FIAT GROUP

Automobiles and
Light Commercial Vehicles

Optimization and Robust Design with modeFRONTIER

Application in automotive Industry

FIAT GROUP AUTOMOBILES – CHASSIS & VEHICLE DYNAMICS

FIAT GROUP

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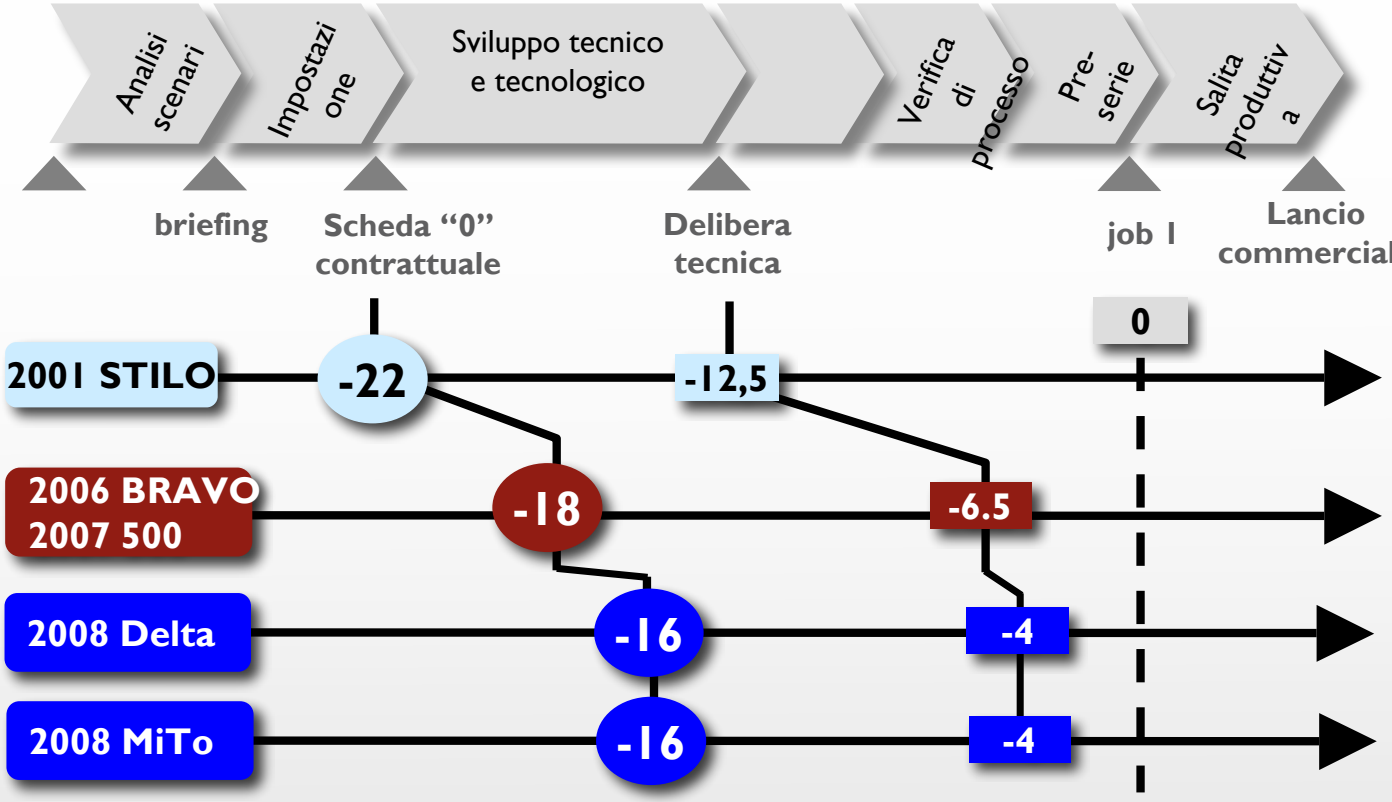
- ✓ **Introduction : Scenario & Targets**
- ✓ **Examples of DOE, ROBUST DESIGN and OPTIMIZATION in Chassis & Vehicle Dynamics**
- ✓ **Summary & Conclusion**

Automotive industry competition

Fiat Group Automobiles is a reference for product development time



+ Quality

+ Innovation

Key success factor :

Virtual Analysis

- Costs

- Time to market

Virtual Analysis in chassis & vehicle dynamics

- ✓ **Vehicle : Handling & ride comfort performances must be take in account at the same time and reach the Vehicle Tecnical Specification coming from targetsetting of Customer Car Profile**

- ✓ **Subsystems : Performances contribution at Subsystems level must be also take in account (PTmounts & Suspension System)**

- ✓ **To improve QUALITY and reduce TIME a better approach could be used from the beginning in virtual analysis of vehicle dynamics :**

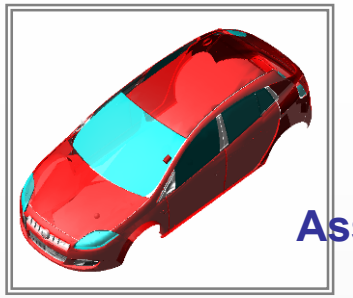
DOE – OPTIMIZATION – ROBUST DESIGN

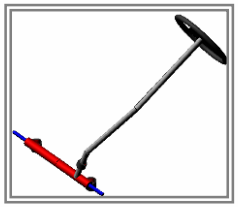
- ✓ **Very high potential of that approach for handling & ride comfort analisys based on integration of :**

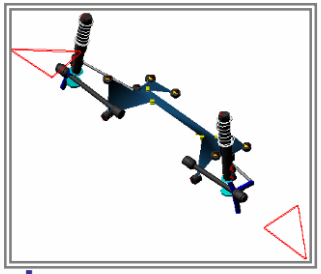
MULTIBODY SIMULATION + OPTIMIZATION TOOLS

Multibody : FIAT Customization of MSC.ADAMS/Car

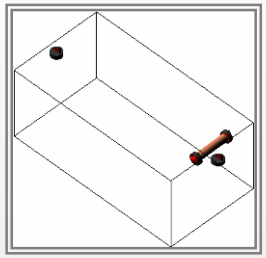
Multi-body Models

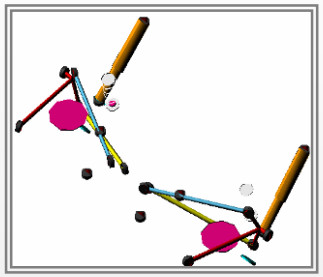






Assembling vehicle subsystems





Assemblies/ Testrig

- Full-vehicle Handling
- Full-vehicle Comfort
- Suspension K&C
- Suspension NVH
- Suspension fatigue
- Engine
- …

