Multi-objective optimization to get the best tolerance-cost design

An effective application on a high performance engine

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1. Background

- Geometric and Dimensional Tolerances (GD&T) are the main contributors on **quality** and **cost** of industrial products
- Dimensional Management (DM) approach through GD&T
- Estimation of production costs

Tolerance-cost optimization

Issues

- Lack of **integration** between DtC and DfT
- Lack of **methodological approach** on tolerance-cost optimization
- Lack of a systematic assessment from **Computer-Aided** tools

Design-to-Cost (DtC)

Production costs as a design constraint

- Identify cost factors as early as possible
- Eliminate expensive designs
- Increase flexibility with respect to market changes and new requirements

Product Cost Management (PCM) software

Design-for-Tolerancing (DfT)

Optimize permissible variations of products

- Simulation-based engineering methodology to analyze dimensional quality
- Improve product quality achieving functional targets
- Enable robust design

Computer-Aided Tolerancing (CAT) software

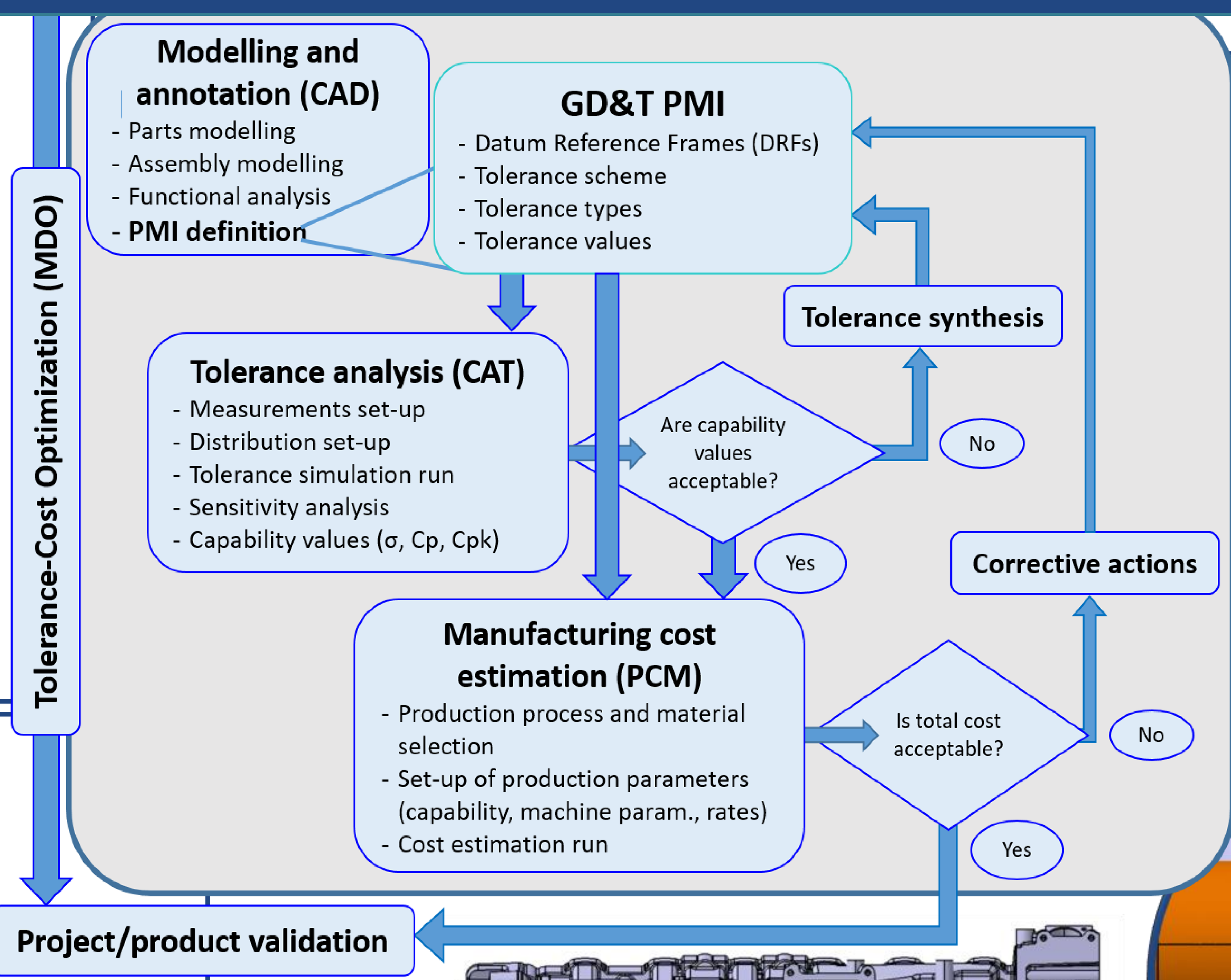
Model-Based approach for Tolerance-Cost Multi-Objective Optimization

