



LS-OPT[®]: Status and Outlook

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LS-DYNA Users Forum, Bamberg, Germany

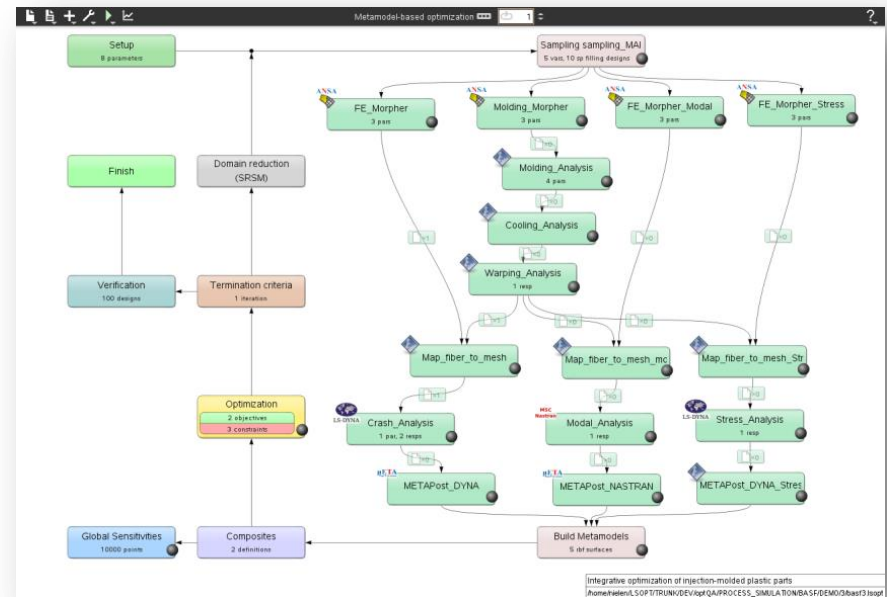
October 7, 2014

Contents

- ◆ Overview
- ◆ Enhancements in 5.1
- ◆ Outlook

LS-OPT: Brief overview

- ◆ Optimization
 - ◆ Direct and Metamodel-based
- ◆ Reliability and Robustness (RBDO)
- ◆ Process Optimization
- ◆ Multiple solvers, pre-, post-processors
- ◆ *Network-based*
 - ◆ *Job scheduling*
 - ◆ *Monitoring*
 - ◆ *Control*
- ◆ Parameter Identification (Materials, Systems)



LS-OPT Methodology

◆ Metamodel-based Optimization/Reliability

- ◆ Discrete-Continuous problems (Sizing/Shape)