Subsystems

- Front Suspension
- Rear Suspension
- Steering system
- Brakes system
- Conceptual Driveline
- Anti-roll bar
- Engine
- Tires
- Body

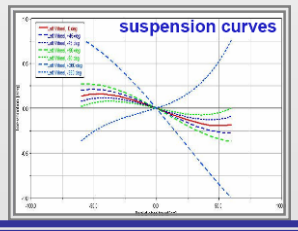
Analysis:

- K&C SUSPENSION
- HANDLING (+driver controls)
- RIDE COMFORT
- FATIGUE TEST
- DRIVEABILITY

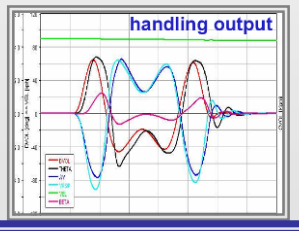
Post-processing:

- Automatic plotting of graphs
- Calculation of single maneuver synthesis parameters
- Calculation of Handling/Comfort/ Steering/Braking Subjective Quality Indexes

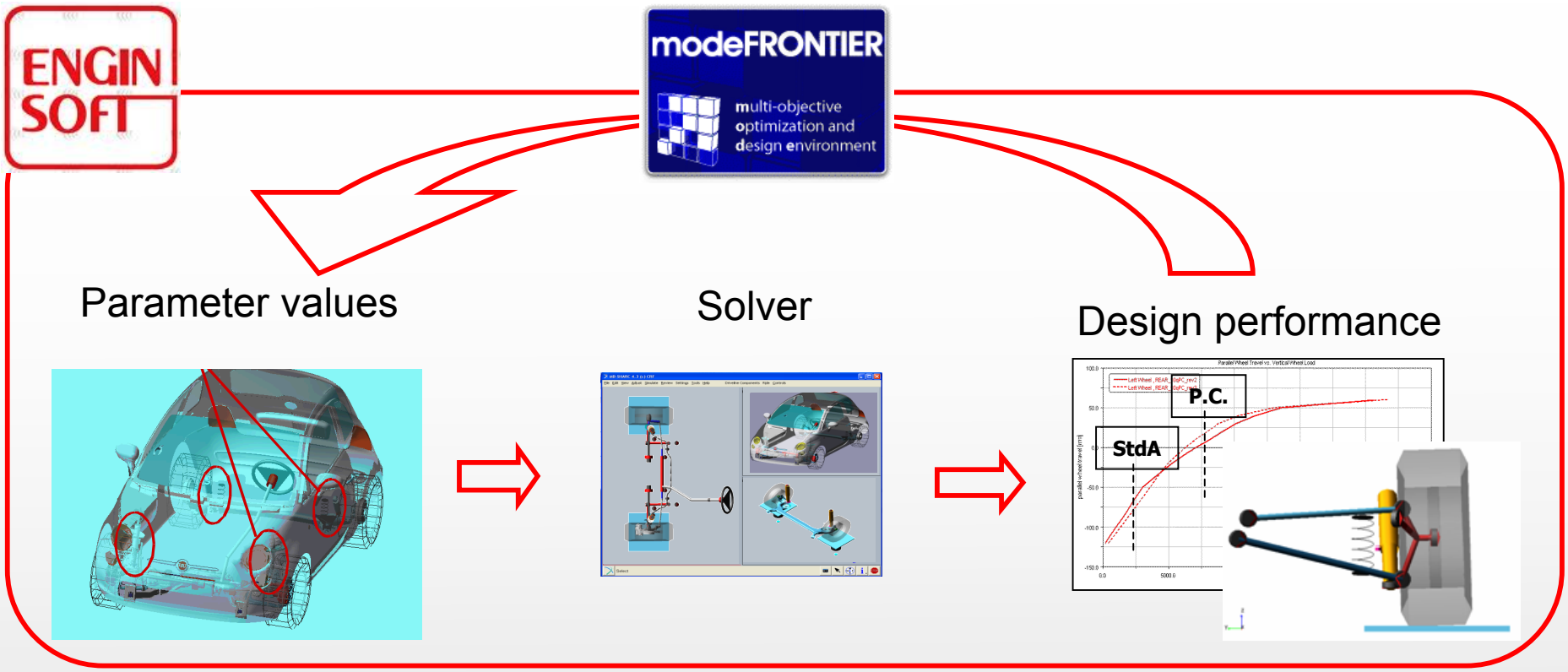
Suspension analysis



Handling maneuvers



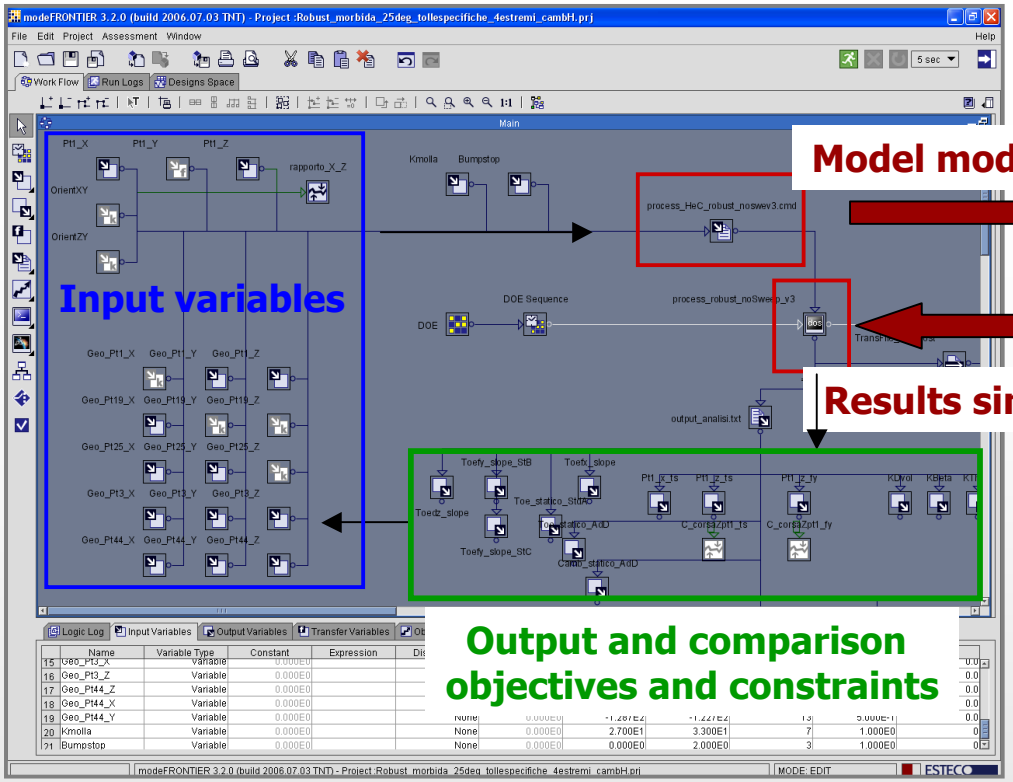
Multiobjective Optimization tool : ModeFrontier



