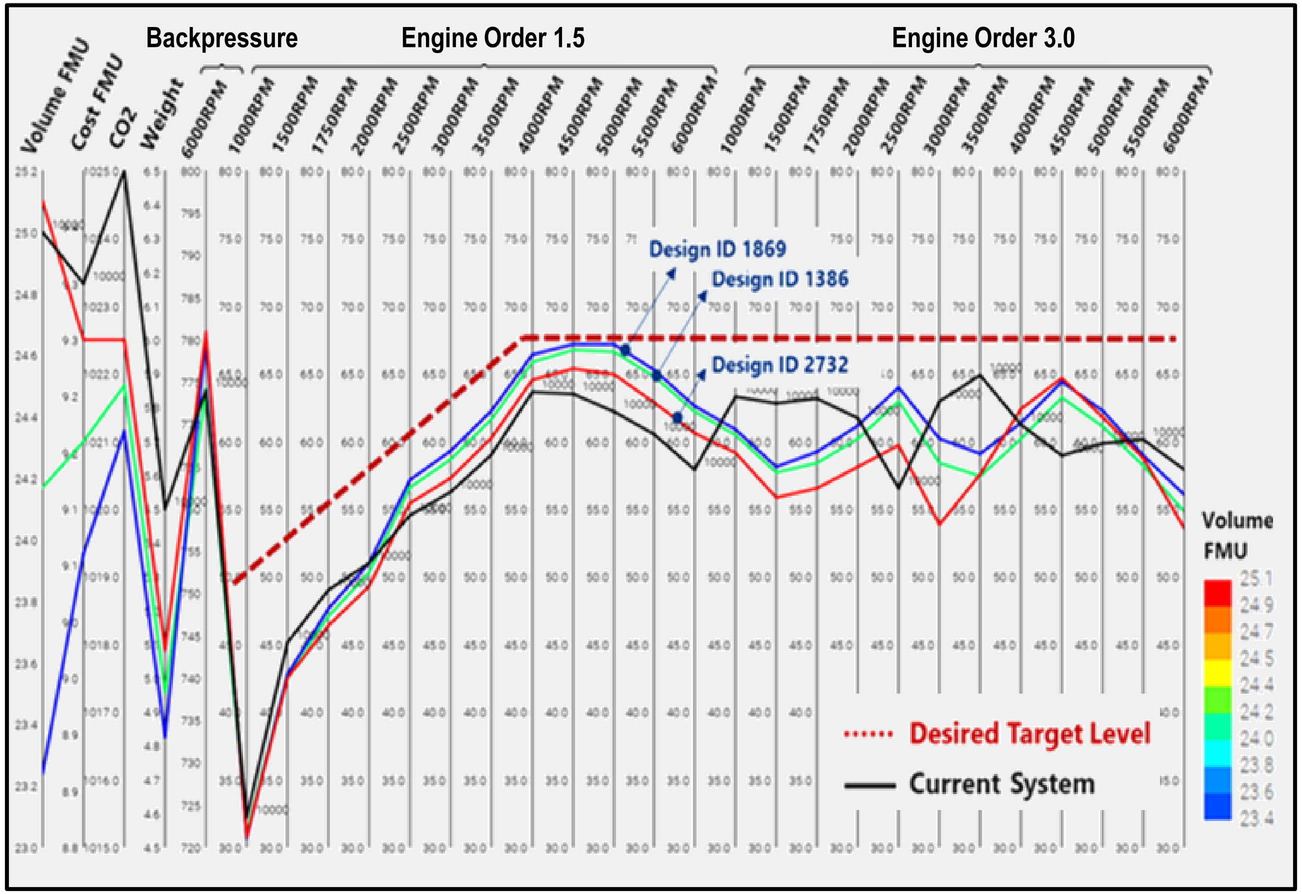
Component Level



System Level

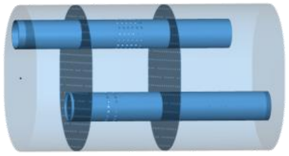


Design Filtration

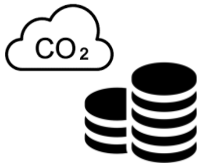


Optimization Approach for Exhaust System Development

Costing and CO2 module



	A	B	C	D	E	F
1	Part Type	Sub Categ	Part Numl	Comment	Yearly Vol	Net Weigl
2	Half Shell:	Simple Mu	2454252X	HALF SHEL	>200000	2.25
3	Half Shell:	Simple Mu	2454255X	HALF SHEL	200000	2.26
4	Tubes	Hydroform	2454254X	TUNING TU	>200000	1.056
5	Tubes	Fixed Len	2501550X	PIPE - D8	>200000	1.293
6	Baffles	Circular Ba	testX	baffle	>200000	1
7	Baffles	Non-Circu	2454253X	BAFFLE - E	>200000	0.455
8	Pipe		FP			
9	Sheet		FMU_Shell			
10	RFPpatch		RFP_Patch1			
11	EAV4		EAV4			
12	RFPpatch		RFP_Patch2			



