Recent Applications in MDO and Material Identification using LS-OPT®

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- Overview
- MDO (Honda R&D)
- Material Identification
- Conclusions
- Preview

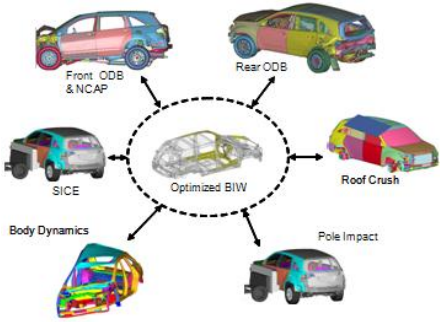
Optimization Strategies in LS-OPT

- Surrogate-based Design Optimization
  - Strategies
    - *Single Stage:* Fixed computational budget
    - *Sequential:* Maximize Surrogate accuracy
    - *Sequential with Domain Reduction:* Classical SRSM algorithm
- Direct Optimization
  - Genetic Algorithm (GA)

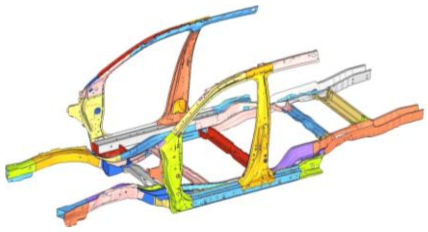
SRSM MDO Application

Large MDO - Setup:

6 Crash Modes + Body Dynamics Mode:
- approximately 3 million element models



35 Continuous Thickness Variables:
33% of BIW mass



Modes:
Front NCAP + Front Offset + SICE + Side Pole + Roof Crush + Rear Offset + NVH

Objective:
Minimize Mass

Constraints:
- Front NCAP:
  - Decelerations
  - Intrusions
- Front Offset:
  - Intrusions
  - Cabin Integrity
- SICE:
  - Intrusions
- Side Pole
  - Intrusions
- Roof Crush:
  - Force
- Rear ODB
  - Intrusions
  - Fuel System Clearance
- NVH:
  - Body Stiffness
  - Body Frequency

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LS-OPT SRSM Settings:

- **Optimization Strategy**
  Sequential RSM with Domain Reduction
- **Termination Tolerance**
  0.1 for design change AND objection function
- **Metamodel**
  Radial Basis Function Network
- **Point Selection**
  Adaptive Space Filling - 54 points per iteration
- **Optimization Algorithm**
  Hybrid ASA

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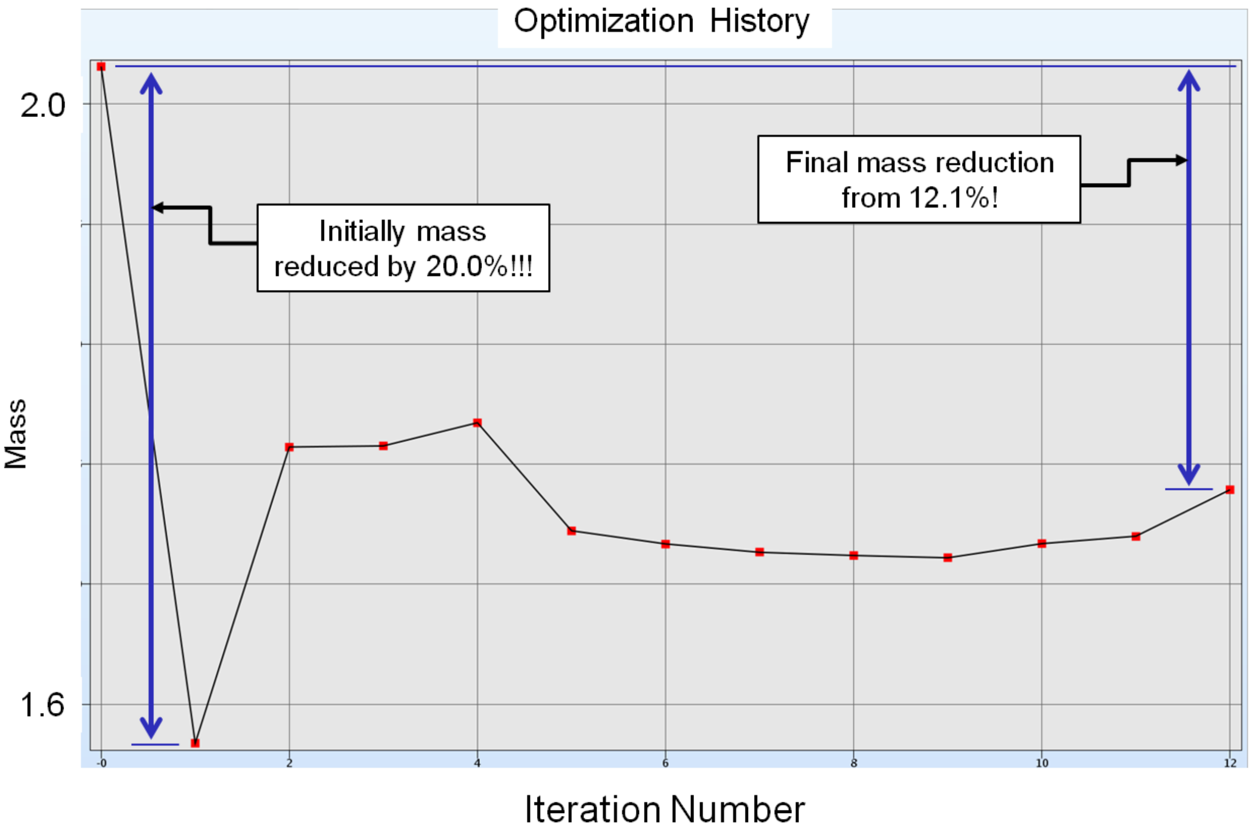
Large MDO - Results:



- Optimization was aggressive with a significant initial mass reduction.
- Then optimization converges as constraints are satisfied.
- Final step shows some increase in mass as variables are switched to discrete values.

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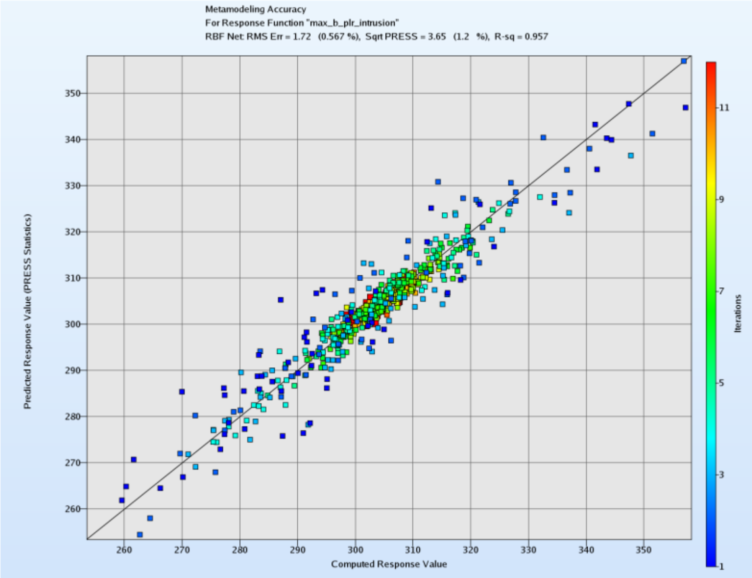
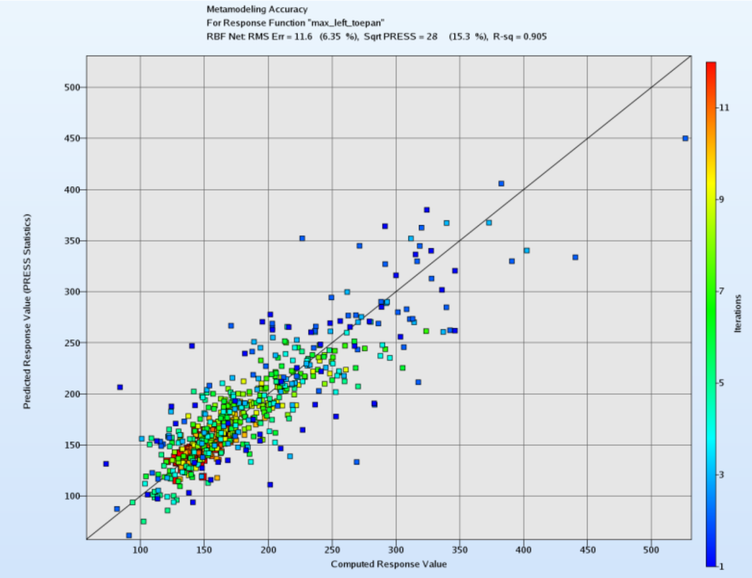
Large MDO - Results:

Side Impact B-Plr Intrusion



Sqrt PRESS 1.2%

Front Offset Left Toepan Intrusion



Sqrt PRESS 15.3%

- Metamodel accuracy for most cases was very good.
- The metamodels for the front crash modes showed the lowest prediction accuracy, though still acceptable.

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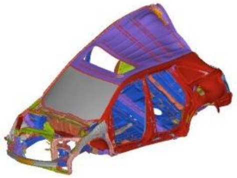
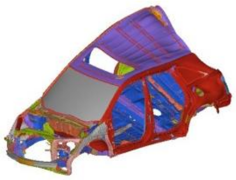
Large MDO - Results:

Performance Requirements Met for all Modes – Examples:

	NVH 1st Torsion	Front Offset	Rear Offset	Side Pole	IIHS SUV
Baseline Design					
Optimum Design					

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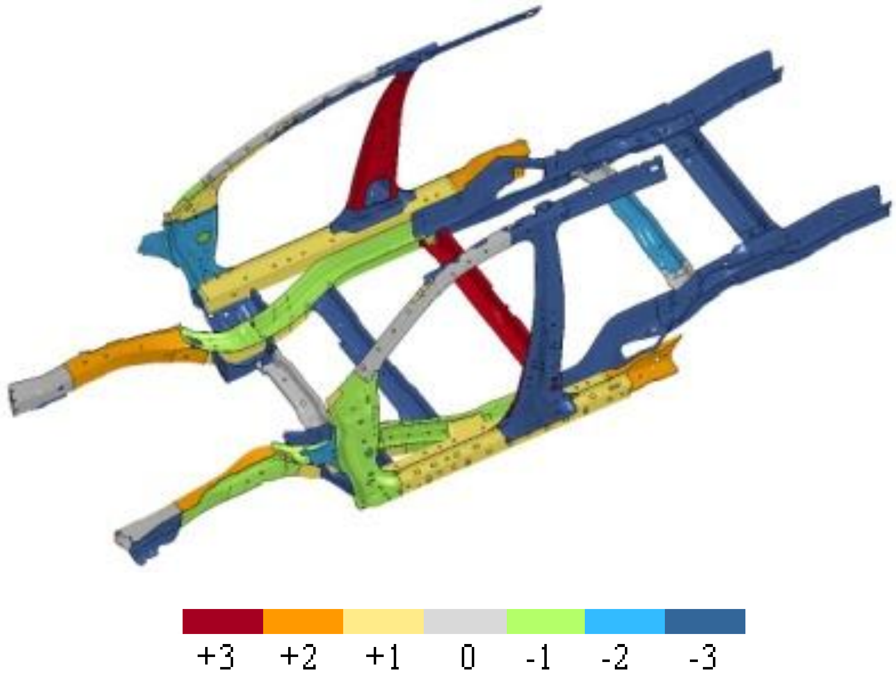
Large MDO - Results:

Gauge Changes



- Gauge changes are non-intuitive.
- Some parts have significant gauge up values.
- Rear portion of structure saw significant gauge down.