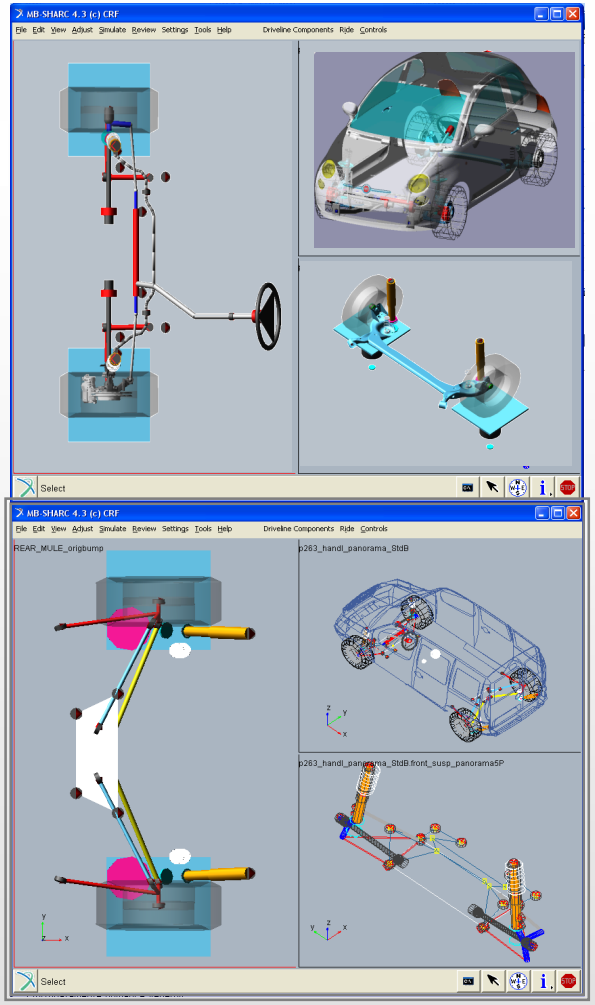
- **Process Integration: integrates any CAE software**
- **Design Automation: automates design process**
- **Design Optimization: algorithms drive design to optimum**

Multiobjective optimization & robust design : Adams/Car linked with modeFrontier

modeFRONTIER



MSC.ADAMS/Car



Input Variables, Objectives and Constraints

Input variables:

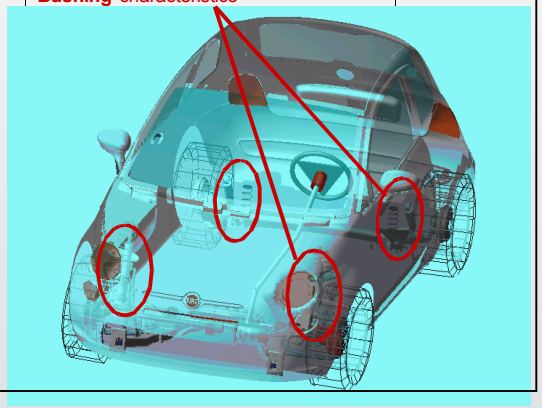
Suspension Vertical Stiffness and Damping
(spring, shock absorber)

Suspension Longitudinal Stiffness and Damping (bushings, shock absorber)

Suspension Rolling stiffness
(spring, anti-roll-bar)

Suspension Elasto-Kinematic

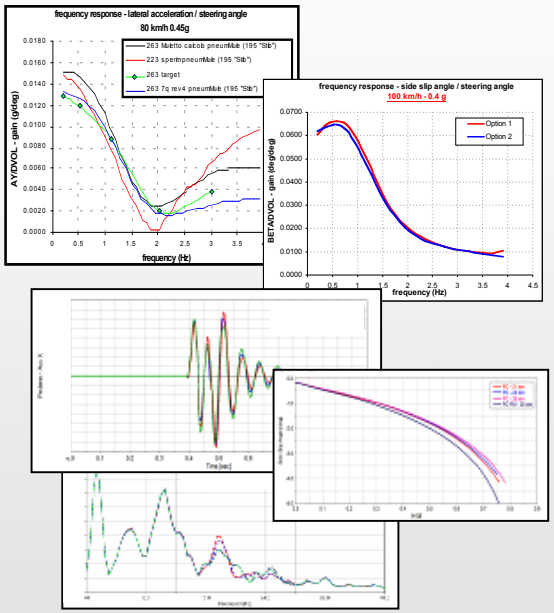
Input variables:
Spring Stiffness and preload
Bumpstop clearance and characteristics
Anti-roll bar diameter
Damper characteristics
Bushing characteristics



Objectives:

Key synthesis Handling parameters
(understeer, sideslip curve, yaw, rolling - gains, time delays)

Key synthesis Comfort parameters (peak accelerations, time dissipations, RMS/RMF)

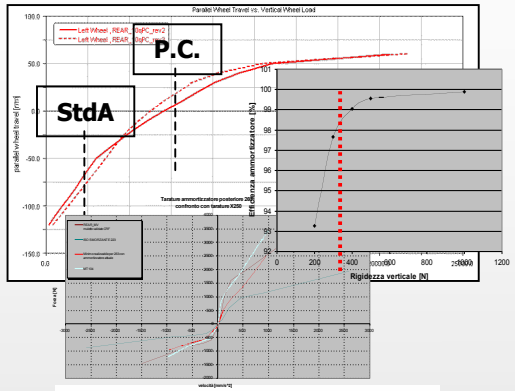


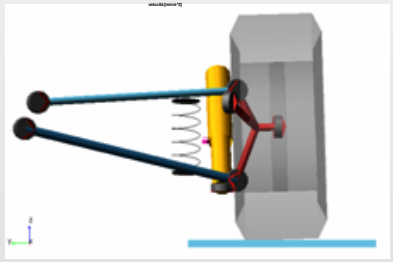
Constraints:

Ride heights in various load conditions

Feasibility of the components for .ex. rate between axial and radial bushing stiffness, damper characteristics, bumpstop length and characteristics etc.