Acoustic Model

↓

Bill of Material

↓

Bill of Material Cost and CO2 estimate

Component Mass and Dimensions →

← *Component Cost and CO2*

Internal Costing and CO2 emission factor Databases

	A	B	C	D	E	F	G	H
1	Replication						add Row	dele
2								
3	Process VA + Material base + Scrap base	Year	From	To	Average volume	PN ------ Comment	No	Process
4		2017	From	To	volume_av	PN	no	steps
5	3.35	2020	Pisek		100 000			
6	0.02	2020	Pisek		100 000	Process Dummy	_01	DUMMY
7	3.34	2020	Pisek		100 000	SheetDummy	_02	MAT
8		2020	Pisek		100 000		_03	

Segment	Mat	CO2 emission [kg CO2 / kg material produced]	Comment
Ferritic Steel	1.4512	1.80	Ferritics with 12%Cr
Ferritic Steel	1.4510	2.57	Ferritics with 18%Cr
Ferritic Steel	1.4509	2.57	Ferritics with 18%Cr
Austenitic Steel	1.4301	5.26	Austenitics w/o Moly
Austenitic Steel	1.4541	5.26	Austenitics w/o Moly
Austenitic Steel	1.4828	5.26	Austenitics w/o Moly
Insulation	Silica	2.00	Estimation, no real values found
Insulation	E-Glass	1.78	Average value based on literature: • LCA GlassFibreEurope Oct 2016: 1.29 • GABI database GlassFibre Europe, Aug 2016: 1.64 • GABI database Sphera Solutions, Aug 2016: 1.68 • SimaPRO, Feb 2021: 2.14 • FACT, Feb 2021: 2.13
Insulation	ECR-Glass		
Insulation	S-Glass		

Optimization Approach for Exhaust System Development

Case Study

System Details:

- Total Tuning Volume = 49.6L
- Total Weight = 19.5kg

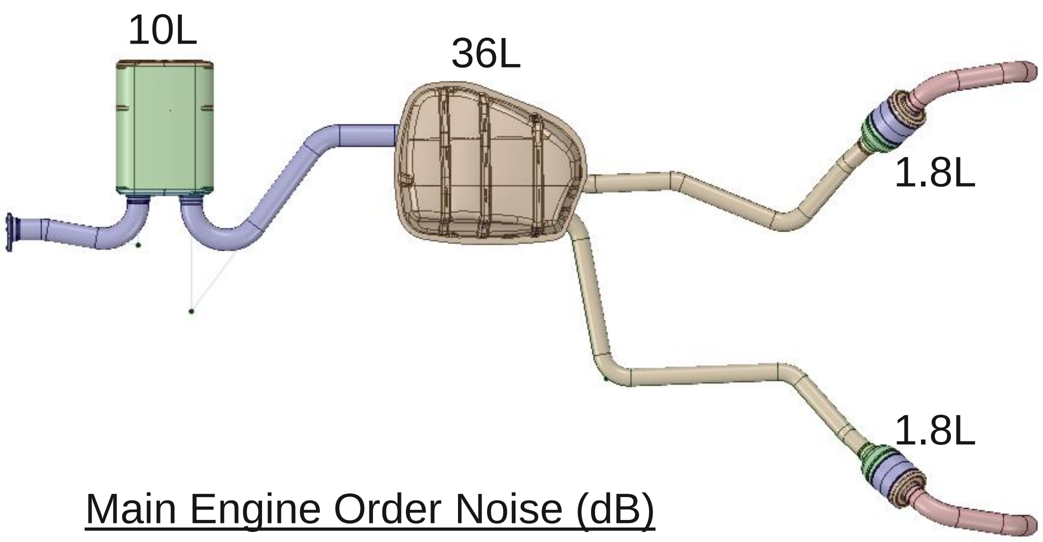
Objective:

Optimize weight of the system by retaining similar Acoustic and Backpressure performance