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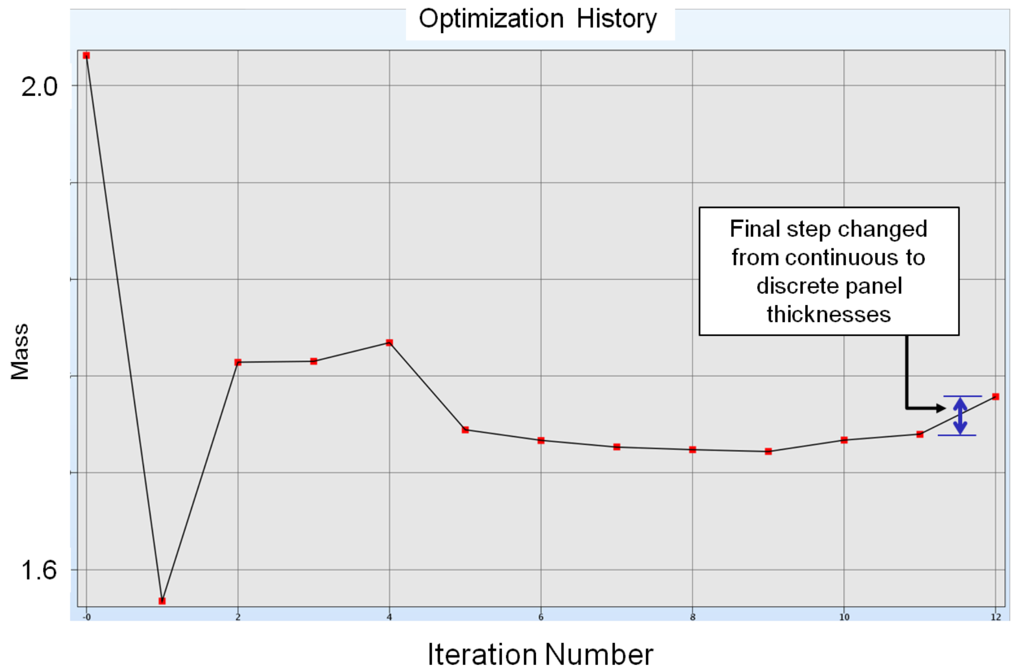
<u>Switched to discrete variables in LS-OPT:</u>

- Changed variable types to discrete and set ranges to discrete gauges which bounded continuous optimum values.
- Re-optimize the last iteration using existing metamodel via the repair task.
- Run metamodel based optimization again to create optimization history for viewer display.
- Clean start from additional iteration number to run verification runs.



Part #	Continuous	Final
60815	1.93475417	2.00
60816	0.700020898	1.00
60817	1.498846	1.40
60821	2.29999883	2.00
60828	0.700007625	0.70
60829	0.700003653	0.70
63121	0.892124782	1.40
63131	0.741664268	1.20
63211	1.05212361	1.20
63216	2.13728689	2.00
63221	0.700000475	1.20
64121	1.21828247	2.00
64131	0.700000733	0.70
64211	0.700000204	1.20
64221	2.19079584	1.60
65116	2.14313003	1.80
65118	1.41987561	1.20
65131	1.75247227	1.80
65136	0.882840044	0.75
65141	2.29998831	1.60
65142	1.2802137	1.60
65145	1.34480367	0.75
65361	0.843405751	1.40
65368	1.59697644	1.20
65611	1.18161726	1.20
65615	0.825944822	1.00
65616	0.909662213	1.00
65625	0.700001546	0.85
65711	1.67796346	2.00
65731	0.700000843	0.70
65741	0.700000098	0.70
60811-0	1.43165276	1.60
60811-1	2.29999659	2.30
60812-0	1.08972173	1.20
60812-1	1.35340555	1.80

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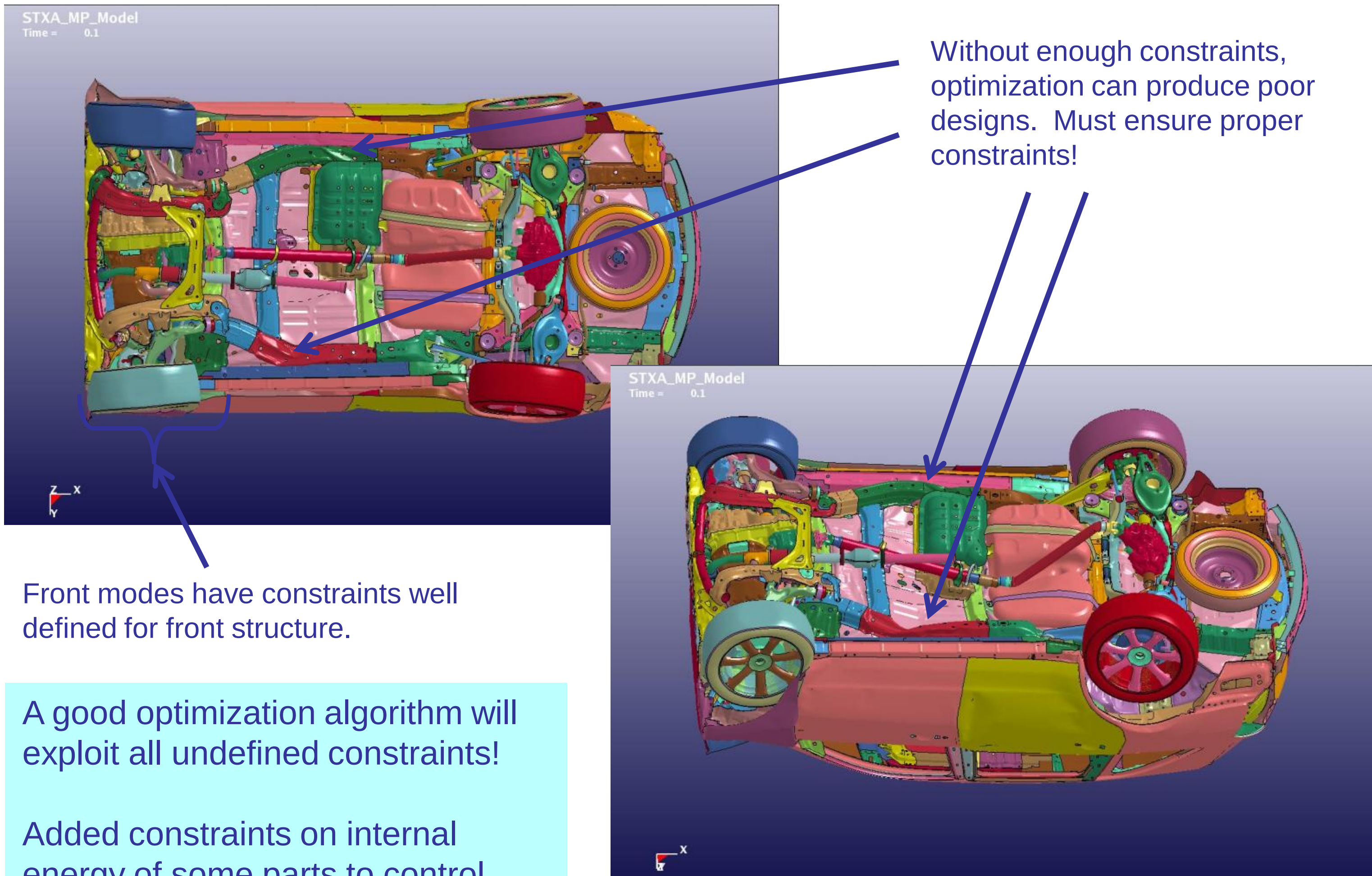
Large MDO - Constraints:



Without enough constraints, optimization can produce poor designs. Must ensure proper constraints!

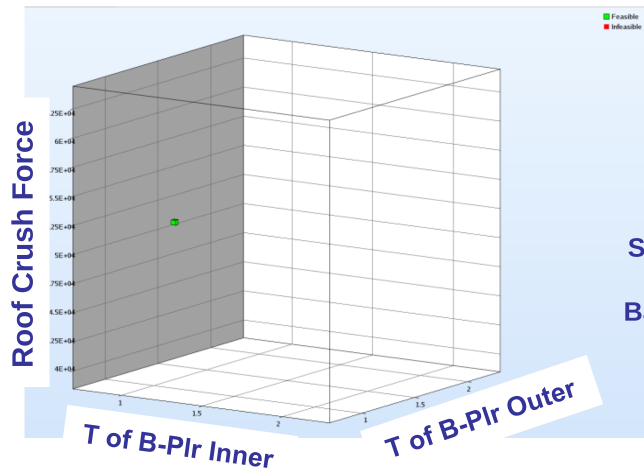
Front modes have constraints well defined for front structure.

A good optimization algorithm will exploit all undefined constraints!

Added constraints on internal energy of some parts to control design decisions.

SRSM MDO Application

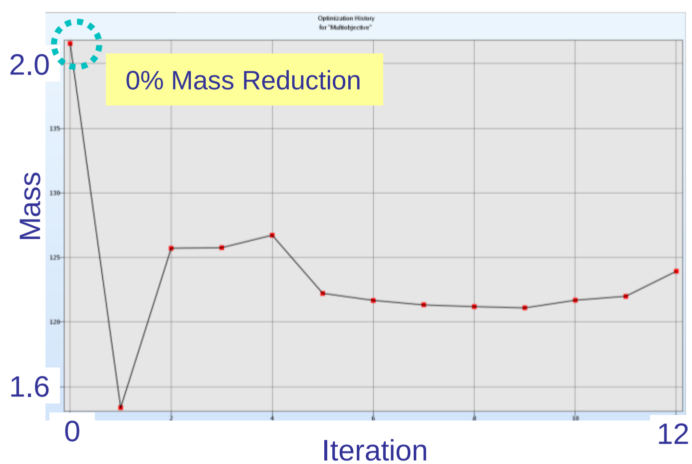
Design space exploration - Baseline:



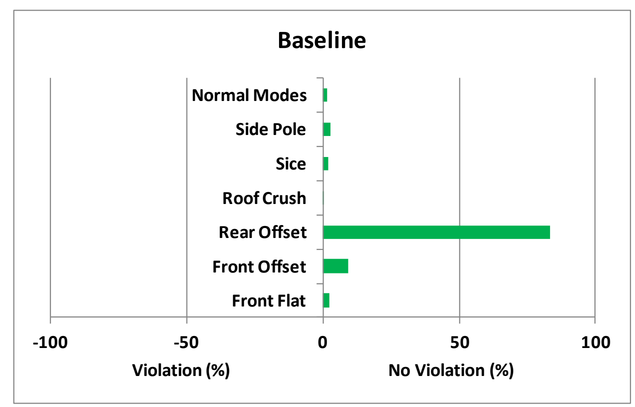
HPC
Job
Submission
of
Base Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	1	56	297
Front Offset	1	56	409
SICE	1	56	157
Side Pole	1	56	347
Roof Crush	1	56	280
Rear Offset	1	56	274
Normal Modes	1	1	1
Running Totals	**7**	**337**	**1765**

Optimization History:

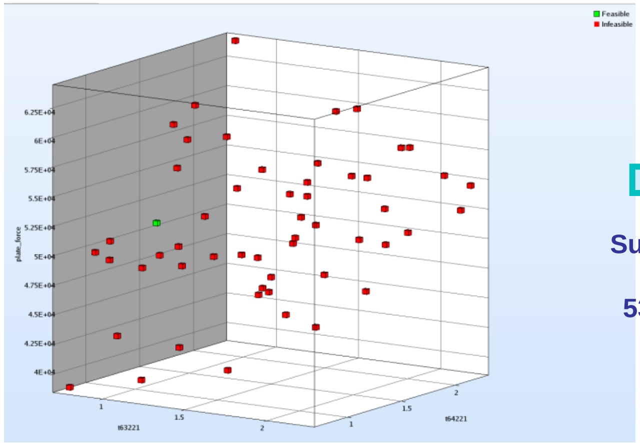


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

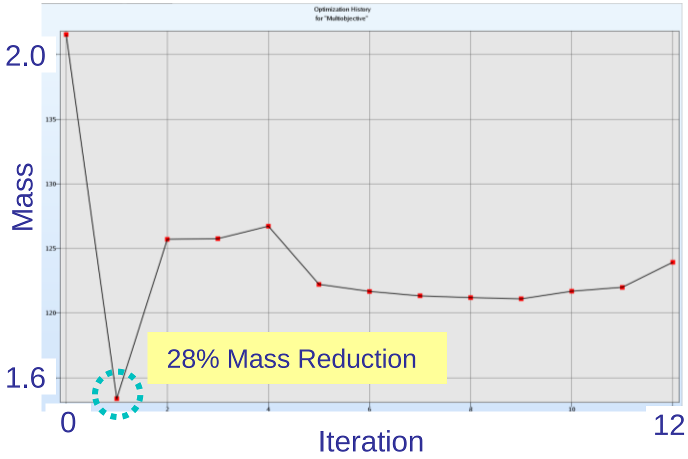
Design space exploration - Iteration 1:



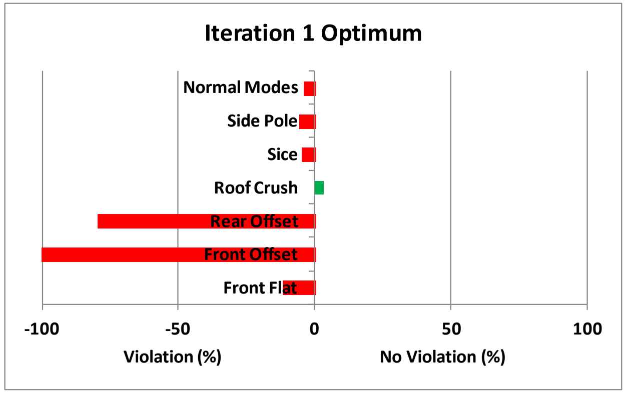
HPC Job Submission of 53 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	53	56	15730
Front Offset	53	56	21666
SICE	53	56	8310
Side Pole	53	56	18402
Roof Crush	53	56	14840
Rear Offset	53	56	14543
Normal Modes	53	1	53
Running Totals	**378**	**18198**	**95310**

Optimization History:

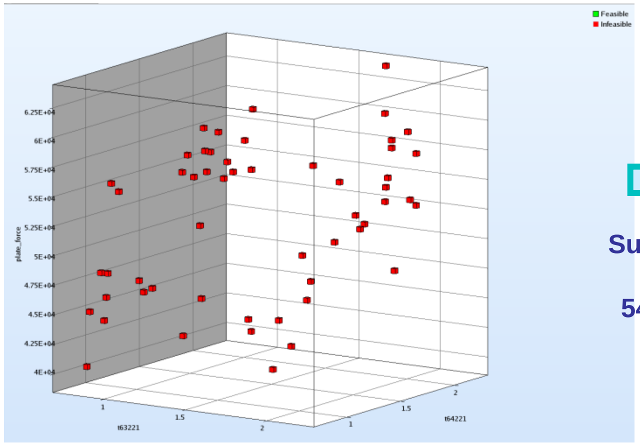


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

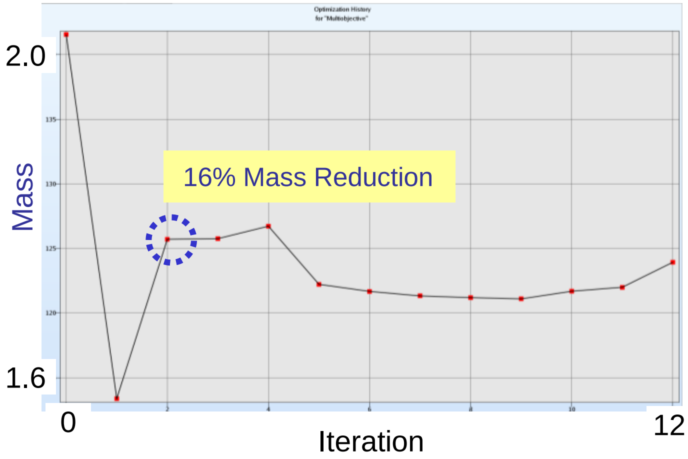
Design space exploration - Iteration 2:



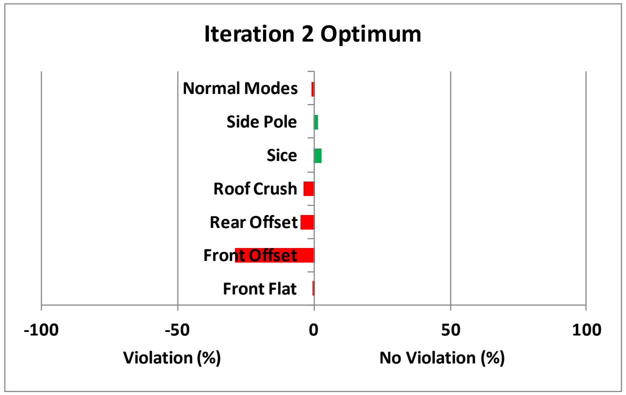
HPC
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**756**	**36396**	**190620**

Optimization History:



Optimal Point - Performance Targets (Constraints):



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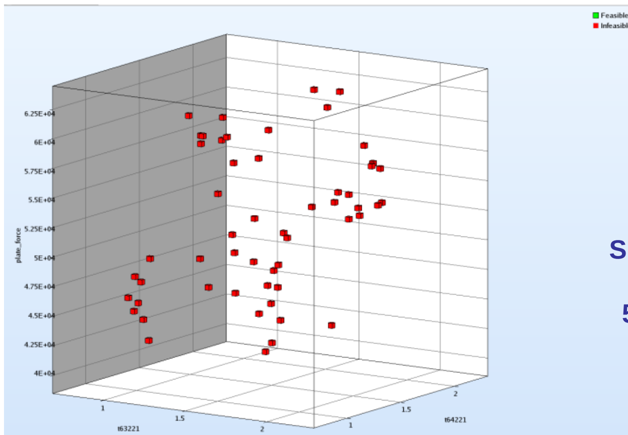
Design space exploration - Iteration 3:

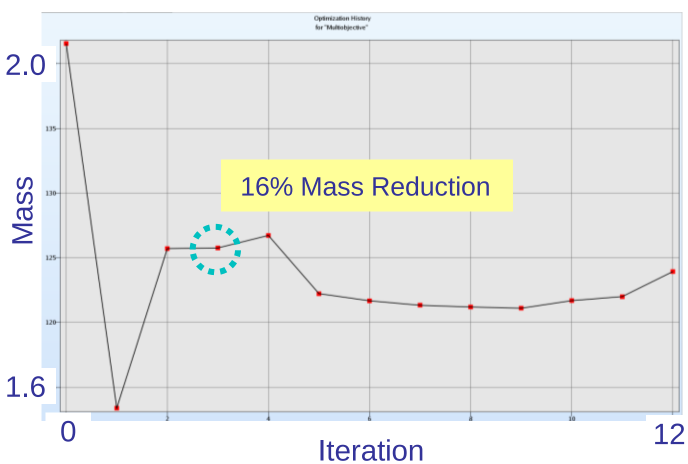


HPC

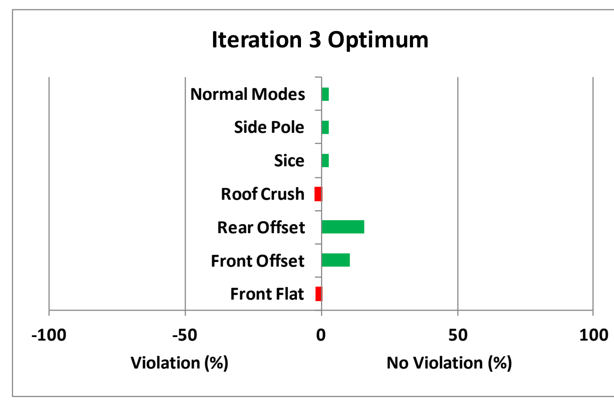
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**1134**	**54594**	**285930**

Optimization History:

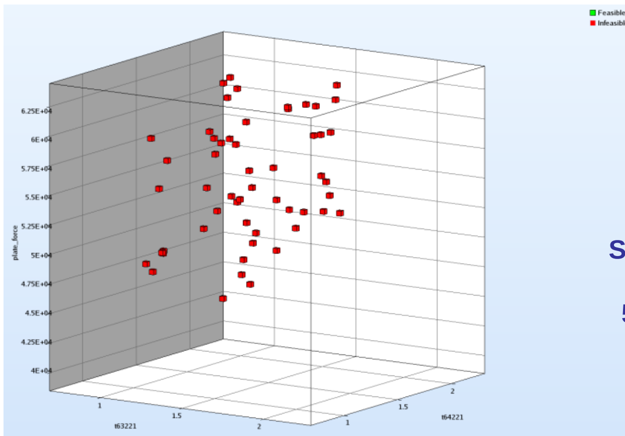


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

Design space exploration - Iteration 4:

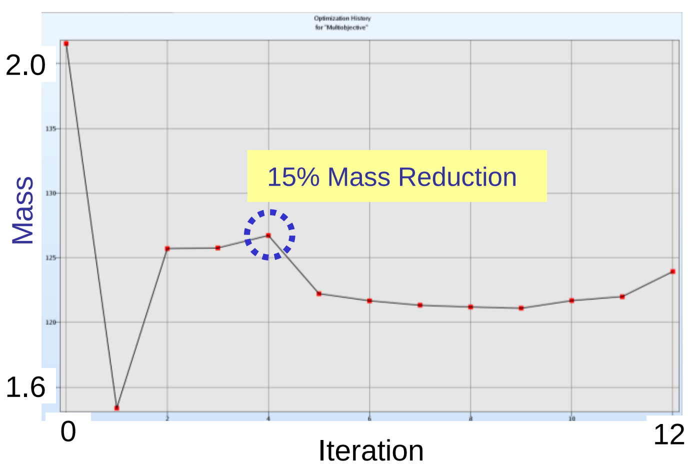


HPC

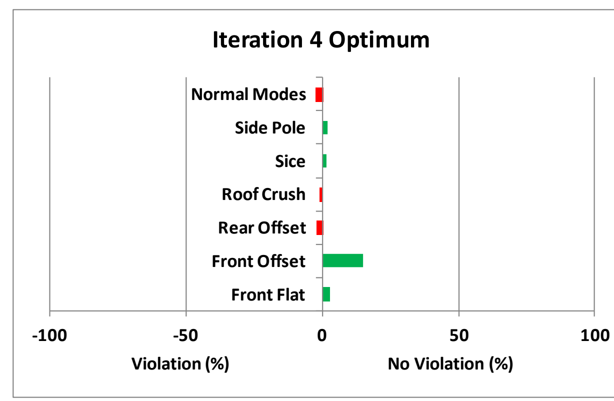
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**1512**	**72792**	**381240**

Optimization History:

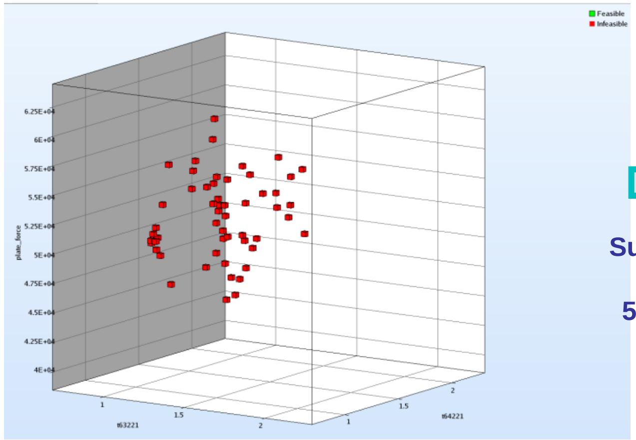


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

Design space exploration - Iteration 5:

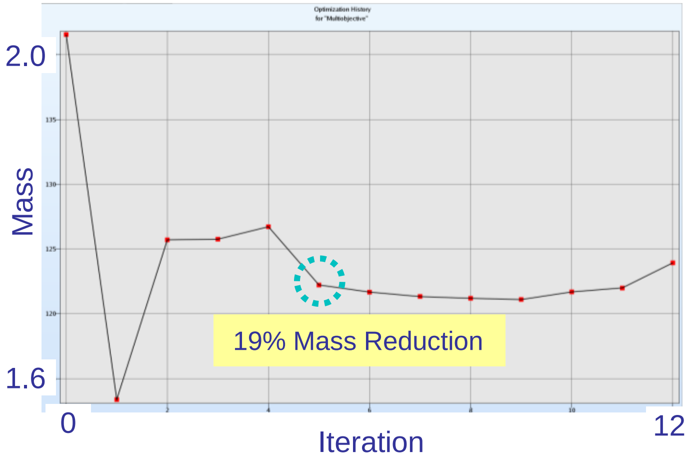


HPC

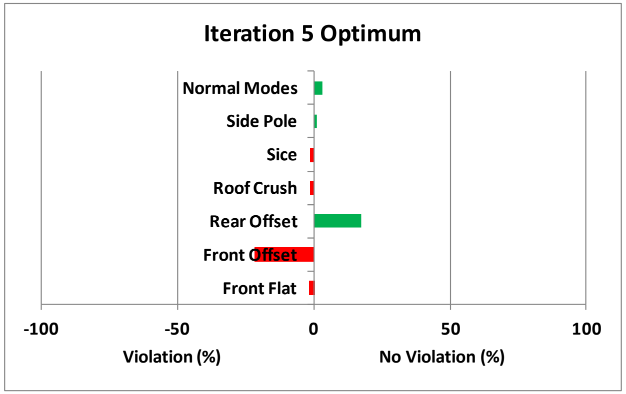
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**1890**	**90990**	**476550**

Optimization History:

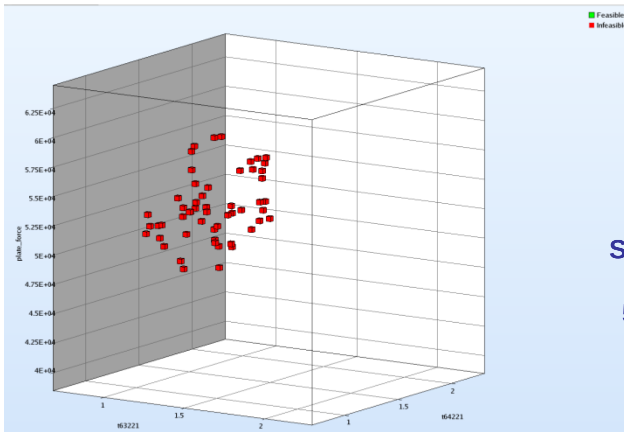


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

Design space exploration - Iteration 6:

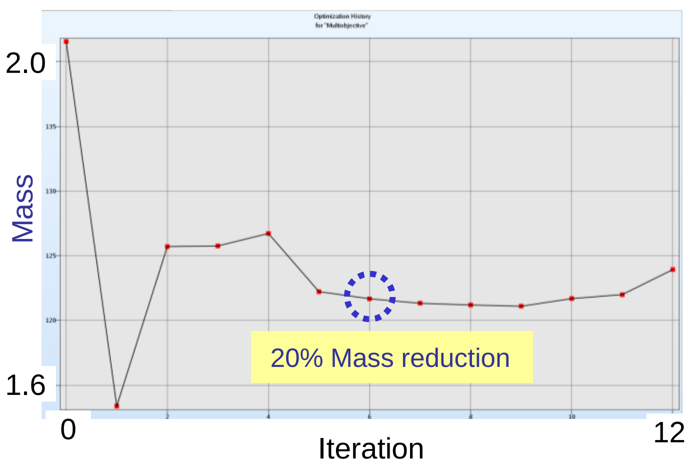


HPC

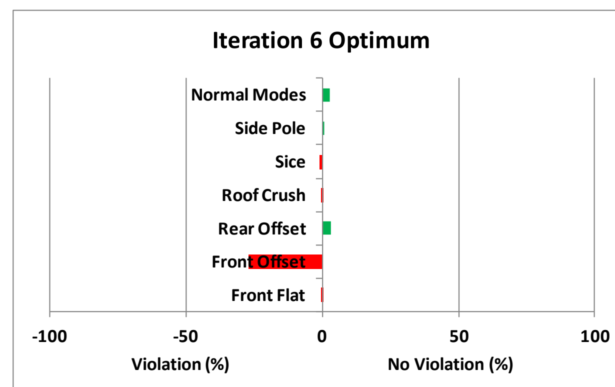
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**2268**	**109188**	**571860**

Optimization History:



Optimal Point - Performance Targets (Constraints):



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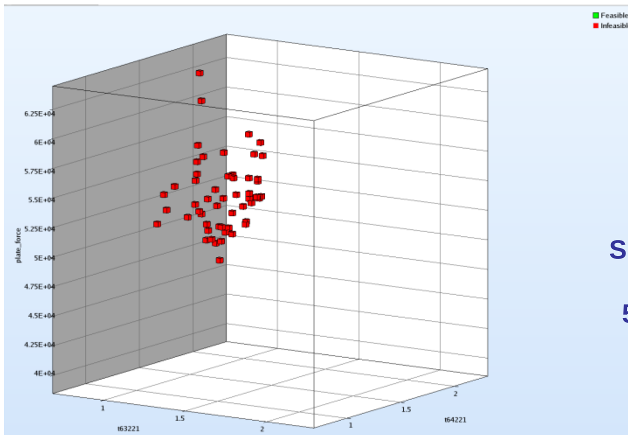
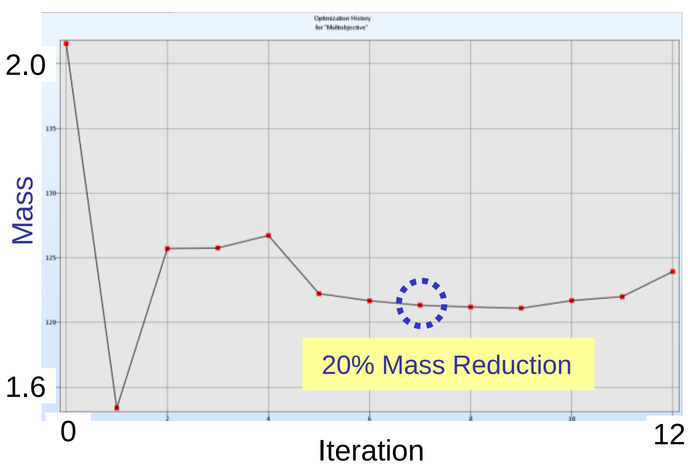
Design space exploration - Iteration 7:



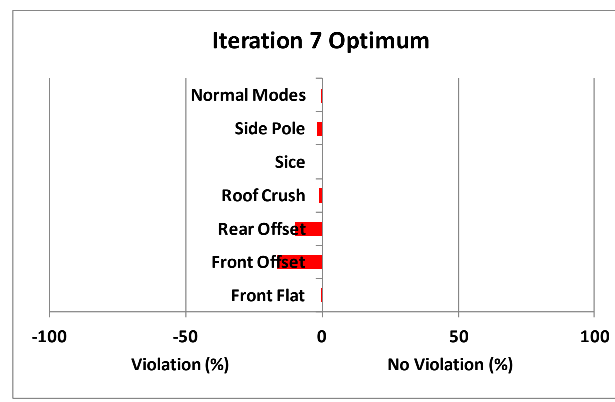
HPC Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**2646**	**127386**	**667170**

Optimization History:



Optimal Point - Performance Targets (Constraints):



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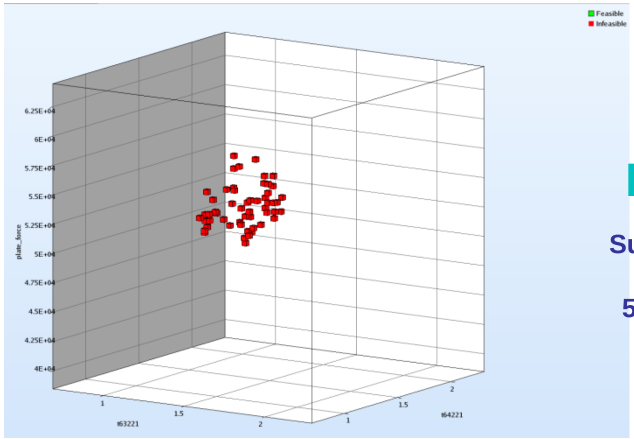
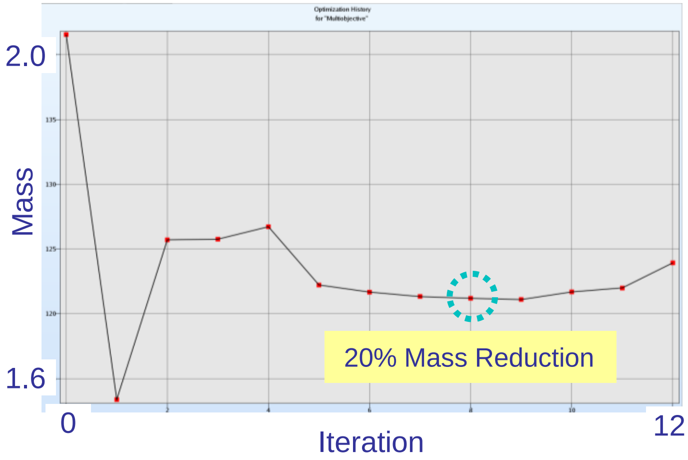
Design space exploration - Iteration 8:



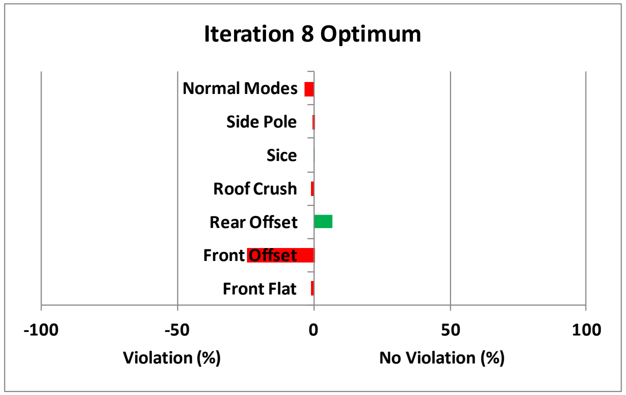
HPC
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**3024**	**145584**	**762480**

Optimization History:



Optimal Point - Performance Targets (Constraints):