Performance constraints





DOE Study and Optimization Method

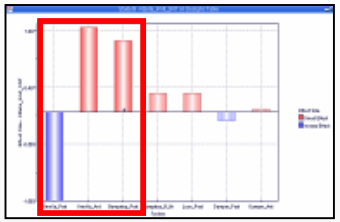
Preliminary Study *:*

DoE Study (Sobol/Reduced-factorial distribution) =>
Selection of principal variables / constraints / objectives

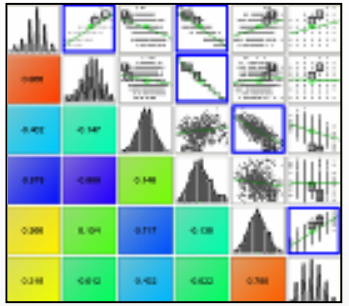
Main Study *:*

✓ ***DoE Study or DoE Study + Optimization of a limited number of input variables & objectives using detailed model or response surfaces***
✓ ***Pareto FRONTIER => Selection of "optimum" solutions of vehicle target setting***
✓ ***Robustness evaluation of Pareto optimal solution***

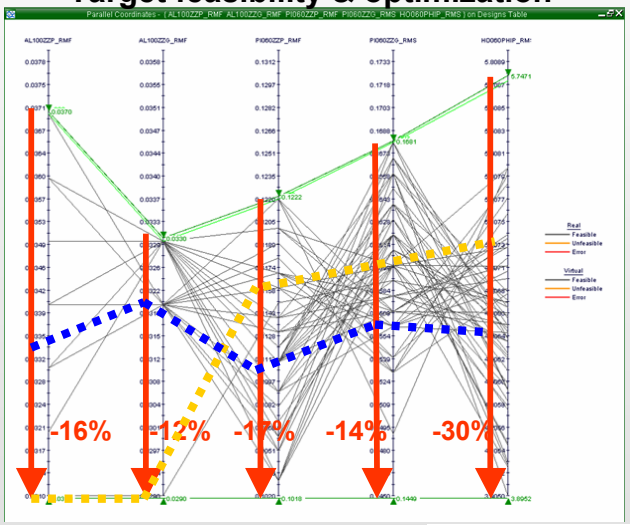
Linear and non-linear correlations



Main Influences (Inputs and Outputs)



Target feasibility & optimization



Results of DOE study:

- **Sensitivity and correlation direct/inverse of design variables vs targets & between each design variables**
- **Principal Heavy costraints (boundary condition)**

Main Goal DOE / Optimization:

- **Optimization of targets**
- **Trade-off scenarios**
- **Robustness of solutions**

- ✓ Introduction
- ✓ **Examples of DOE, ROBUST DESIGN and OPTIMIZATION in Chassis & Vehicle Dynamics**
- ✓ Summary & Conclusion

Applications – some examples

- Handling & Ride Comfort

- K&C Suspension
- PT Mounts System

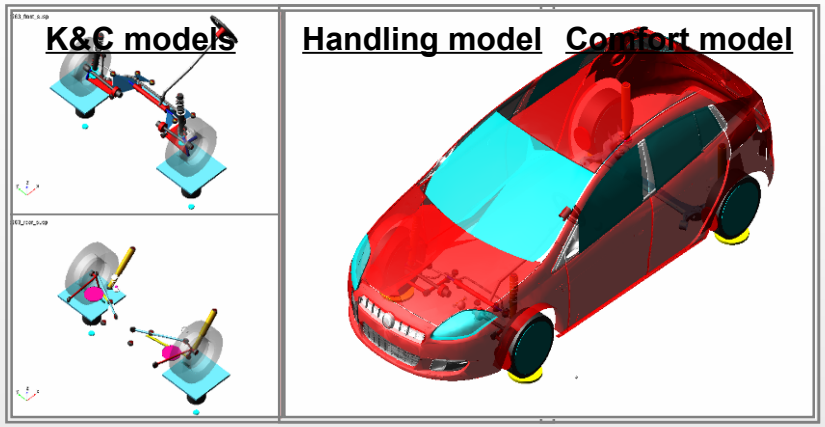
- Suspension NVH - Handling
- Active Systems (ARB)

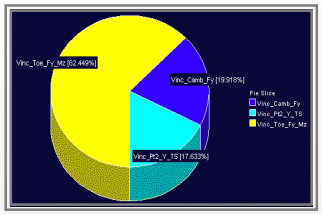
- → Focus on Timing & optimization results
- → Method comparison

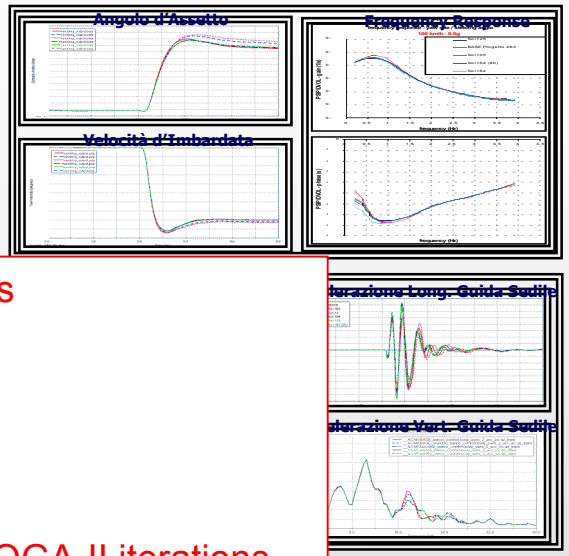
Handling&Comfort

DOE & Optimization handling&comfort performances

Input Variables	Constraints	Objectives
- Spring stiffness and preload	- Vehicle Heighs (different load conditions)	Handling&Comfort synthesis parameters
- Bumpstop clearance and stiffnesses	- components feasibility	- Roll,Pitch,yaw velocity,sideslip angles
- Bushing stiffnesses X,Y,Z		- time delays,pk/gain frequency
- Shock-absorber characteristics		- Peak/peak obstacle passing
- ARB diameter		







Simulated manoeuvers :
K&C : Elastokinematics
Handling : Sweep, Step Steer
Comfort : Obstacle passing,
Motorway, Pavè

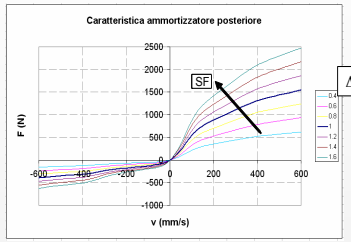
Results:
Performance target optimization