2. Aim and Methodology

- Optimal selection of product tolerances
- Combine DtC and DfT approaches
- Include analysis of manufacturing and assembly into product design environment

Through

- Model-Based approach with **Product Manufacturing Information (PMI)**
- **Multi-Disciplinary Optimization (MDO)** environment
- Integration of dimensional variation simulations and manufacturing cost estimation



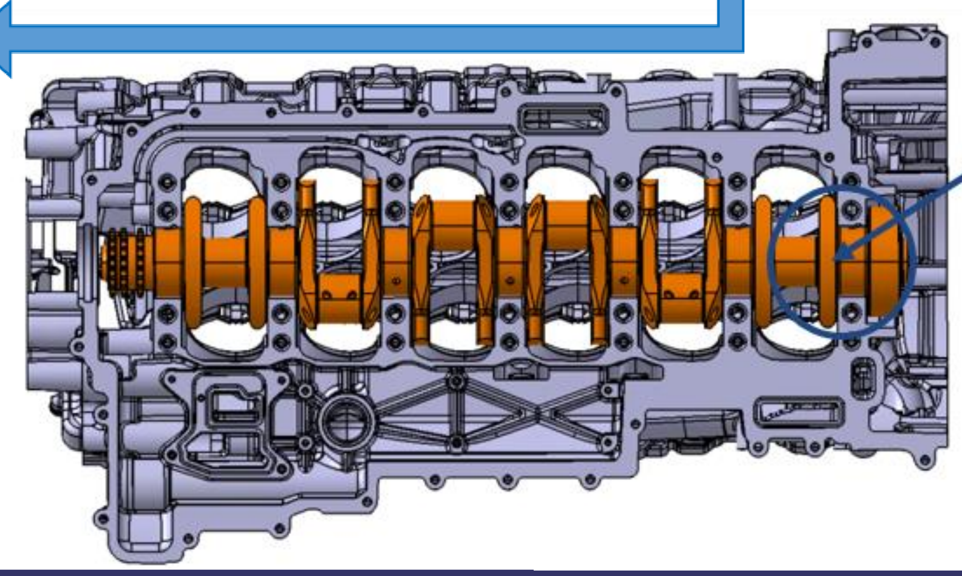
Adopted Software

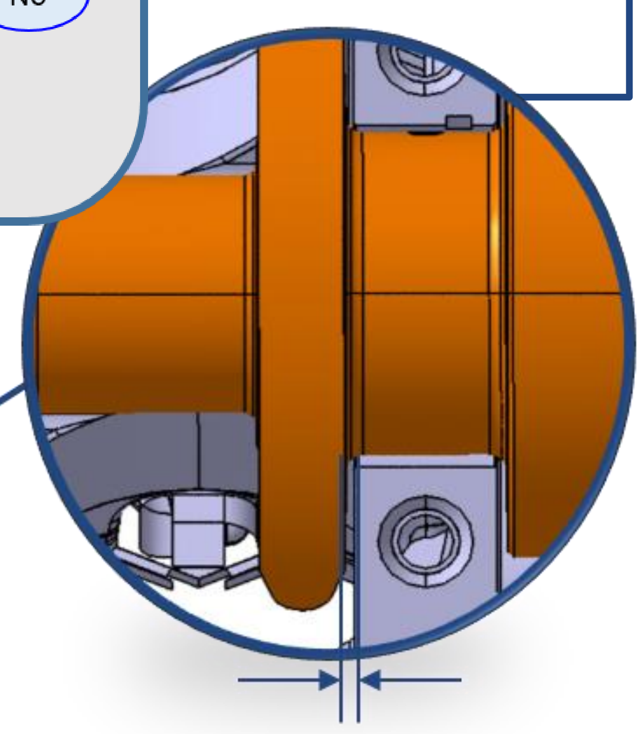
- CAD: CATIA
- CAT: CETOL 6σ
- PCM: aPriori
- MDO: modeFRONTIER