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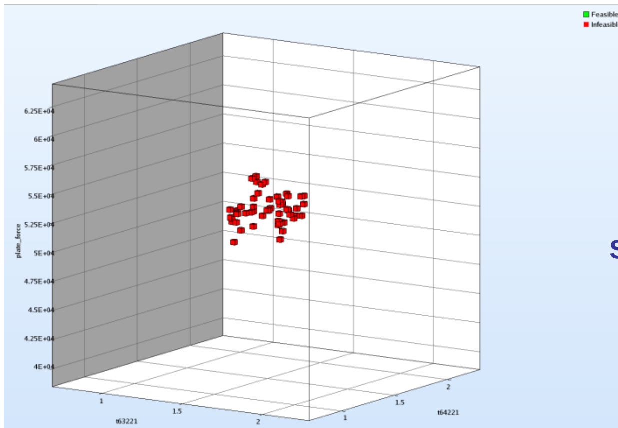
Design space exploration - Iteration 9:

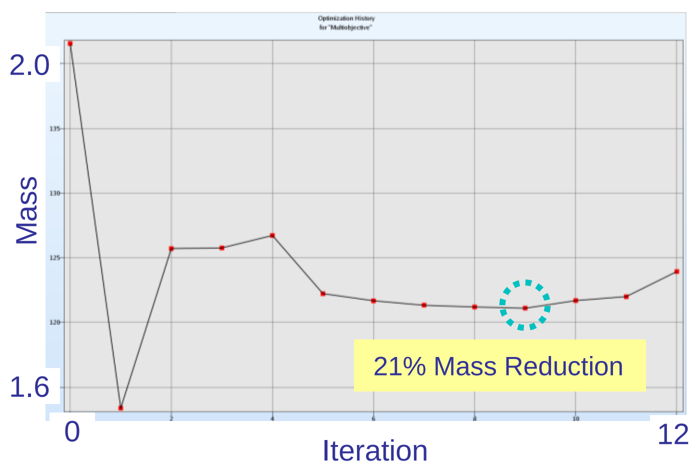


HPC

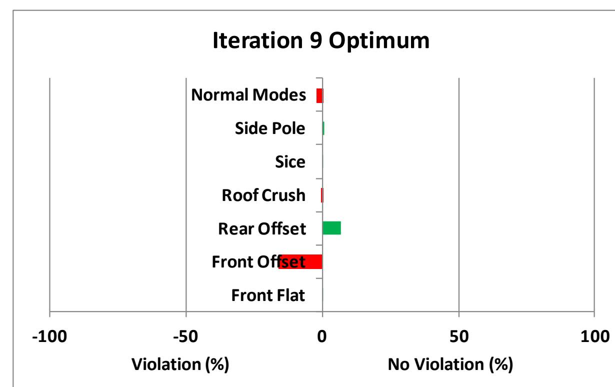
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**3402**	**163782**	**857790**

Optimization History:

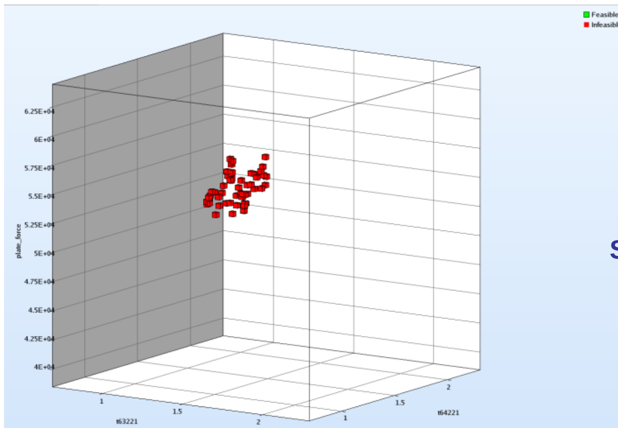


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

Design space exploration - Iteration 10:

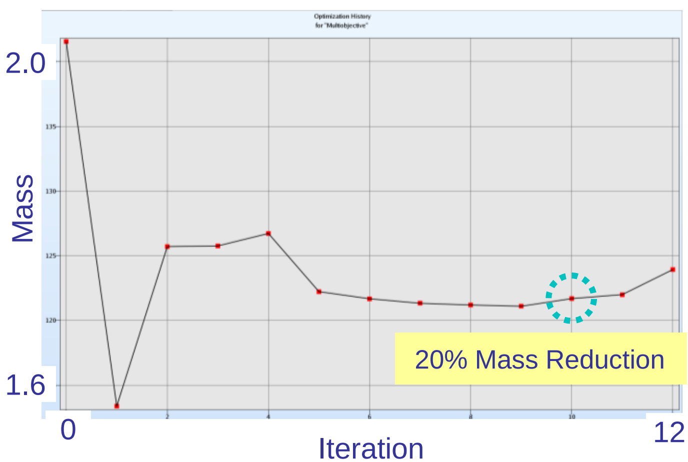


HPC

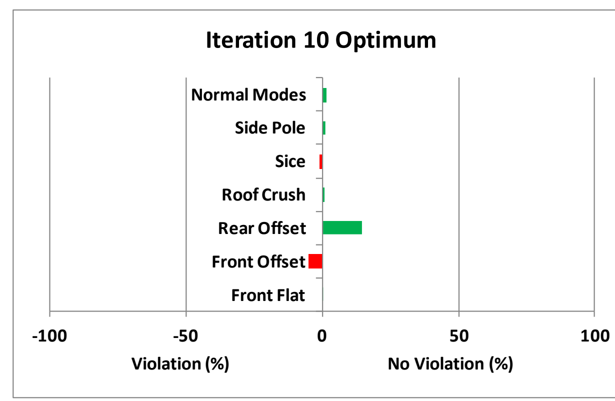
Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**3780**	**181980**	**953100**

Optimization History:

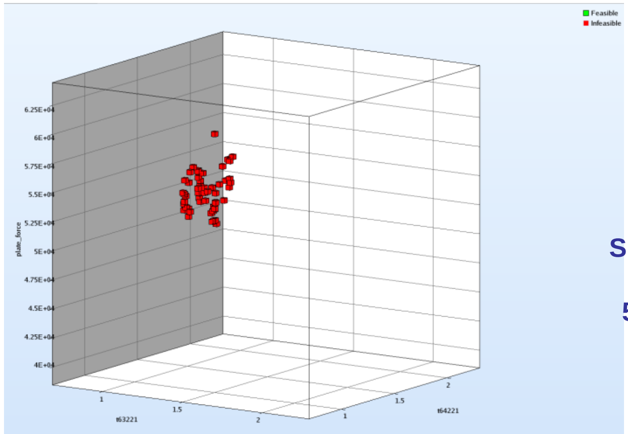


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

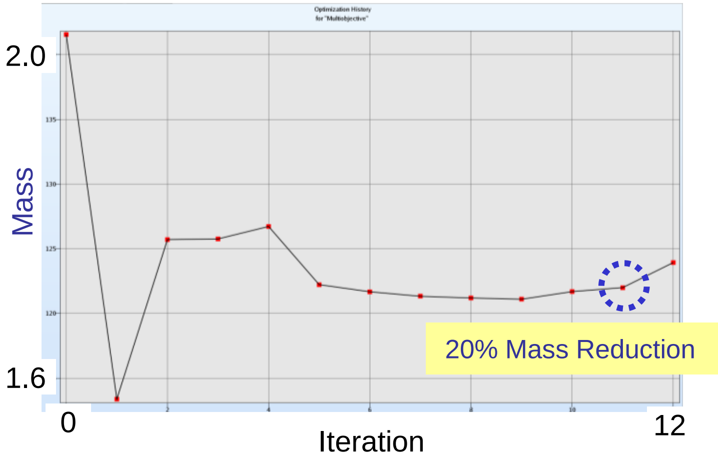
Design space exploration - Iteration 11:



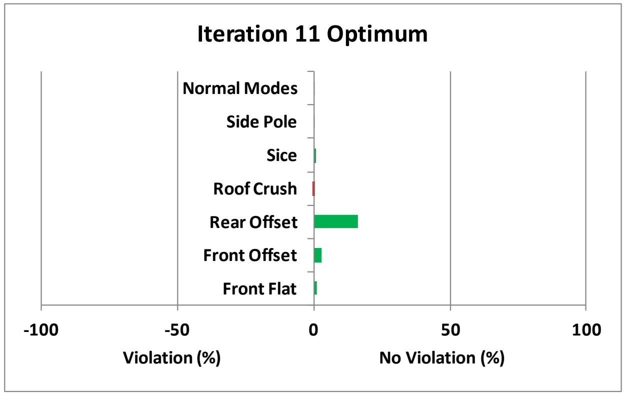
HPC Job Submission of 54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**4158**	**200178**	**1048410**

Optimization History:

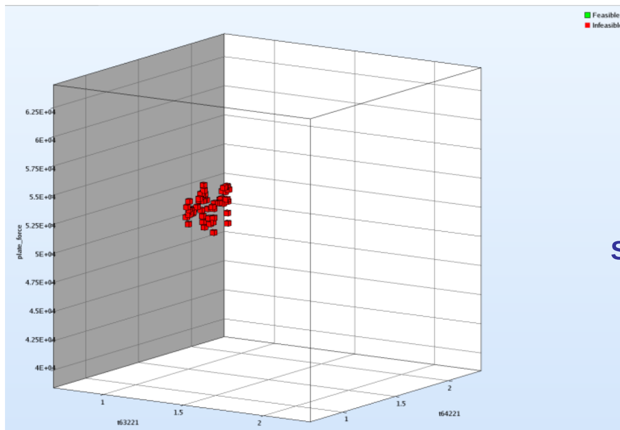


Optimal Point - Performance Targets (Constraints):



SRSM MDO Application

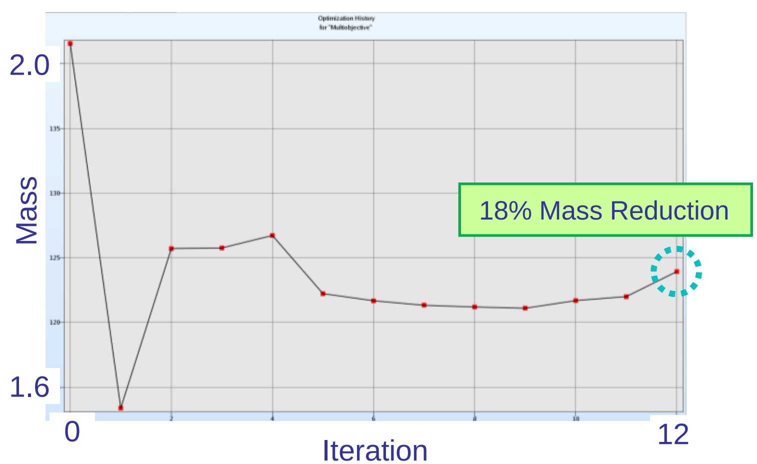
Design space exploration - Iteration 12:



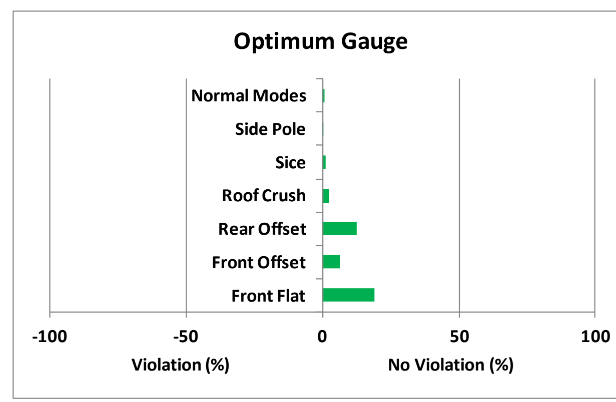
HPC
Job
Submission
of
54 Design

Case	Runs	CPU/Run	CPU Hours
Front Flat	55	56	16027
Front Offset	55	56	22075
SICE	55	56	8467
Side Pole	55	56	18748
Roof Crush	55	56	15120
Rear Offset	55	56	14818
Normal Modes	55	1	54
Running Totals	**4536**	**218376**	**1143720**