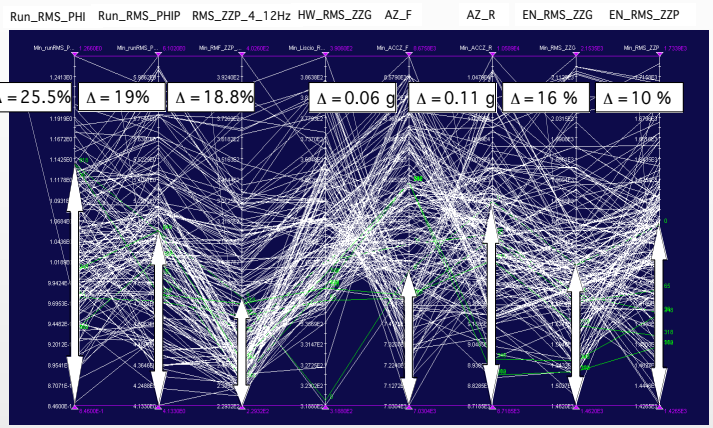
9 input variables
6 objectives
12 constraints
7 maneuvers
350 designs:
70 Sobol x 5 MOGA-II iterations
alt. 350 Sobol
3.5 days

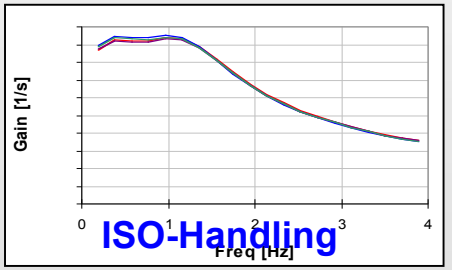
Ride Comfort (Handling Constraints)

DOE & optimization comfort performances satisfying handling targets

Input Variables	Constraints	Objectives
- Spring stiffness and preload	- Vehicle Heighs	- Seats acceleration (RMF, amplitude)
- Bumpstop clearance and stiffnesses	- components feasibility	- Peak/peak obstacle passing
- Bushing stiffnesses X,Y,Z	Handling parameters :	- body motion (velocity&acceleration)
- Shock-absorber characteristics	- gain ay,Theta,Psip,Beta	
	- time delays Psip/Ay,…	







Simulated manoeuvers :
K&C : Elastokin.
Handling : Sweep,
Step Steer
Comfort : Ostacle,
Hole,
Pavè track
Motorway

Results:
Max performance allowed under constraints
Driver characteristics

7 input variables
9 objectives
9 constraints
14 maneuvers
300 Sobol alt.
80 Sobol + MOGA-II 4 iterations => 320 designs

Handling & Comfort Robust Design

DOE & Robust design of handling & ride comfort performances

Input Variables (noise variables)	Constraints	Objectives
- Spring stiffness and preload	- Vehicle Heighs (different load conditions)	Handling&Comfort synthesis parameters
- Bumpstop clearance and stiffnesses	- components feasibility	- Roll,Pitch,yaw velocity,sideslip angles
- Shock-absorber characteristics		- time delays,pk/gain frequency
- STD DEV Parameters		- Peak/peak obstacle passing
Input Variables (optimization var.)		
- Bushing stiffnesses X,Y,Z		

Approach :

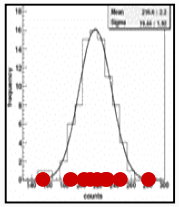
1. DOE + optimization to find Pareto solutions. –>Robust Design of Pareto Solutions including STDEV as parameter
2. DOE & optimization including STDEV for all interesting inputs from the beginning

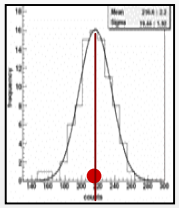
Best compromise time - accuracy :

1. Large DOE with evaluation main parameters, correlation inputs-outputs,correlation between objectives
2. Reduction of number of input variables & objectives using direct / inverse correlation
3. New DOE + optimization to find Pareto solutions
4. Evaluation of Pareto solutions including stdev – check max/min performances

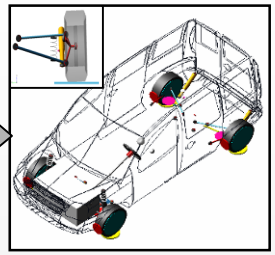
Handling & Comfort Robust Design

Statistic distribution input variables

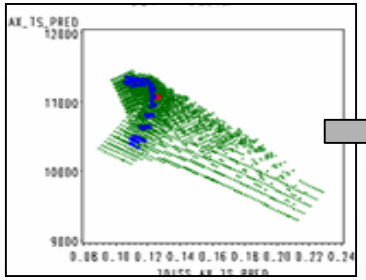


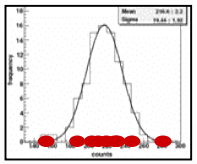


Full-vehicle analysis

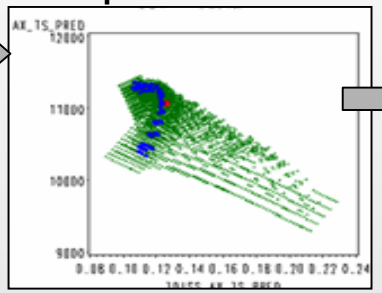


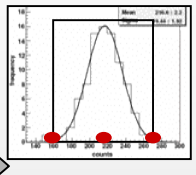
Optimization of MEAN and STDEV

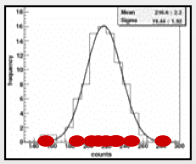




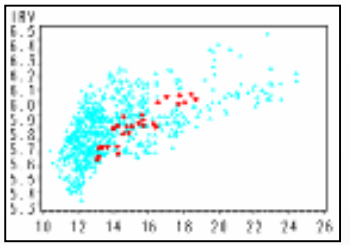
Optimization of nominal performance

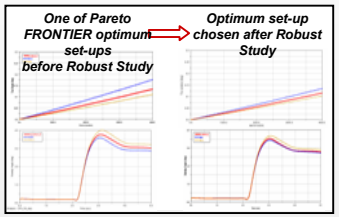


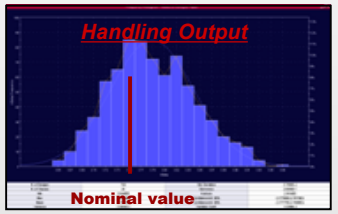




25 Sobol x 26 LHS + MOGA-II 5 iterations => 3300 designs







4 input variables
6 objectives
2 constraints
7 maneuvers

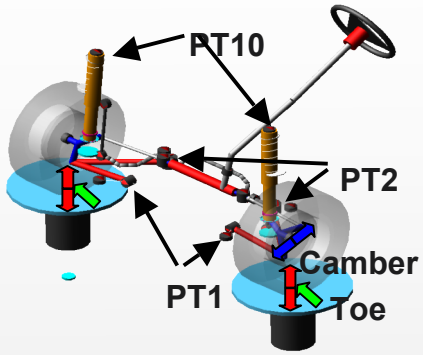
Results:
Robust design evaluation of handling & ride comfort performances