- ◆ Benefits derived from metamodels

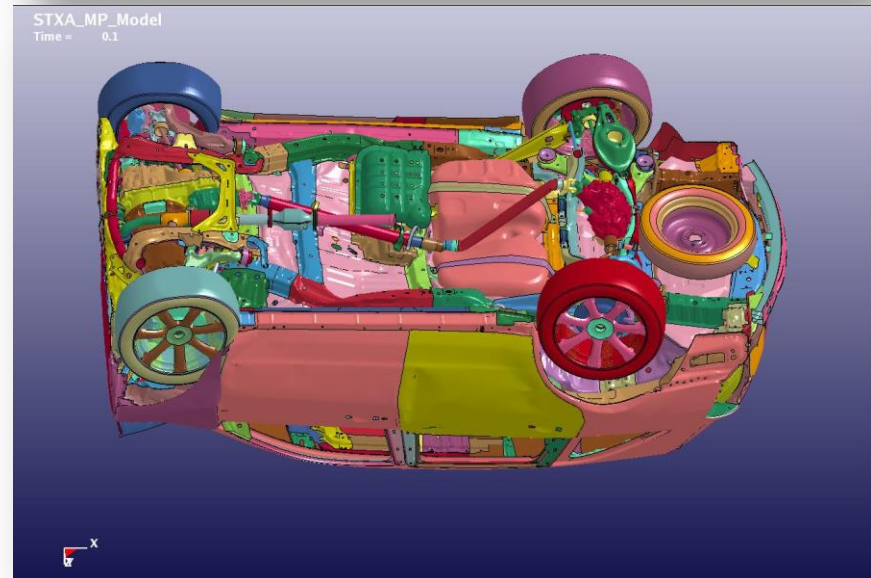
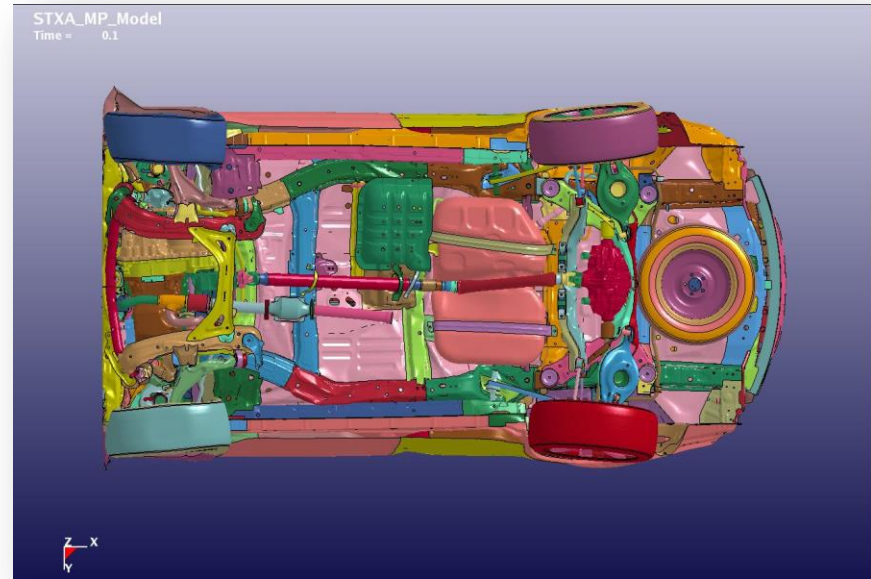
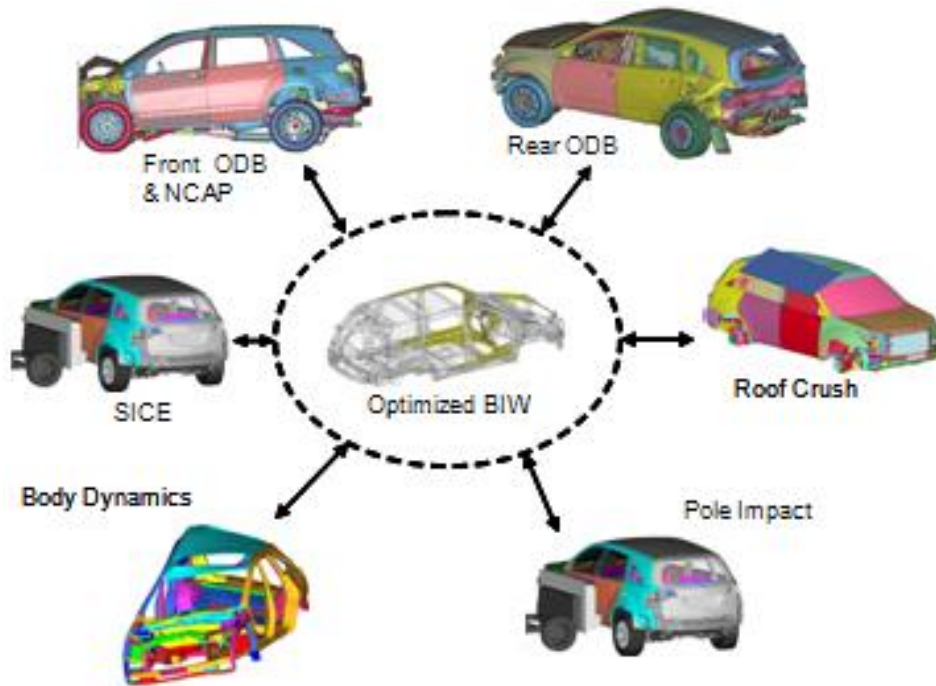
- Build a global model of the design for graphical exploration
- Stochastic methods inexpensively applied
 - ◆ Reliability and Robustness Analysis/Optimization
 - ◆ Global Sensitivity Analysis
 - ◆ Outlier Analysis
 - ◆ Tolerance Optimization