Optimization History:

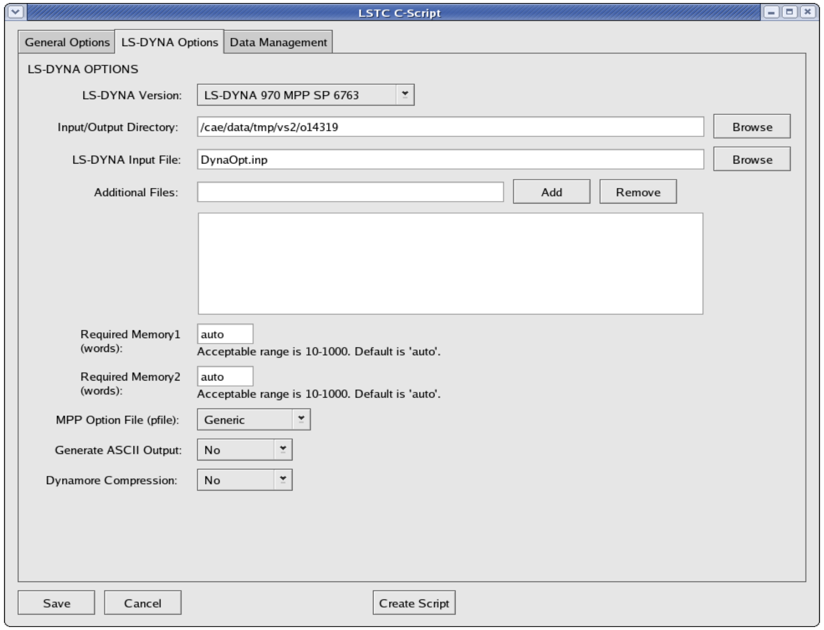


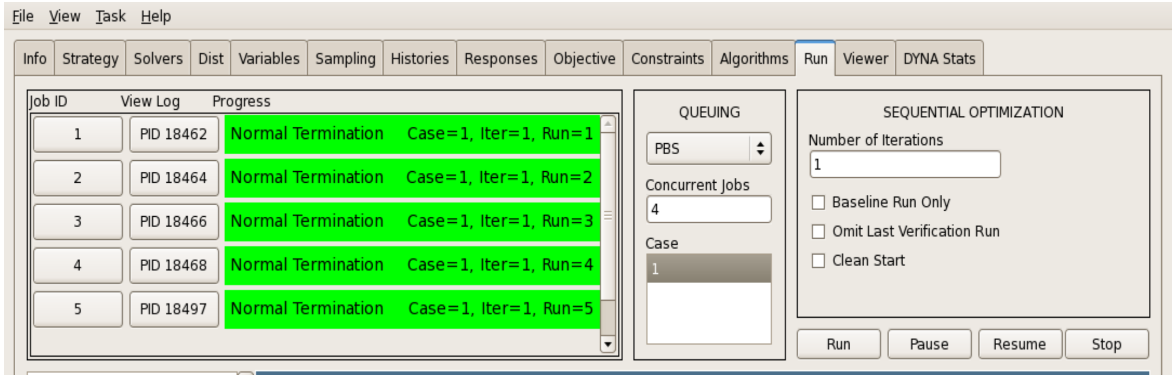
Optimal Point - Performance Targets (Constraints):



LSOPT 4.x/VM Server

HPC Integrated Environment within LS-OPT:





Conclusions

- The sequential response surface method with domain reduction (SRSM) of LS-OPT has proved very effective in finding optimal solutions for single objective multi-disciplinary design optimization problems.

- By developing the LS-OPT server the application has been integrated into the HPC environment and is an effective and efficient tool for optimization.

Acknowledgements

- The author would like to acknowledge the work of colleagues at Honda R&D:

- Allen Sheldon[1], Edward Helwig[1], and Yong-Bae Cho[2], *"Investigation and Application of Multi-Disciplinary Design Optimization for Automotive Body Structure Development", Proceedings of the 8th LS-DYNA Users Conference, Strasbourg, 2011*

- Ohio Supercomputing Center

- Trent Eggleston (LSTC)

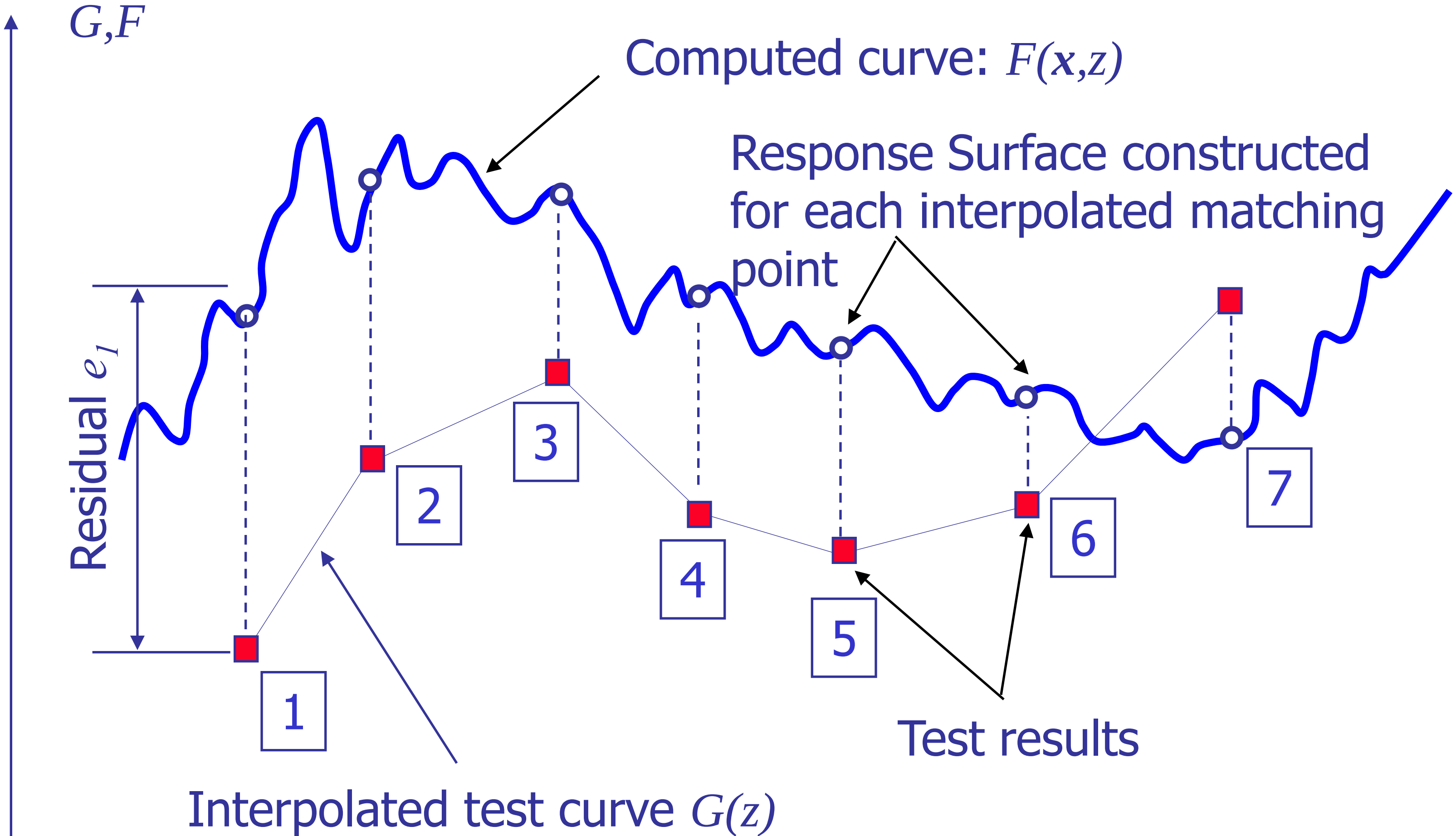
[1] *Honda R&D Americas, Inc.*

[2] *CSM Software, Inc.*

Parameter Identification

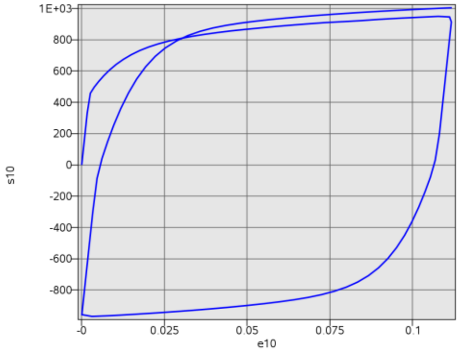
- Used for calibrating material or system properties
- Technologies
  - Curve Matching
    - **Ordinate-based**: Use differences in the Y-coordinate
    - **Curve Mapping**: Use the area between curves
  - Optimization
    - Sequential with Domain Reduction
  - Approximation
    - Metamodel at each time history increment

Ordinate-based



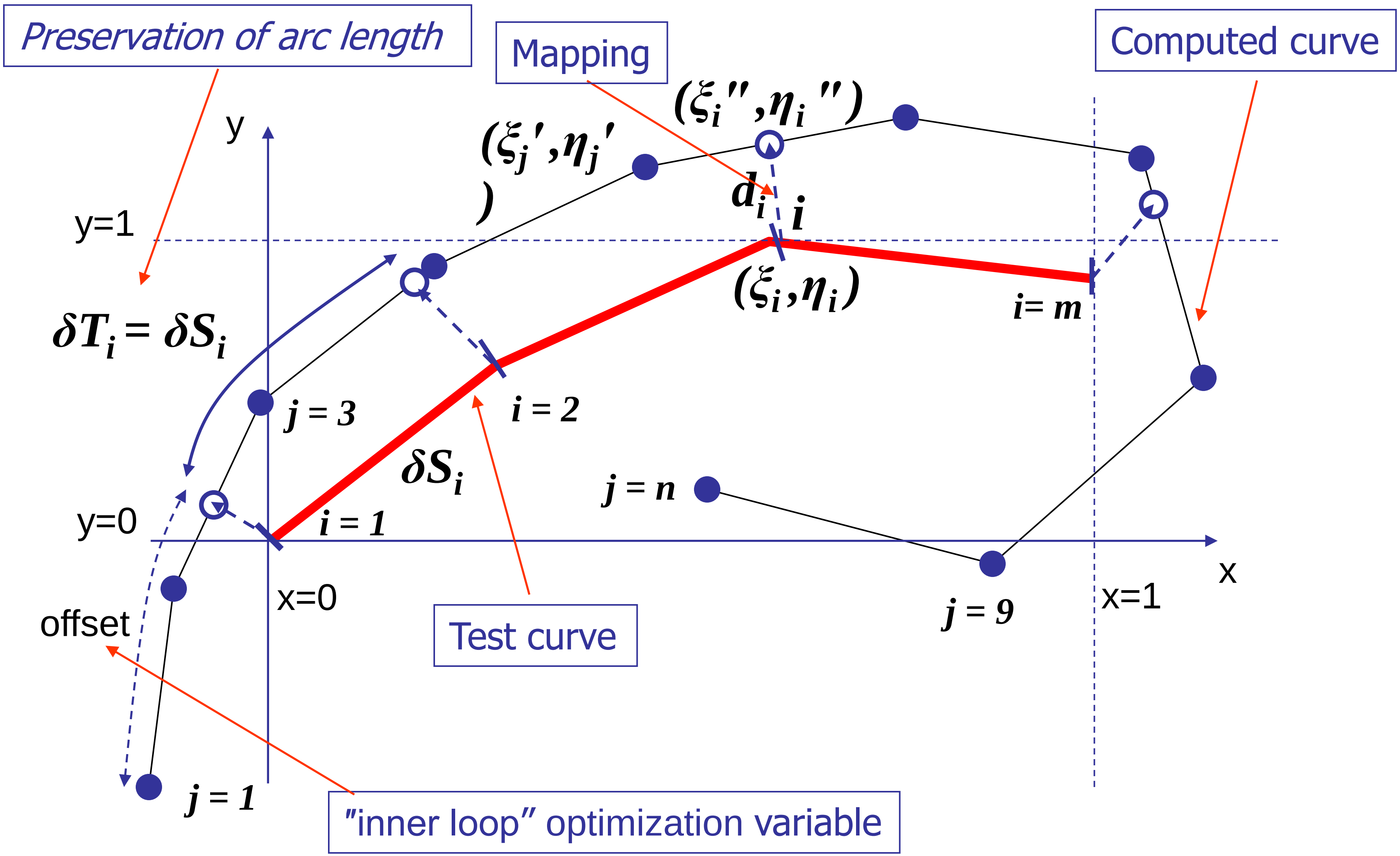
Problems with ordinate-based curve matching