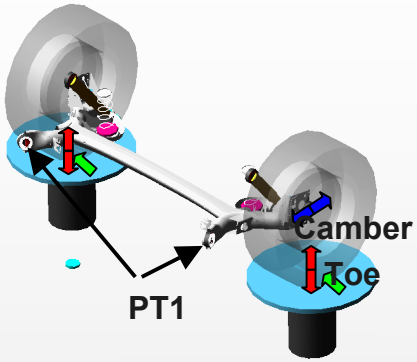
50 Sobol + MOGA-II 5 iterations => 250 designs

K&C Suspension

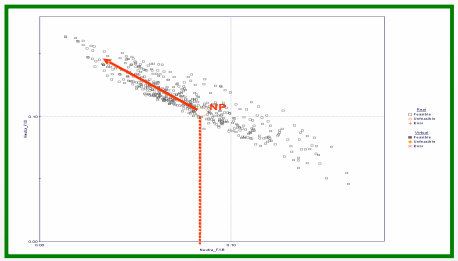
DOE & Optimization K&C targets new suspension layout

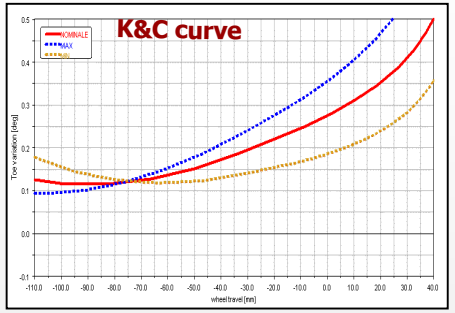
Input Variables	Constraints	Objectives
Suspension attachments : - geometry X,Y,Z - Bushing characteristics X,Y,Z	Layout bushing feasib. Durability	Elastokinematics parameters : - toe & camber gain - Wheelbase & track var. vs Fx,Fy,Fz





Strictly correlated output parameters





Simulated manoeuvers (ride height StdA & 2P) :

Parallel travel

Lateral load 2W parallel

Braking 1W

Results:

Correlation & Sensitivity input/output variables

Correlation design variables vs targets

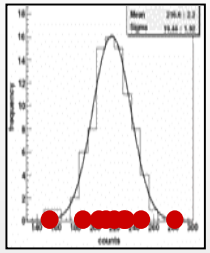
Optimization of K&C targets

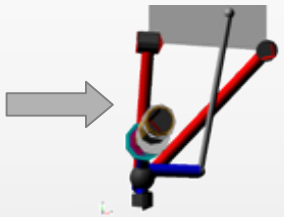
16 input variables
8 objectives
5 constraints
4 analysis
1000 designs:
200 Sobol x 5 MOGA-II iterations
17 hours

K&C Robust Design

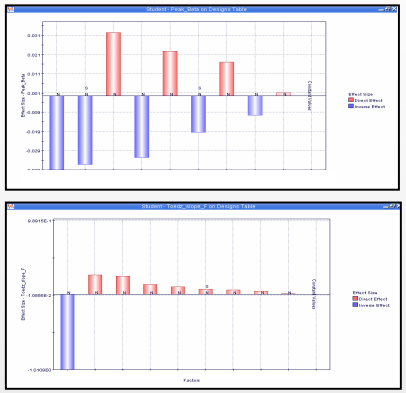
DOE & Robust design of suspension characteristics and tolerances analysis

Input Variables	Constraints	Objectives
- Geometric Tolerances of suspension attach.		- K&C - Handling VTS



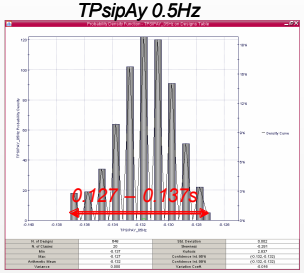


Influences from input variables on handling output parameter

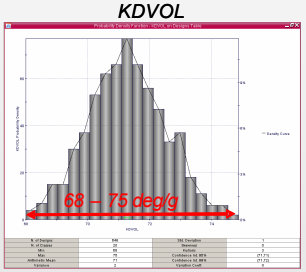


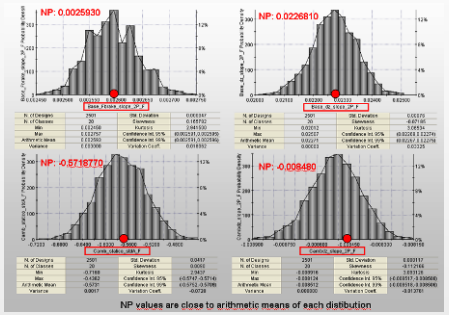
Influences from input variables on K&C output parameter

TPsipAy 0.5Hz



KDVOL



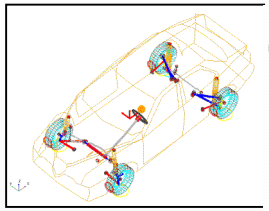


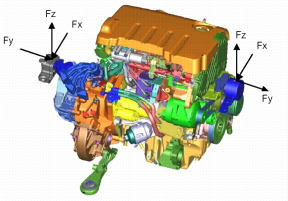
Results:
Influence of geometric tolerances on K&C and handling VTS

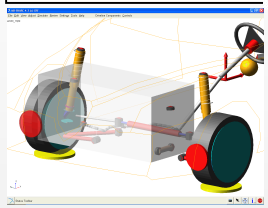
PT Mounts System

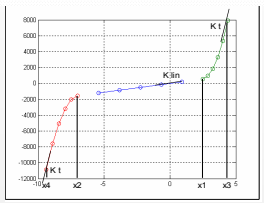
Optimization of PTMounts System

Input Variables	Constraints	Objectives
- Geometry (Elastic center) - Mounts stiffnesses characteristics (X,Y,Z)	- components feasibility - geometry layout	- Force trasmission,working points - RMS/RMF seat acceleration - peak acceleration