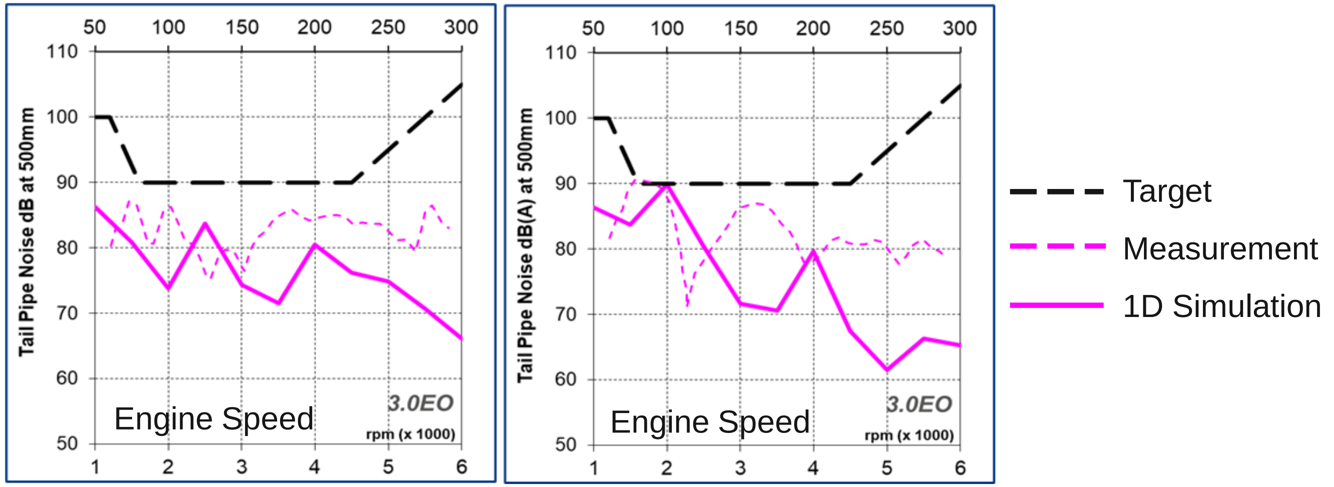
Performance evaluation based on:

- Virtual analysis only

  (1D simulation using GT-Power)
- Tailpipe Noise and Backpressure estimation



Main Engine Order Noise (dB)



Backpressure : 5.9kPa at rated RPM

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Optimization Approach for Exhaust System Development

Methodology

Loop 1:

Start → Mid and Rear Muffler concepts + IP & TP Diameter → BP Simulation → WOT Simulation → End

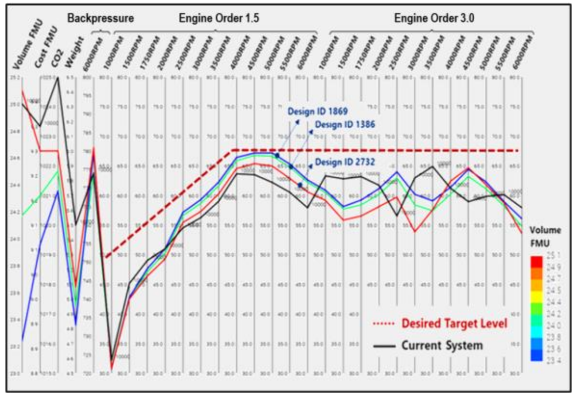
Post processing Bubble charts, Parallel coordinates, Sensitivity analysis, Correlation Matrix

Loop 2:

Start → Mid and Rear Muffler concepts + IP & TP Diameter → BP Simulation → WOT Simulation → Costing Module → End

Elimination of non correlated variables, Re-parameterization

Use best designs from Loop1 Optimization as starting concepts in DOE Table



Filter designs based on System mass reduction, NVH performance and BOM cost, CO2 indicators