- Steep parts of the response are difficult or impossible to incorporate, e.g. linear elastic range or failure (damage models such as the GISSMO model in LS-DYNA®)
- Robustness: Ranges of the computed and test curves do not coincide in the abscissa at an interim stage of the optimization resulting in instability
- Hysteretic test curves or springback cannot be matched since the ordinate values are non-unique



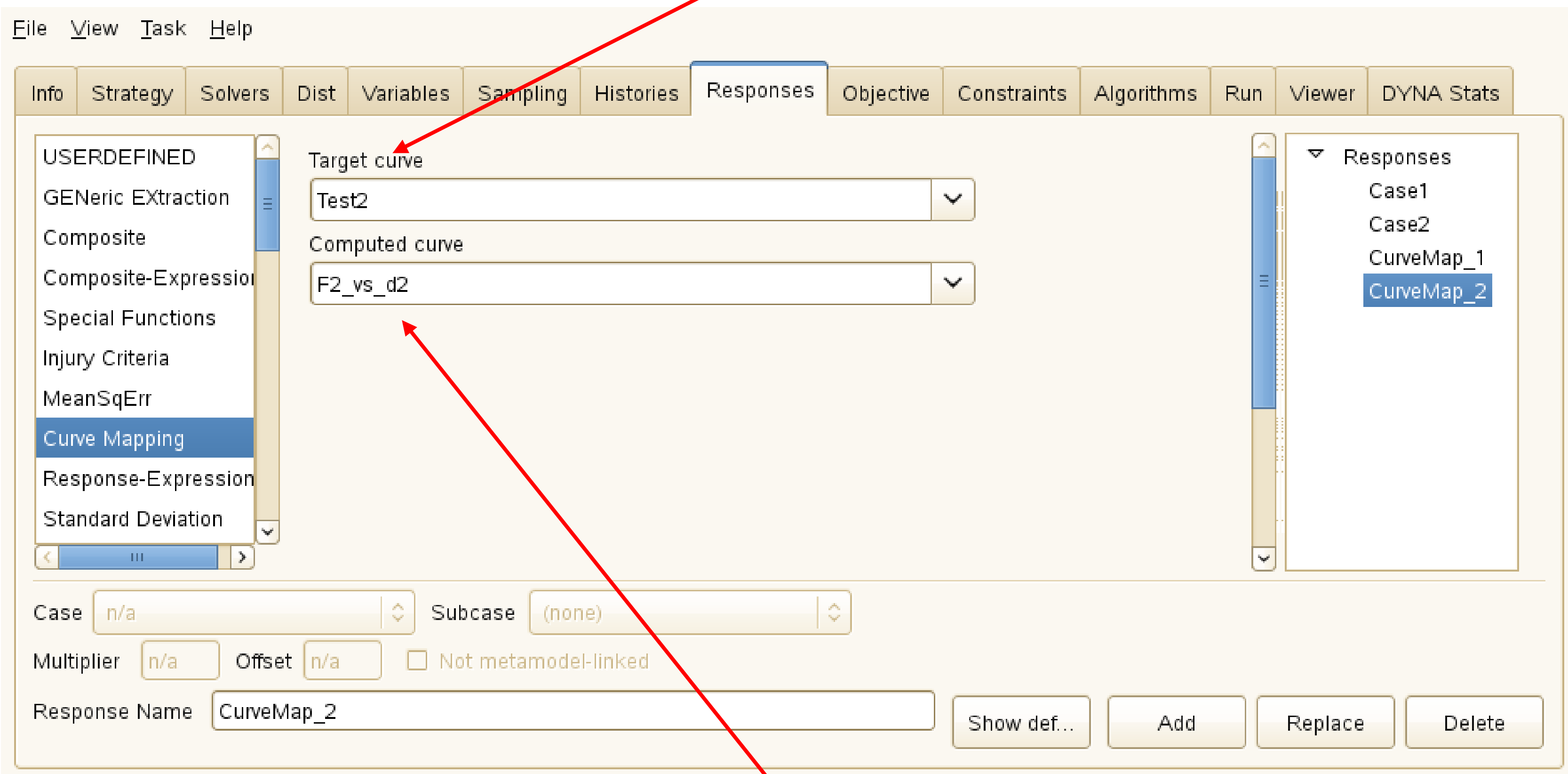
Witowski K, Feucht M & Stander N, An Effective Curve Matching Metric for Parameter Identification using Partial Mapping. *Proceedings of the 8 th European LS-DYNA Users Conference, Strasbourg, 2011*

Partial Curve Mapping



LS-OPT 4.2 Interface for Curve Mapping

Imported experimental curve in 2-column format

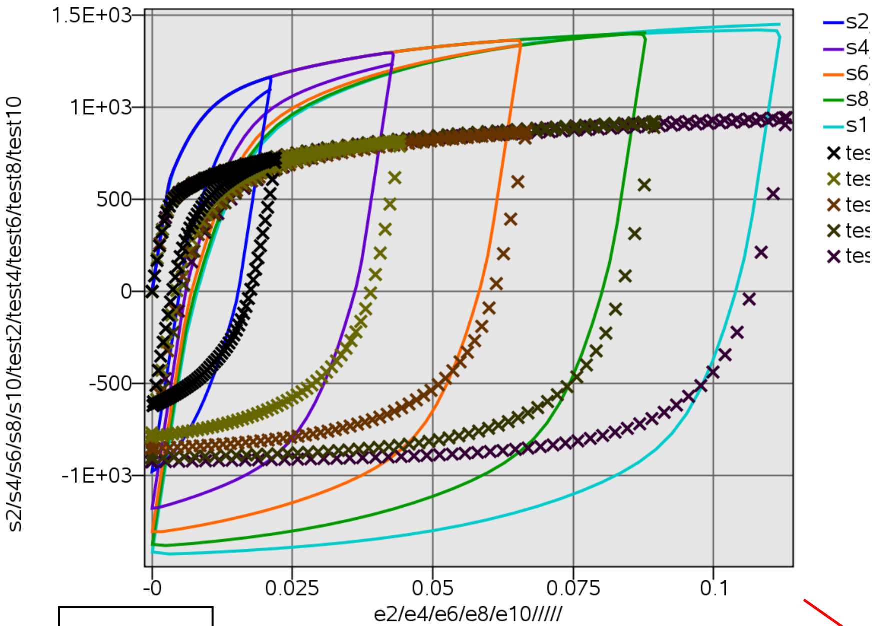


Computed history/crossplot

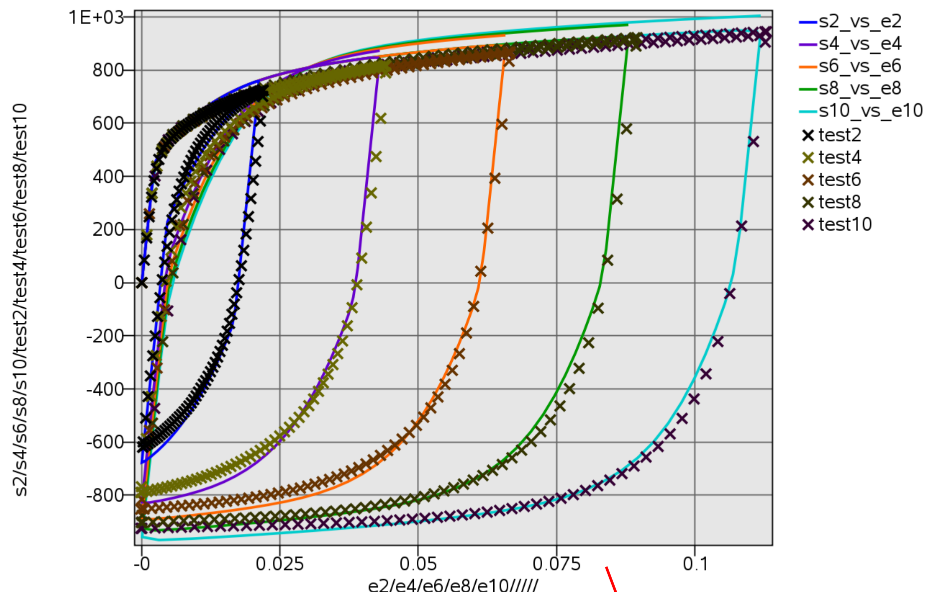
Example 4: Bauschinger effect (Material 125)

- Automotive sheet steel, particularly advanced high strength steels, display the Bauschinger effect and require special material models
- LS-DYNA Material *125* (Yoshida model with recent improvements by Shi, Zhu, Xia & Stoughton)
- Model identification requires a tension and compression test

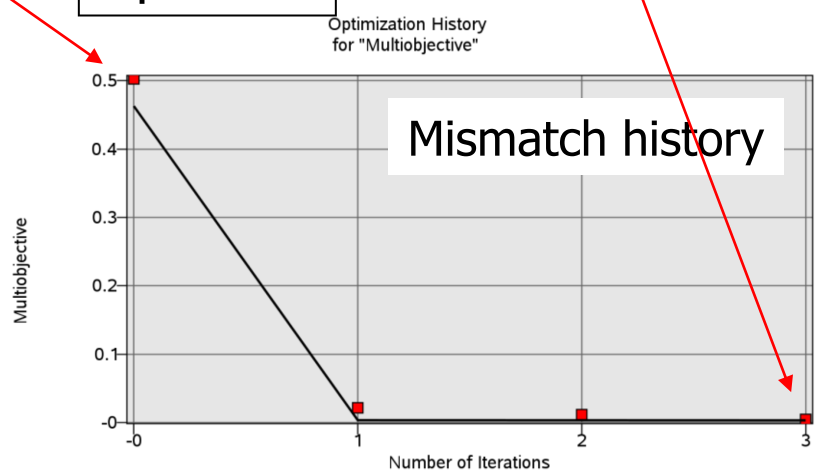
Example 4: Bauschinger effect (Material 125)