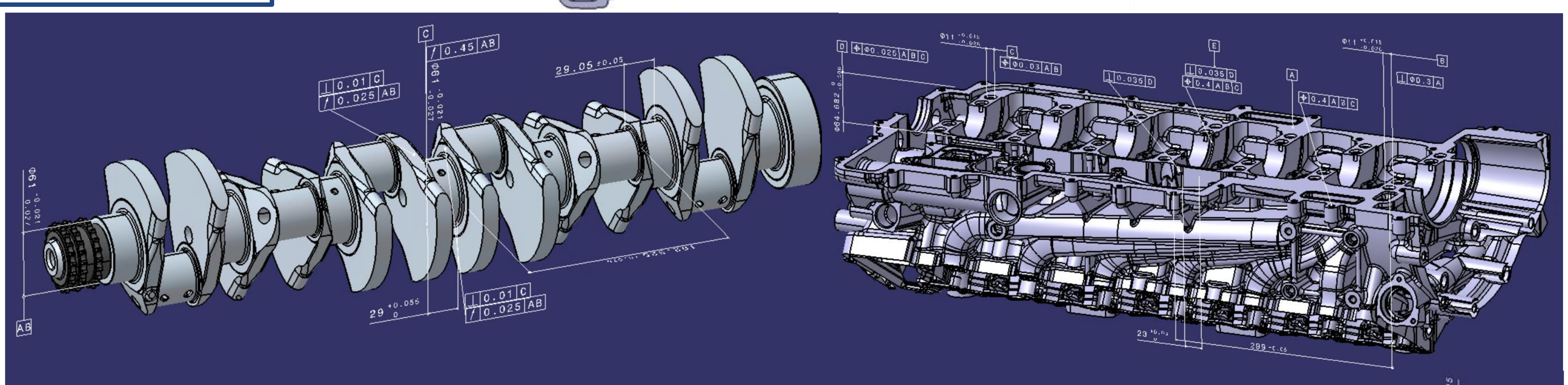
3. Industrial application

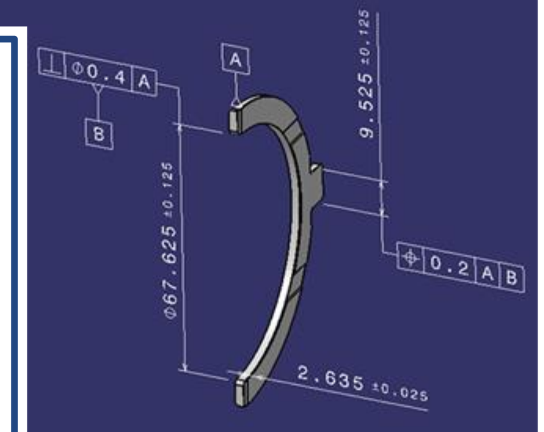
V12 engine tolerance-cost optimization

- **Tolerance design** for functionality and cost reduction
- Engine block, crankshaft and thrust washers (x2)
- Functional requirement: axial distance between crankshaft shoulders and engine block shoulders
- GD&T inserted on the 3D models as semantic PMI
- Optimization set-up: 4 components, 26 tolerances, 5 objectives
- Multi-Strategy Self-Adapting pilOPT Algorithm, 600 evaluations









4. Optimization results

- A set of 67 configurations achieves the functional requirement (Cpk ≥ 1.33)

Optimal configurations are identified and selected considering Total Cost, Cpk, Number of Rejects**

- #0 = starting configuration
- #463 = Best Cpk
- **#527 = Best trade off**
- #575 = Least cost

ID	Crankshaft	Thrust washer		Engine Block	Ass. Op.*	Total Cost	Cpk	DPMU**
0	$ 1133.22	$ 1.67	$ 1.67	$ 197.00	$ 2.25	**$ 1335.81**	**1.29**	**95.21**
463	$ 1133.20	$ 1.24	$1.68	$ 190.87	$ 2.25	**$ 1329.24**	**1.59**	**1.54**
527	$ 1133.20	$ 1.24	$ 1.24	$ 190.85	$ 2.25	**$ 1328.78**	**1.48**	**7.28**
575	$ 1133.20	$ 1.24	$ 1.24	$ 189.94	$ 2.25	**$ 1327.87**	**1.42**	**17.75**

*Assembly Operation Cost; **Defects Per Million Units

5. Conclusions

- Optimal selection of tolerance types and associated ranges
- Concurrent view of tolerance effects on performance and costs
- Process integration and automation

Obtain maximum quality at the lowest possible cost

6. Outlook

- Stress the approach with respect to further industrial products
- Extend optimization variables to nominal dimensions and tolerance schemes

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