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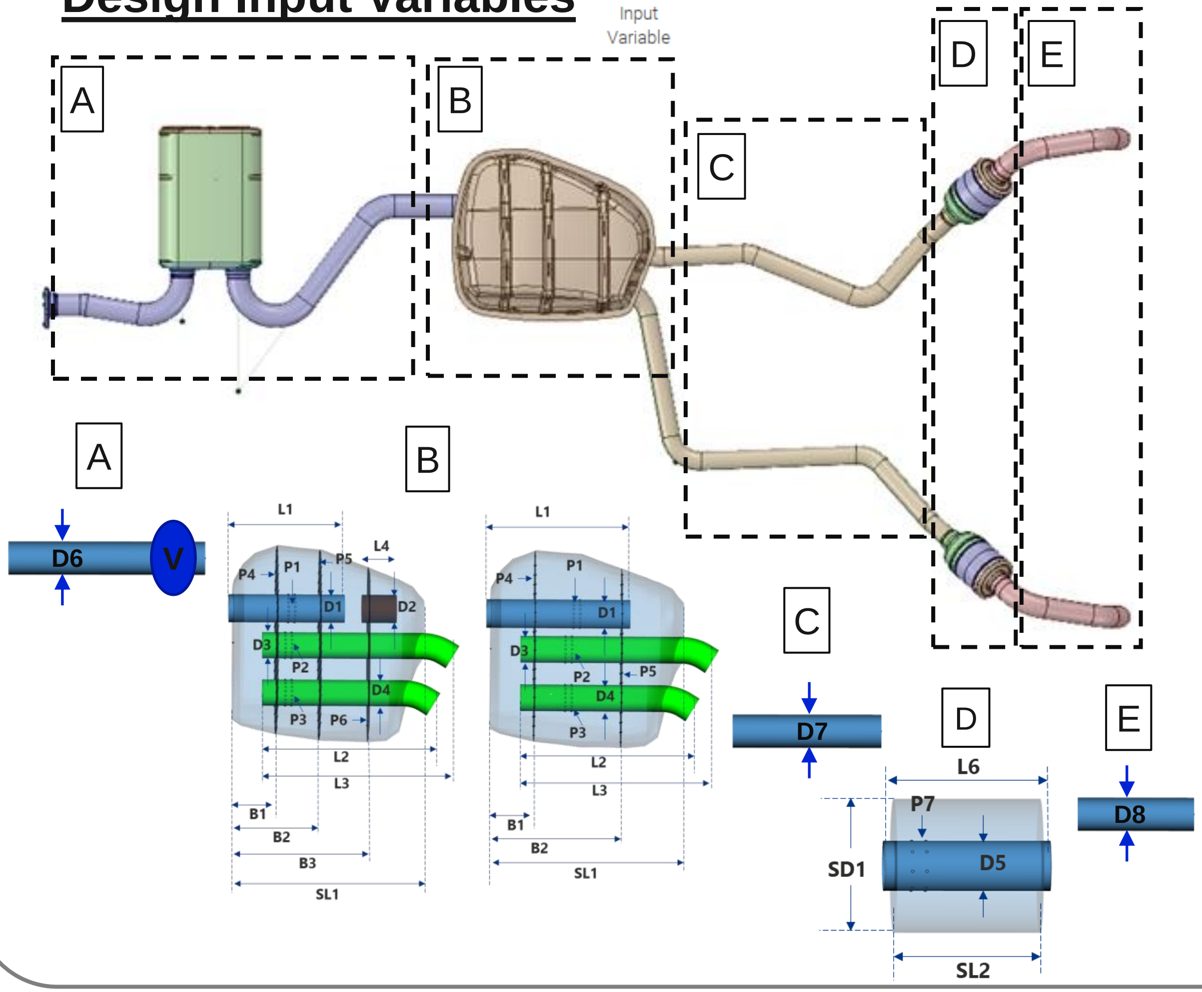
Optimization Approach for Exhaust System Development

Optimization Process

Design Input Variables

Input Variable



L = Pipe Length

D = Pipe Diameter

P = Pipe & Baffle Perforation

B = Baffle Distance

SL = Shell Length

SD = Shell Diameter

Design Output Variables

Output Variable

- Acoustics: Engine order 1.5 and 3.0
- Backpressure
- Silencer Volume
- BOM Cost
- Weight
- CO2 cost