◆ Direct Optimization

- ◆ Global Optimization
- ◆ Integer (category, material), Discrete-Continuous, Multi-Objective

Vehicle Crash Example: MDO Model detail

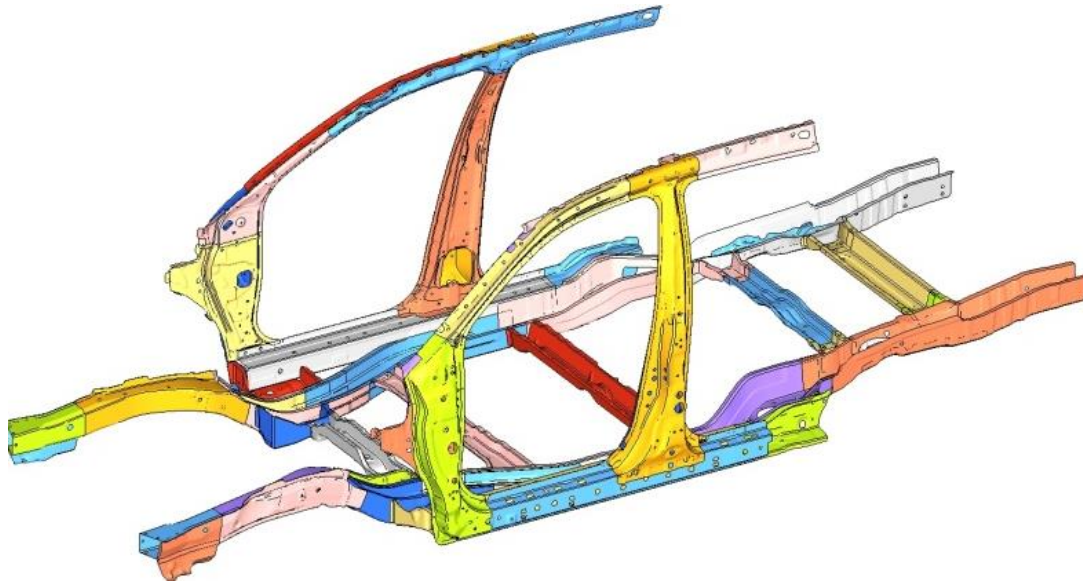
6 Crash Modes + Body Dynamics Mode:
- approximately **3 million element** models



Allen Sheldon, Ed Helwig (Honda R&D)

Vehicle Crash Example: Design Formulation

35 Continuous Thickness Variables:
33% of BIW mass



Allen Sheldon, Ed Helwig (Honda R&D)

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:

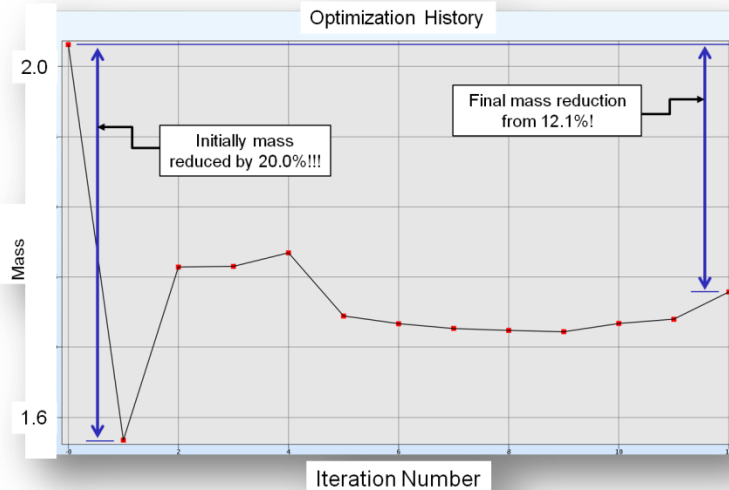
Body Stiffness

Body Frequency

Vehicle Crash Example: Setup and results

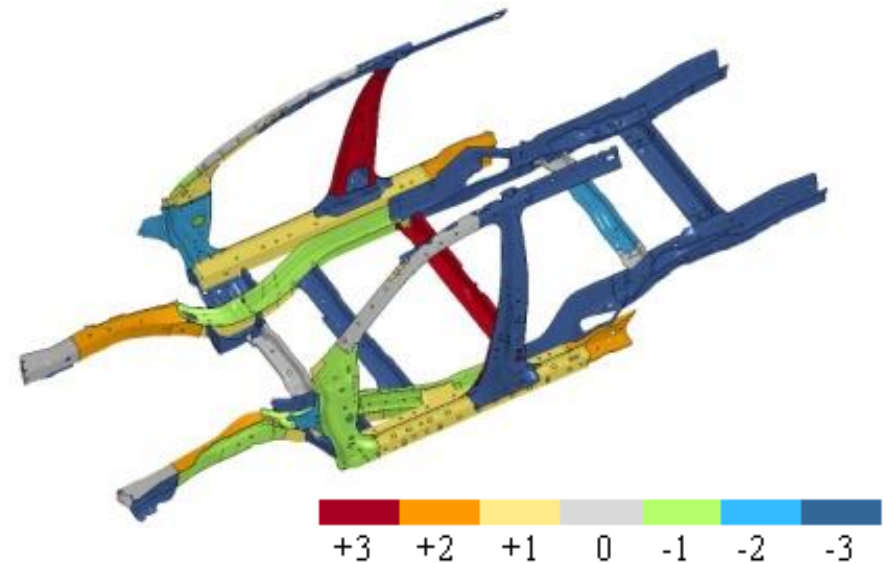
LS-OPT SRSM Settings:

- **Optimization Strategy**
SRSM (Domain Reduction)
- **Metamodel**
Radial Basis Function Network (global)
- **Point Selection**
Adaptive Space Filling
54 points per iteration



Allen Sheldon, Ed Helwig (Honda R&D)