Start



Optimum



9 parameters

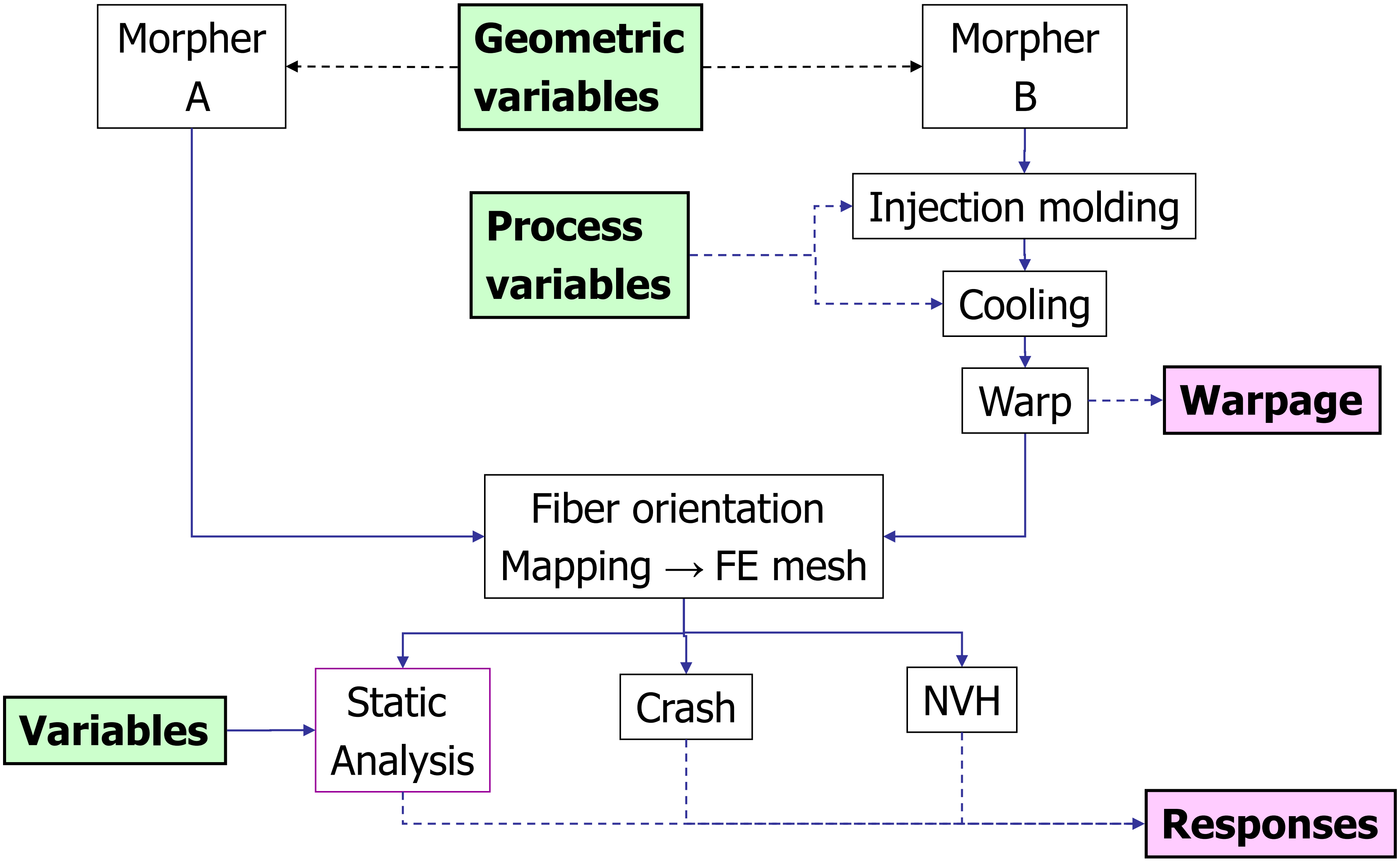
5 tension/compression cases

Conclusions

- LS-OPT has been shown to run successfully on industrial design optimization and material identification problems
- The design problem was solved entirely on site by the customer with support of the LS-OPT team.
- The bulk of the effort was to refine the job scheduling capabilities
- As a result, and with the correct support, a similar setup could recently be achieved very quickly at another major automotive customer
- Material calibration: The Partial Curve Mapping algorithm is able to easily identify complex materials with hysteretic behavior

Preview: Version 5

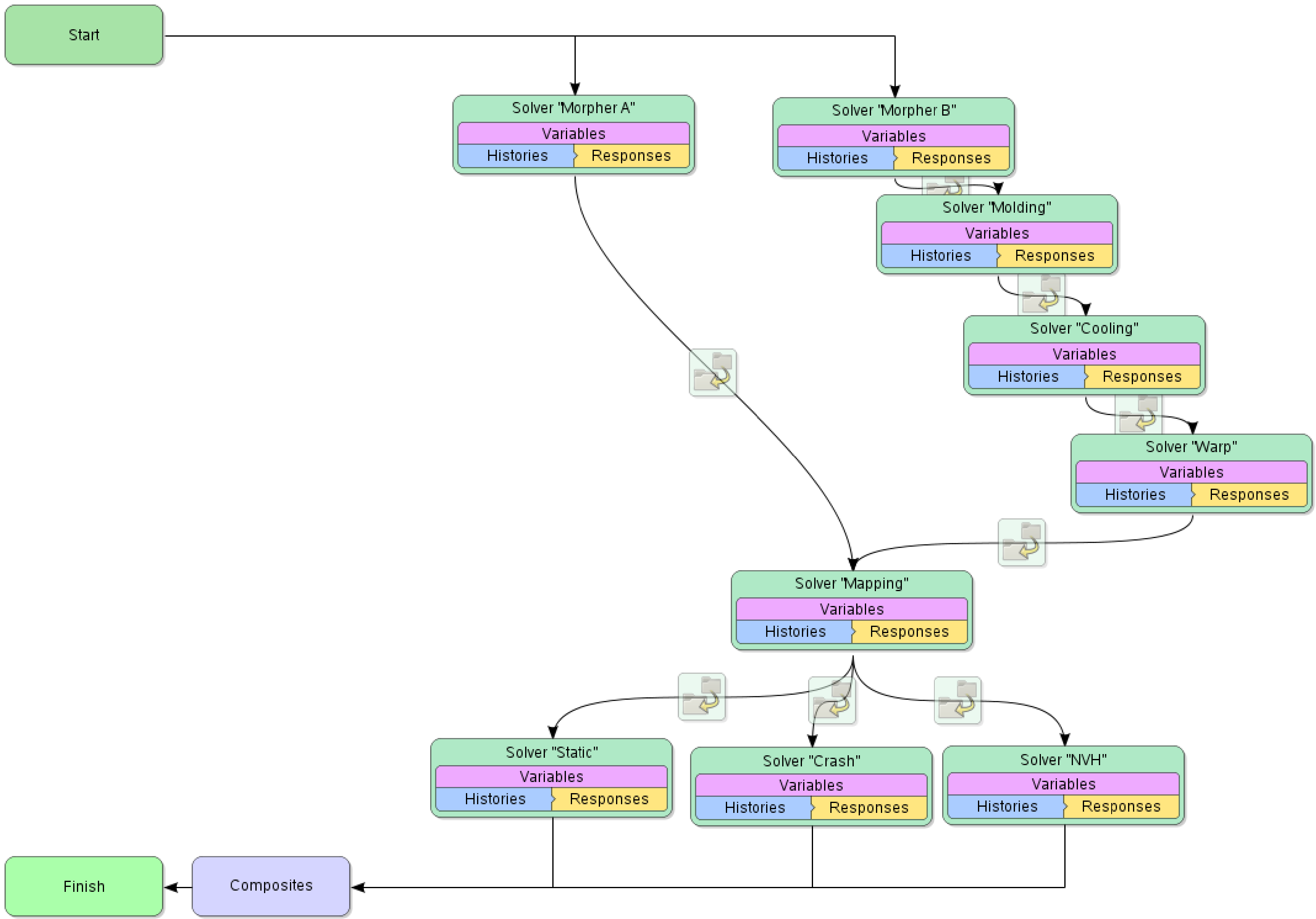
Process modeling
Merging and branching



LS-OPT Goals – Version 5

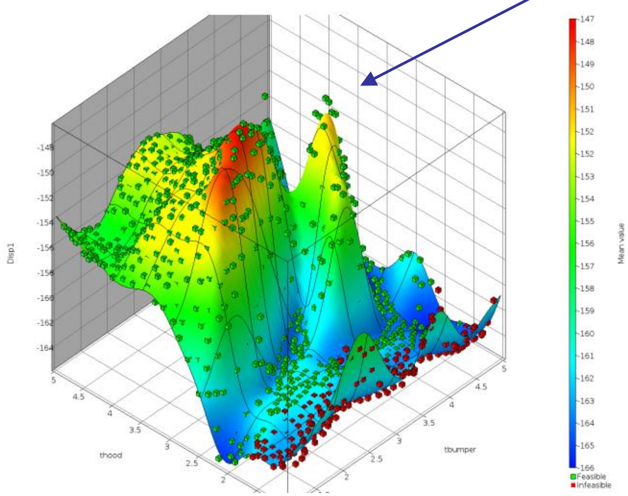
- Process Simulation & Optimization
  - Process flow with merging and branching
  - File handling: Copy, move, link, delete
  - Load balancing of the process jobs
- Preserve simplicity: launch/monitor single Dyna job
- Step-wise analysis
- Display run status
  - Unfinished stages, error terminations

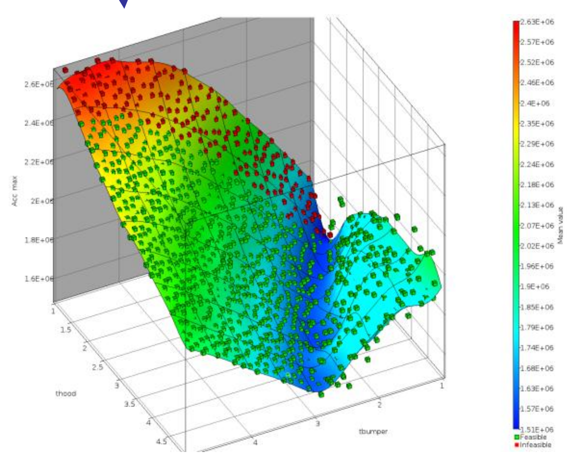
Process Modeling (Version 5)

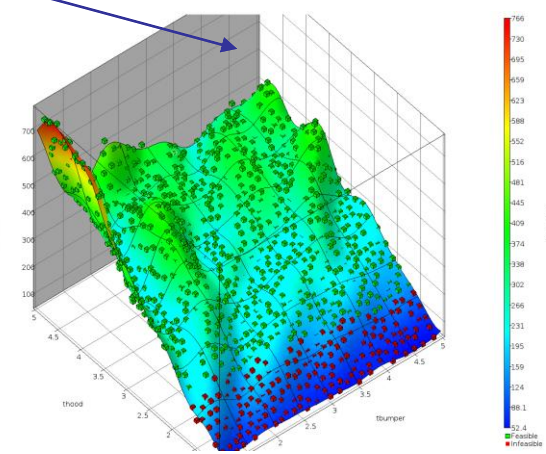


Outlook: Multiple surrogates

- <u>Improved accuracy</u>: Use multiple surrogate types as basis models for generating a surface potentially more accurate than any single surrogate
- <u>Automates the model choice:</u> Eliminates user choice
- Basis models: polynomials, RBF, neural nets, Kriging, <u>Support Vector Regression</u>







Other topics/recent implementations

- Upgrade of Mode Tracking for MPP implicit version of LS-DYNA (v4.2) - complete
- Standalone history filter (v4.2) - complete
- Improved convergence for Multi-objective optimization (v5.0).