Constraints

Constraint

- Acoustics: Engine order 1.5 and 3.0
- Backpressure

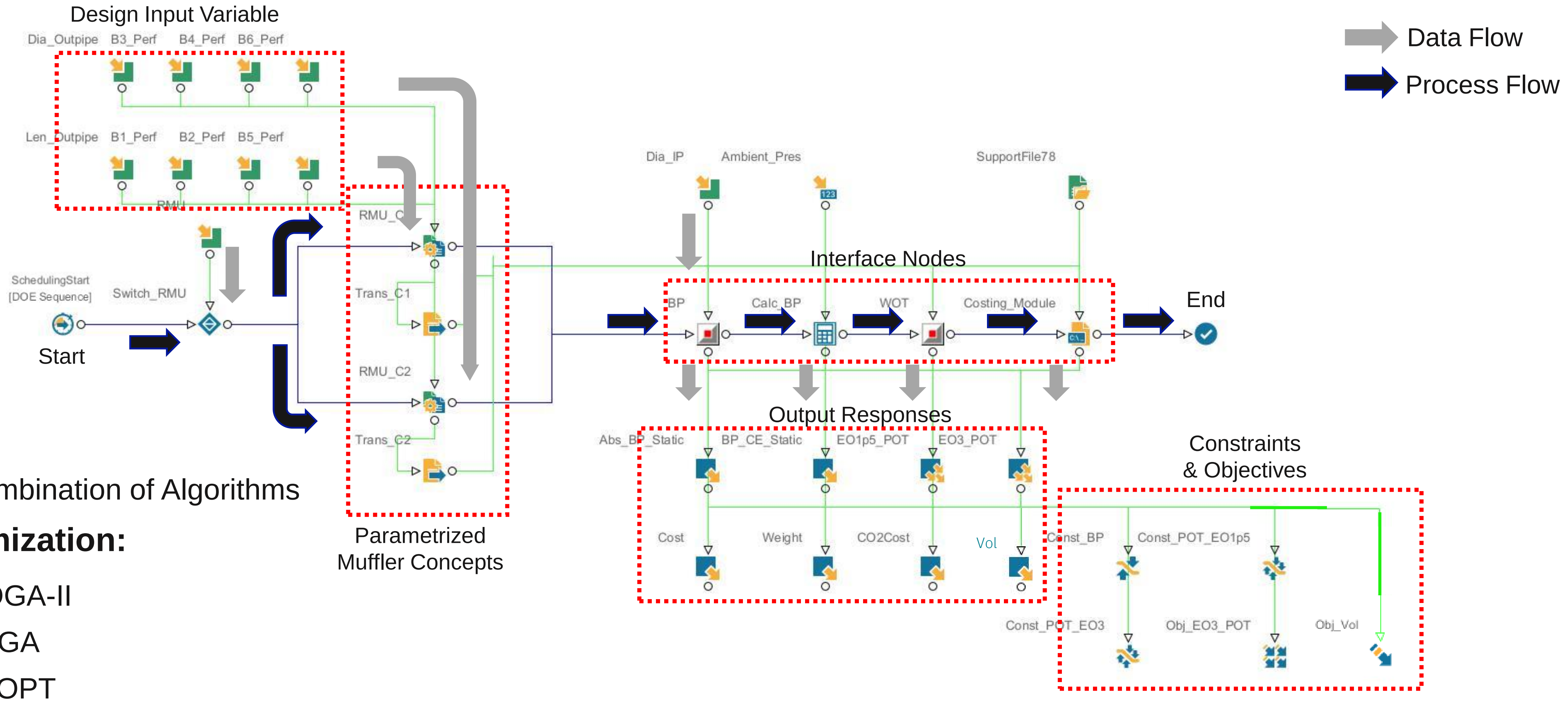
Objectives

Objective

- Acoustics: Engine order 3.0
- Silencer Volume

Optimization Approach for Exhaust System Development

Optimization Process



DOE:

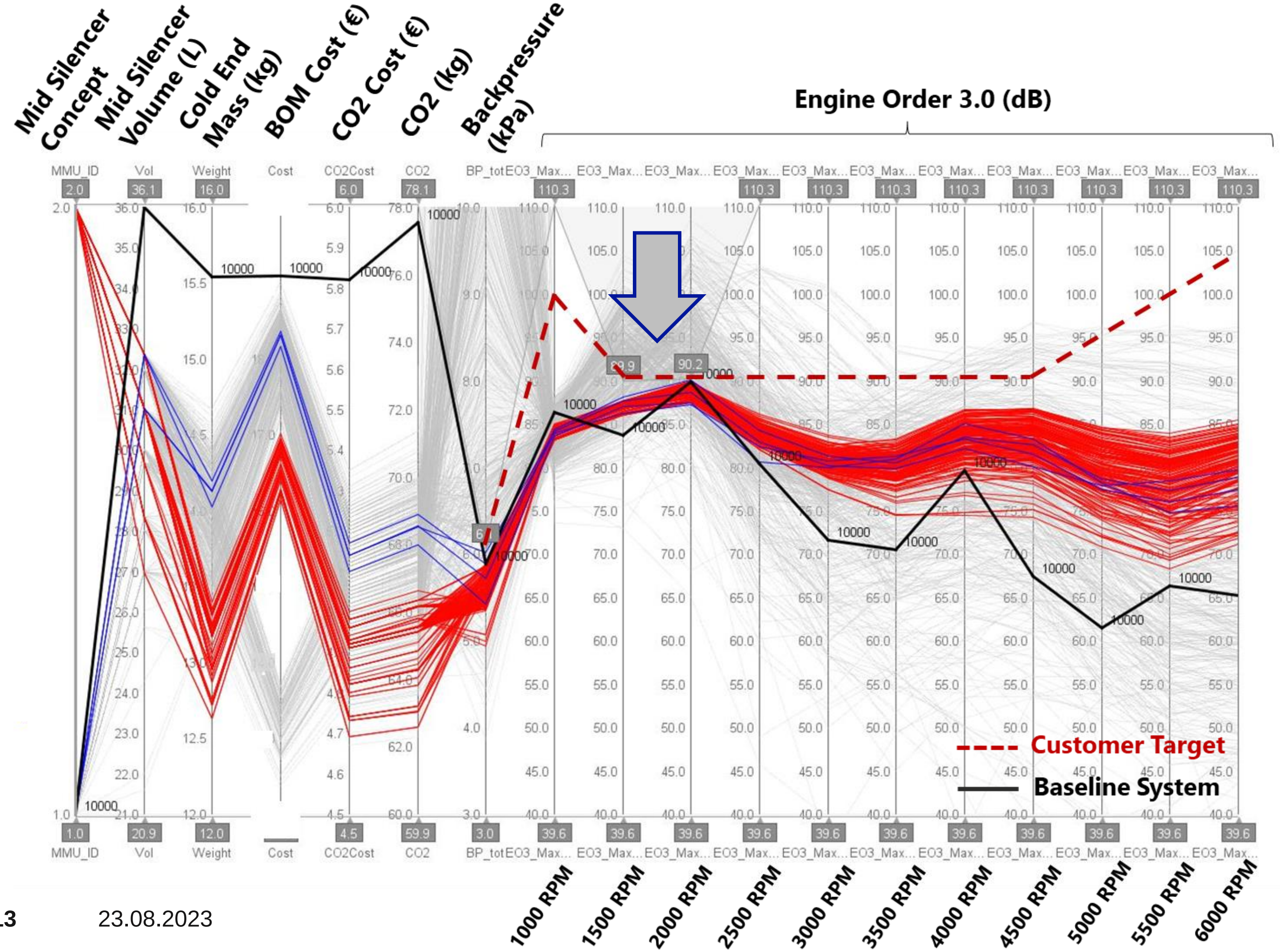
- Combination of Algorithms

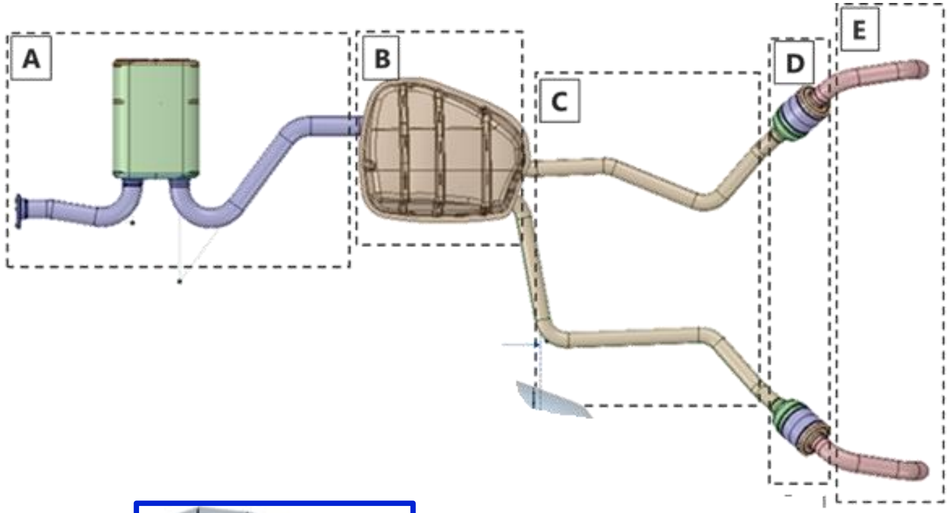
Optimization:

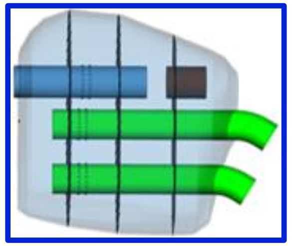
- MOGA-II
- NSGA
- piLOPT

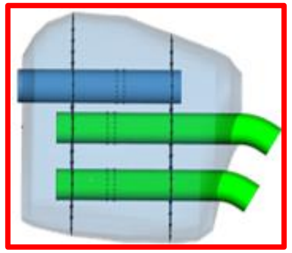
Optimization Approach for Exhaust System Development