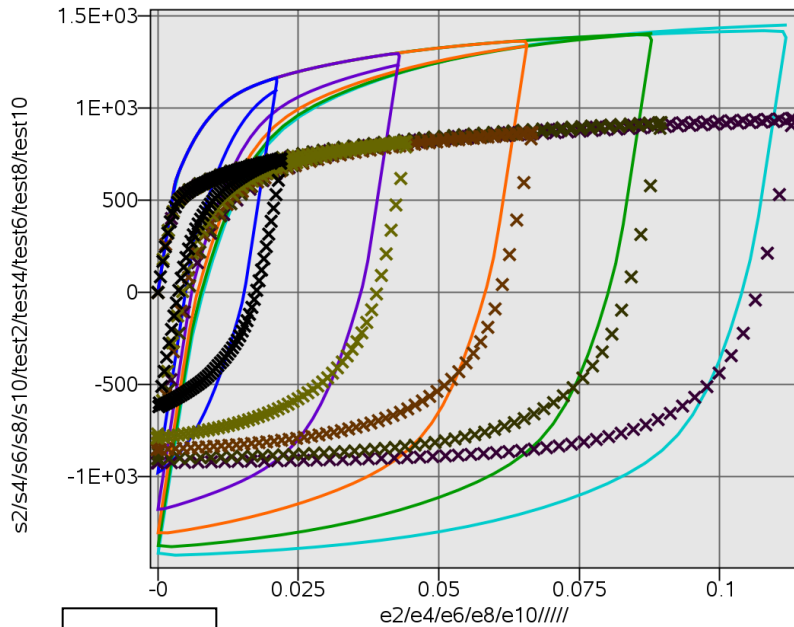
Gauge Changes



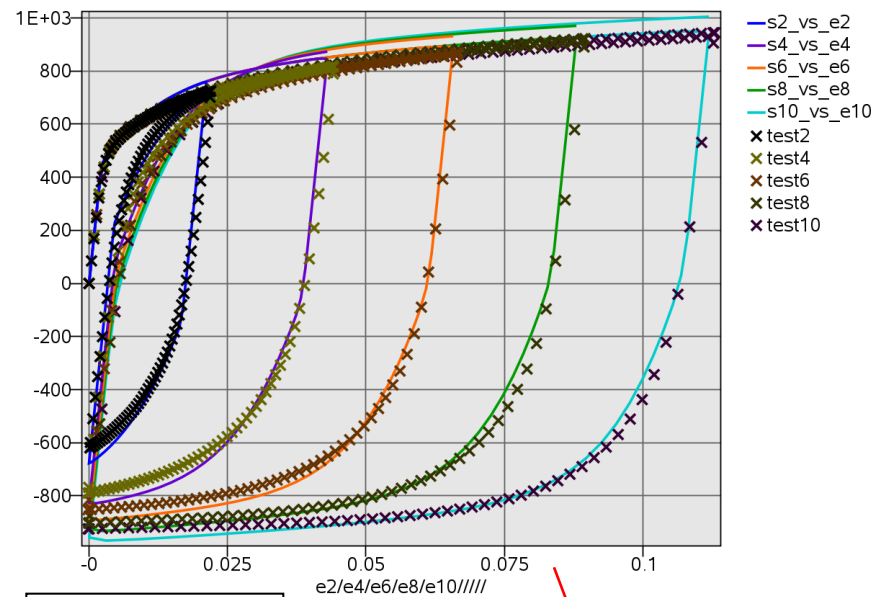
- Optimization was aggressive with a significant initial mass reduction.
- Then optimization converges as constraints are satisfied.
- Final step shows some increase in mass as variables are switched to discrete values.

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

Example: Calibration of material 125



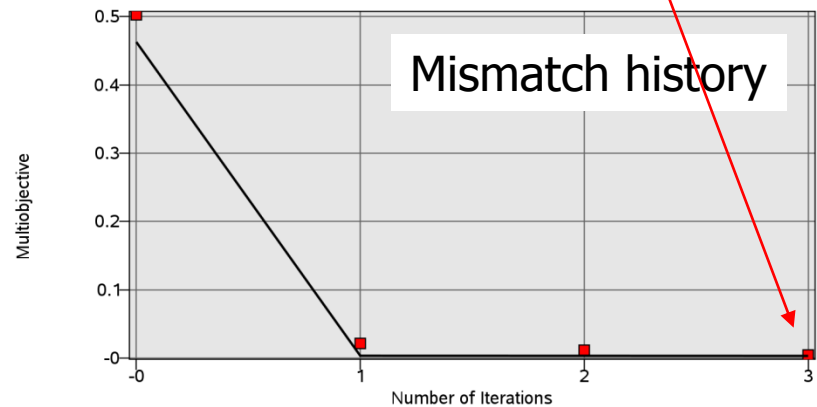
Start



Optimum

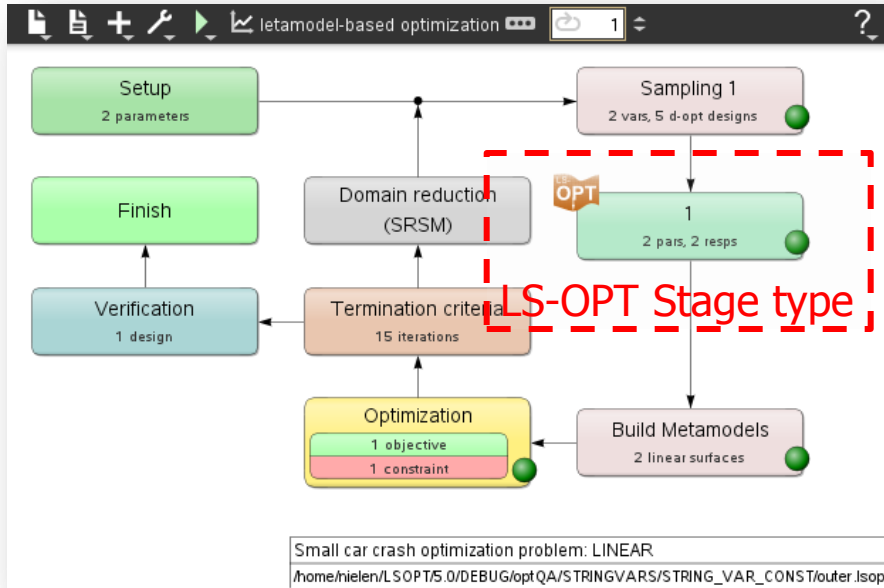
Optimization History for "Multiobjective"