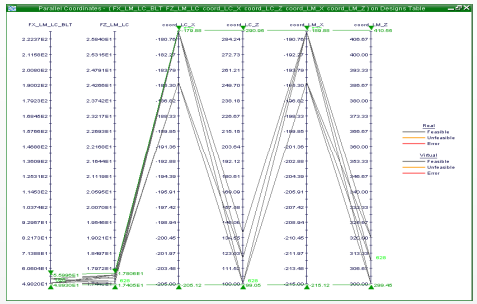




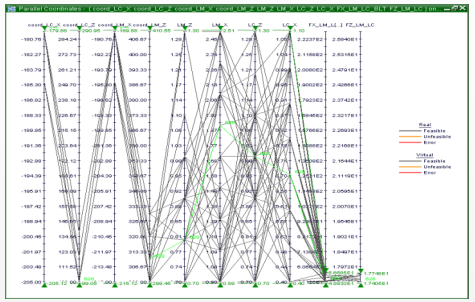




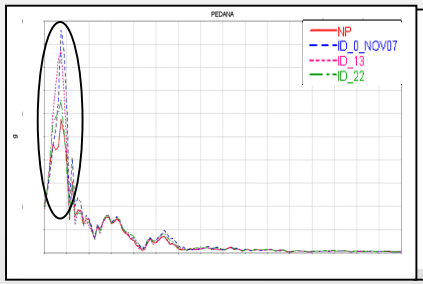
Targets Force trasmission& geometry



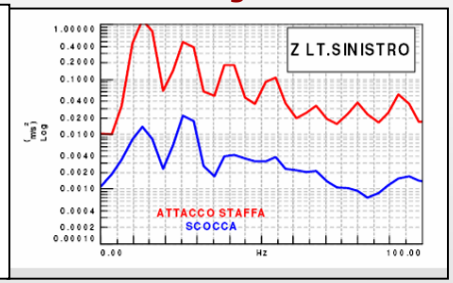
Targets Force trasmission& stifnesses



Ride comfort



Filtering AV3



Simulated manoeuvers:
Static analysis (loads fatigue & misuse)
Dynamic analyses (idle,WOT)
Ride comfort pavè & motorway

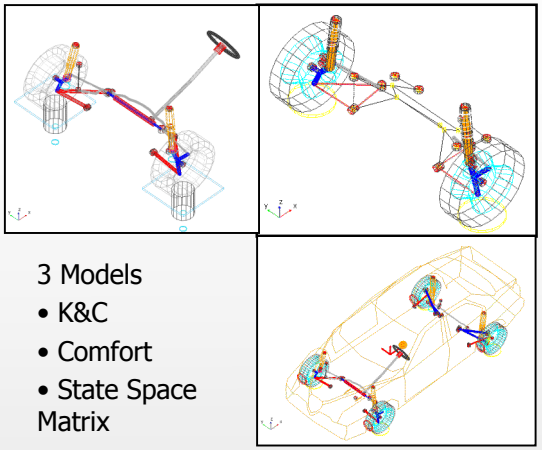
Results:
Optimize engine suspension characteristics in multiple mission
Trade off in performances ride comfort , idle & acoustic

12 input variables
9 objectives
4 maneuvers
500 designs:
100 Sobol x 5 MOGA-II iterations

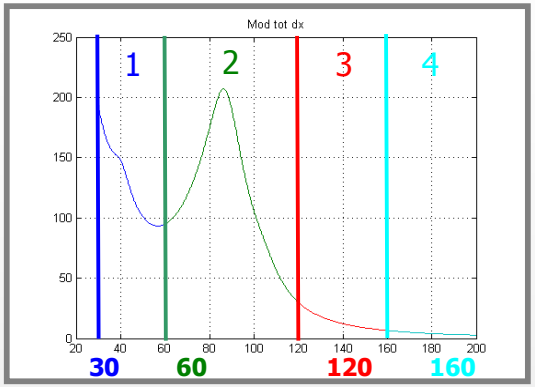
Suspension NVH - Handling

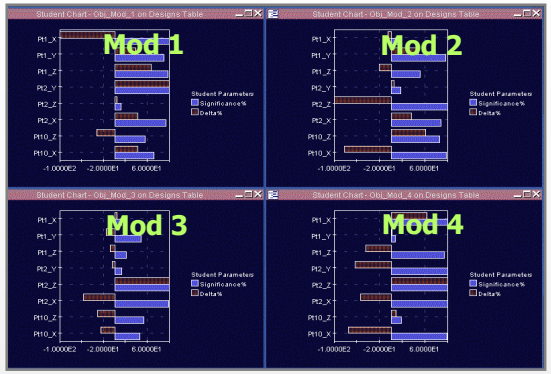
DOE & Optimization forces trasmitted from suspension

Input Variables	Constraints	Objectives
- Bushing stifnesses X,Y,Z	Handling performance : - toe vs Fy, toe vs Mz - camber vs Fy	Ride performance : - Peak/peak obstacle passing - Med./High frequency force trasmission



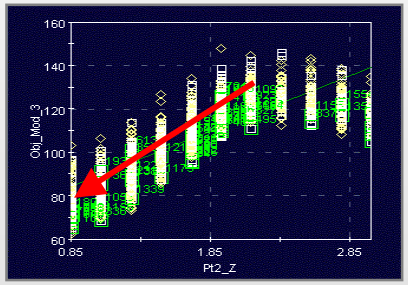
3 Models
- K&C
- Comfort
- State Space Matrix





Results:
NVH-Ride Optimization determining optimum vehicle set-ups considering Handling constraints. Response surfaces used for FEM model analysis and final optimization.

8 input variables
5 objectives
3 constraints
4 analysis/maneuvers
500 designs:
100 Sobol x 5 MOGA-II iterations
1.5 days

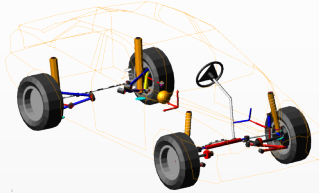


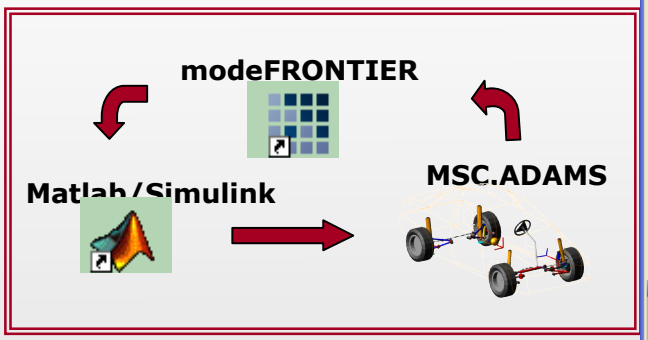
modeFrontier - ADAMS - Matlab co-simulation