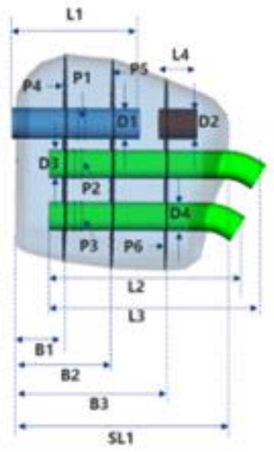
Case Study











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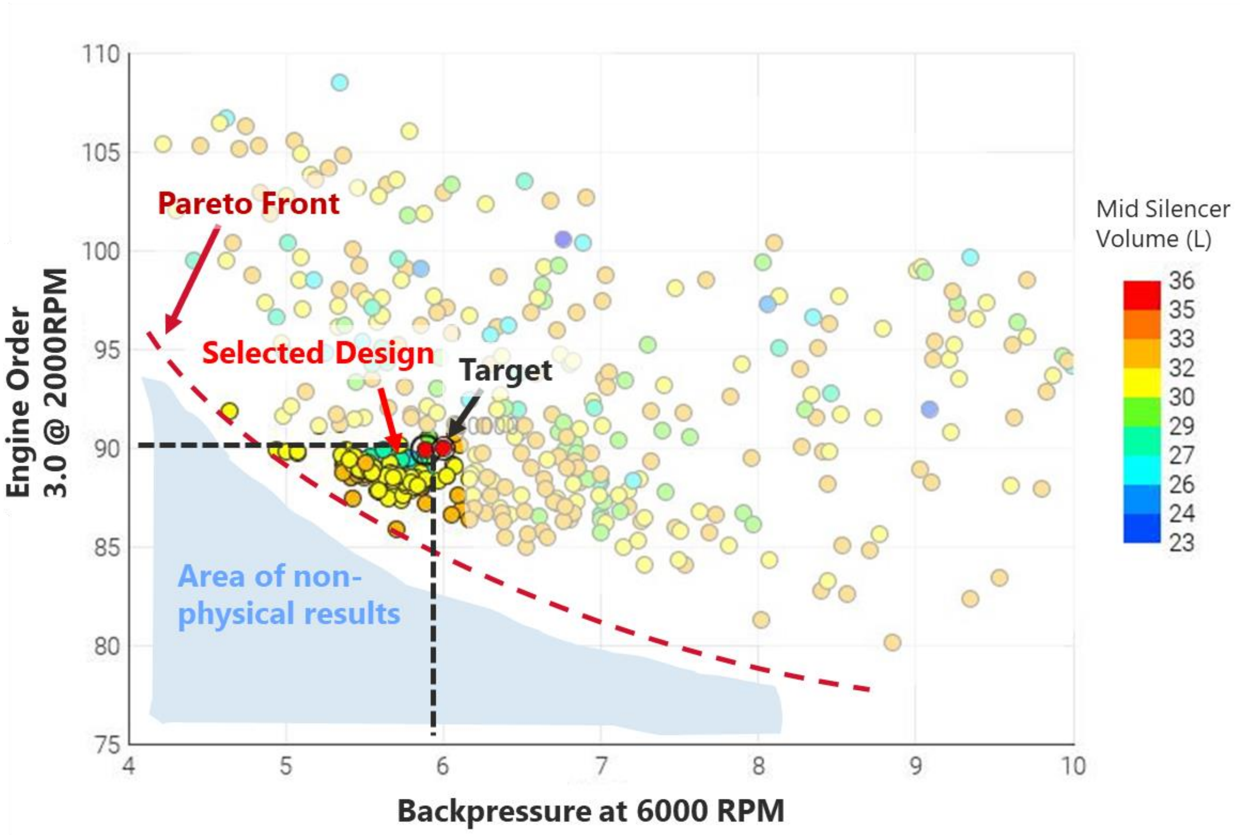
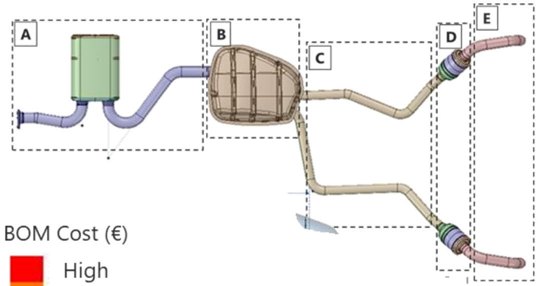
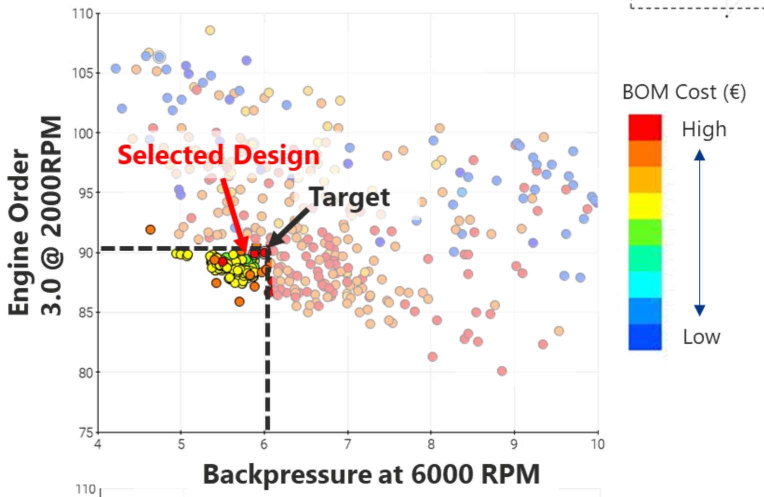
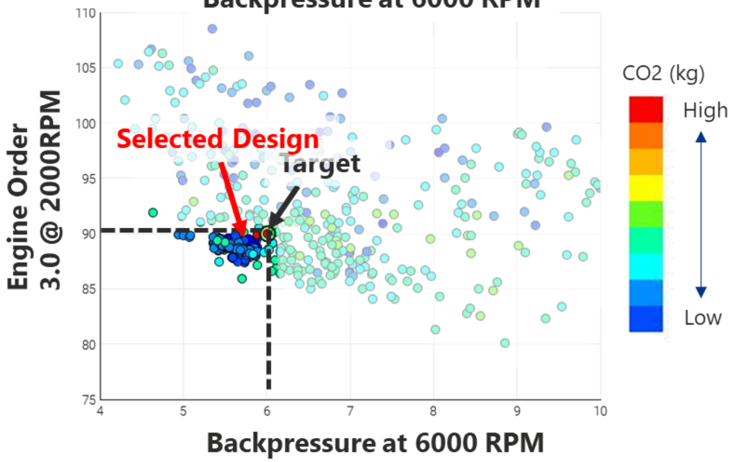
Optimization Approach for Exhaust System Development

Case Study Results









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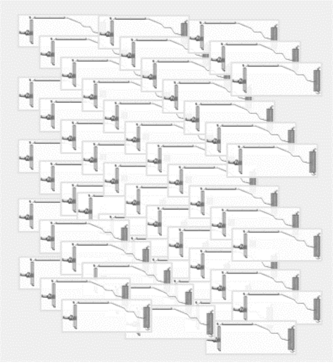
Optimization Approach for Exhaust System Development

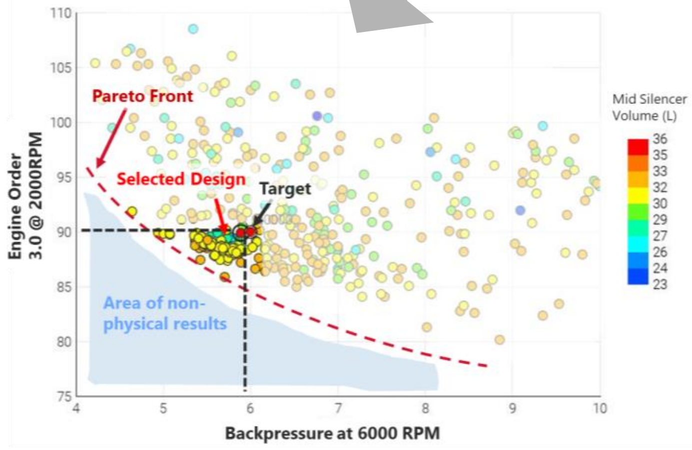
Conclusion

- Advanced Multi-objective optimization method -
  - Assess high number of designs to find the best trade-off
  - Ecological and Economical aspects as performance parameters at early stages of development
  - Speed up development and respond faster with efficiency
- Chosen design has lower BoM costs, lower CO2 emissions and a reduced mid silencer volume, while meeting acoustics & mass reduction objective

	Total volume [l]	System mass [kg]	Backpressure [kPa]	Engine Order Performance	Estimated BOM Cost	Estimated CO2 Emissions
Baseline	49.6	19.2	5.9	OK	A	B
Optimized design	32.0 (-35%)	12.6 (-34%)	5.8	OK	A-15%	B-20%

- Lessons learnt:
  - Two step workflow, IF criteria
  - Quicker convergence → pilOPT





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