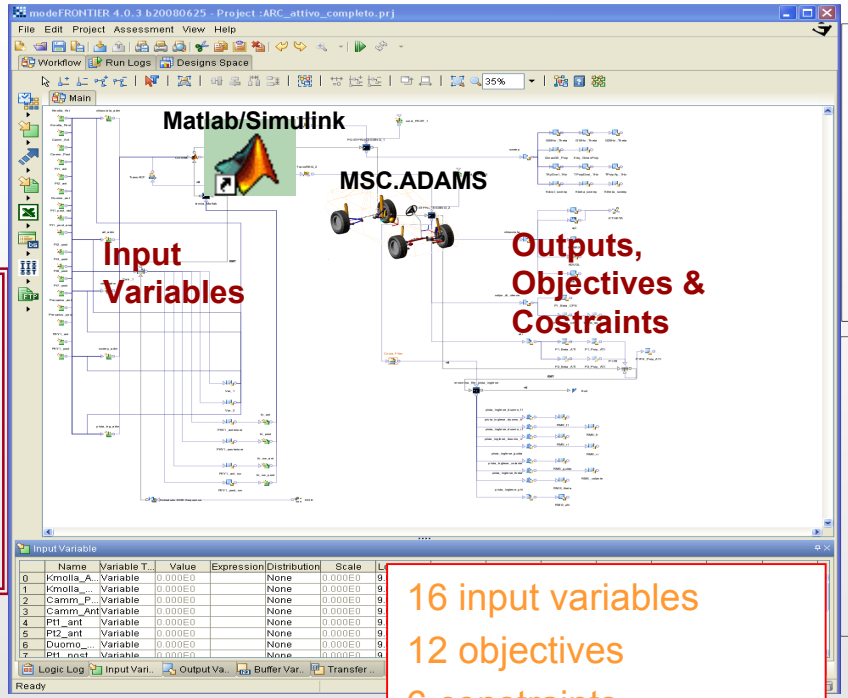
Active Systems : DoE handling and comfort parameters

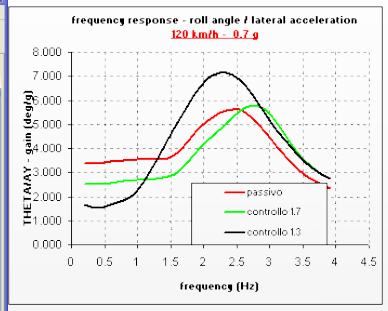
Input Variables	Constraints	Objectives
- Spring stiffness and preload - Shock-absorber characteristics - Bushing stiffnesses X,Y,Z	- specific handling parameters	- Handling & Comfort VTS

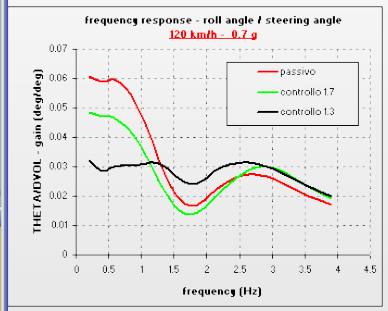
New front active ARB











16 input variables
12 objectives
6 constraints
5 analysis
250 designs: 250 Sobol

Results:
- Handling and comfort targets,
- Correlation & sensitivity input/output variables
- Study of controls in all vehicle condition

DOE-Optimization Study results

Simulation	Time	%Perf. Improv.
Handling&Comfort	15min/design, 350designs => 3.5ggr	15%
Handling / Comfort Robust Design	8min/design, 3300 designs => 20ggr	10%
K&C Suspension	1min/design, 1000designs => 17h	25%
PT Mounts System	4min/design, 500designs => 1.3ggr	30%
Co-simulation MSC.ADAMS-Matlab Active Control System	70min/design, 250designs => 10ggr	+10% of feasible design
Suspension NVH	4min/design, 500designs => 1.5ggr	+25% of feasible design

Methods Comparison – a test case

Handling and Ride-Comfort Performances
Comparison between traditional & multi-objective optimization approach

Handling/Comfort simulation - test case	TRADITIONAL APPROACH	MULTIOBJECTIVE OPTIMIZATION APPROACH
Needs	Knowledge and experiences about vehicle dynamics & simulation	Knowledge and experiences about vehicle dynamics & simulation . Basic knoledge of Doe, optimization techniques
Method	'Trial and error'	Multiobjective & statistical
Human time dedicated (pre/post)	8 days	3 days
Calculation time	1 day	5 days
Total time	2 weeks	< 2 weeks
Human activities	80% for model modification & run , 20% postprocessing	20% for model modification & run , 80% postprocessing and scenarios analysis
Numbers of solutions / scenarios evaluated :	X	10X – 100X
Optimal performance reached	70-80%	100%

- ✓ Introduction
- ✓ Examples of DOE, ROBUST DESIGN and OPTIMIZATION in Chassis & Vehicle Dynamics
- ✓ **Summary & Conclusion**

Summary

❖ *Fiat's latest success products, were developed using intensive use of virtual analysis in only 16-18 months.*

❖ *New target for future projects : increment of virtual analysis to reduce cost & time development and to allow more robust experimental testing*

DOE, Robust design & multiobjective optimization are success key factor

❖ *The use of modeFRONTIER in Chassis Virtual Analysis as a DOE or/and optimization tool enables:*

- ✓ *To Reduce time and calculation loops*
- ✓ *To Gain a deeper understanding of the system and the correlation between input variables and output parameters*
- ✓ *To increase possibility to explore best solutions & scenarios*
- ✓ *To evaluate robust and stable solutions*

Conclusion & next steps…

Advantages in extended application :

- ✓ ***REDUCTION OF DEVELOPMENT TIME***
- ✓ ***VEHICLE TESTING & EXPERIMENTAL TUNING QUALITY ORIENTED***
- ✓ ***APPROACH THE OPTIMUM SOLUTION ALREADY FROM THE BEGINNING***
- ✓ ***TARGET FEASIBILITY & MAIN COSTRAINTS ARE KNOWN FROM EARLY PHASE***
- ✓ ***CLEAR & OPTIMIZED TRADE OFF OF PERFORMANCES***
- ✓ ***EXPLORE BEST SCENARIOS AND GIVE MORE CHOISES TO MANAGEMENT***

Don't forget to improve…

- ✓ ***Model complexity & detail of physical systems and components***
- ✓ ***Statistical approach in model correlation : numerical model & measurements statistically correlated***

... Words to take in mind...

"DOE - OPTIMIZATION - ROBUST DESIGN"

Thanks !

Thank you for your attention