9 parameters
5 tension/compression cases



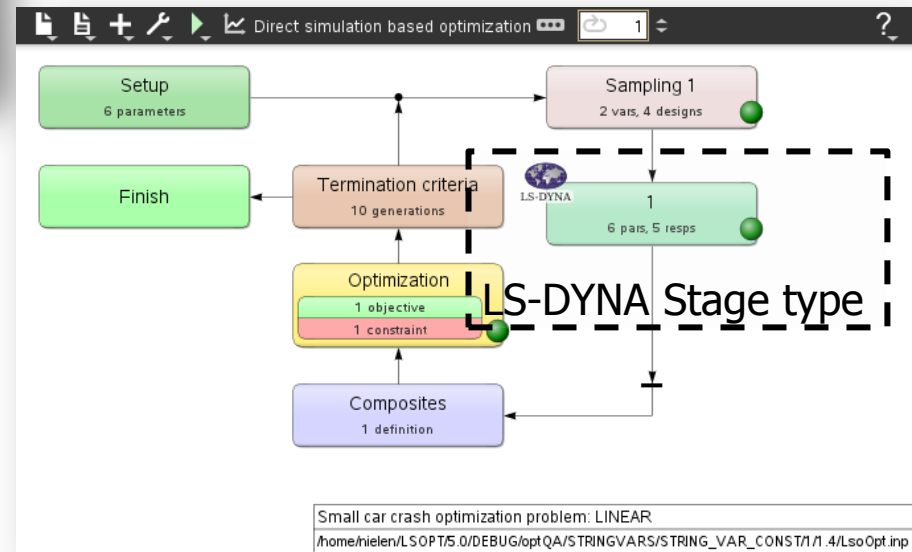
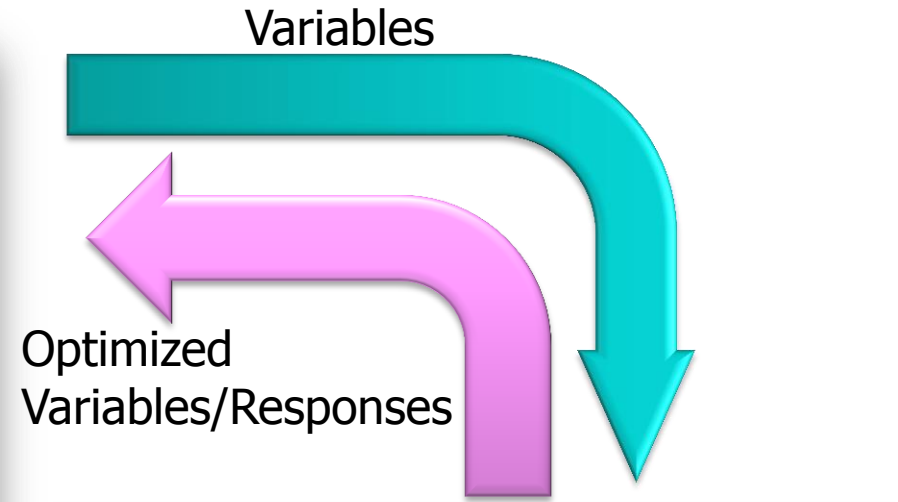
New Features

Multi-level Optimization



OUTER

- Subdivision of problem into levels
- *Nesting* the optimization problem
- *Variables* and *responses* are transferred between levels
- Inner level optimization is done for each outer level sample



INNER

Multi-level Optimization: Why?

- ◆ *Organization*. Easier to organize the problem as a collection of subsystems
- ◆ *Efficiency*. Solution algorithm takes advantage of the subproblem type
 - ◆ Can match optimization methods with variable types, e.g. materials (categorical), sizing/shape (continuous).
- ◆ *Robustness and accuracy*. Smaller sub-problems are typically solved in a relatively low-dimensional space
- ◆ Critical framework for rational decomposition methods: *Analytical Target Cascading*
 - ◆ Iterative method which resolves *inconsistencies* between individual processes with *shared* variables

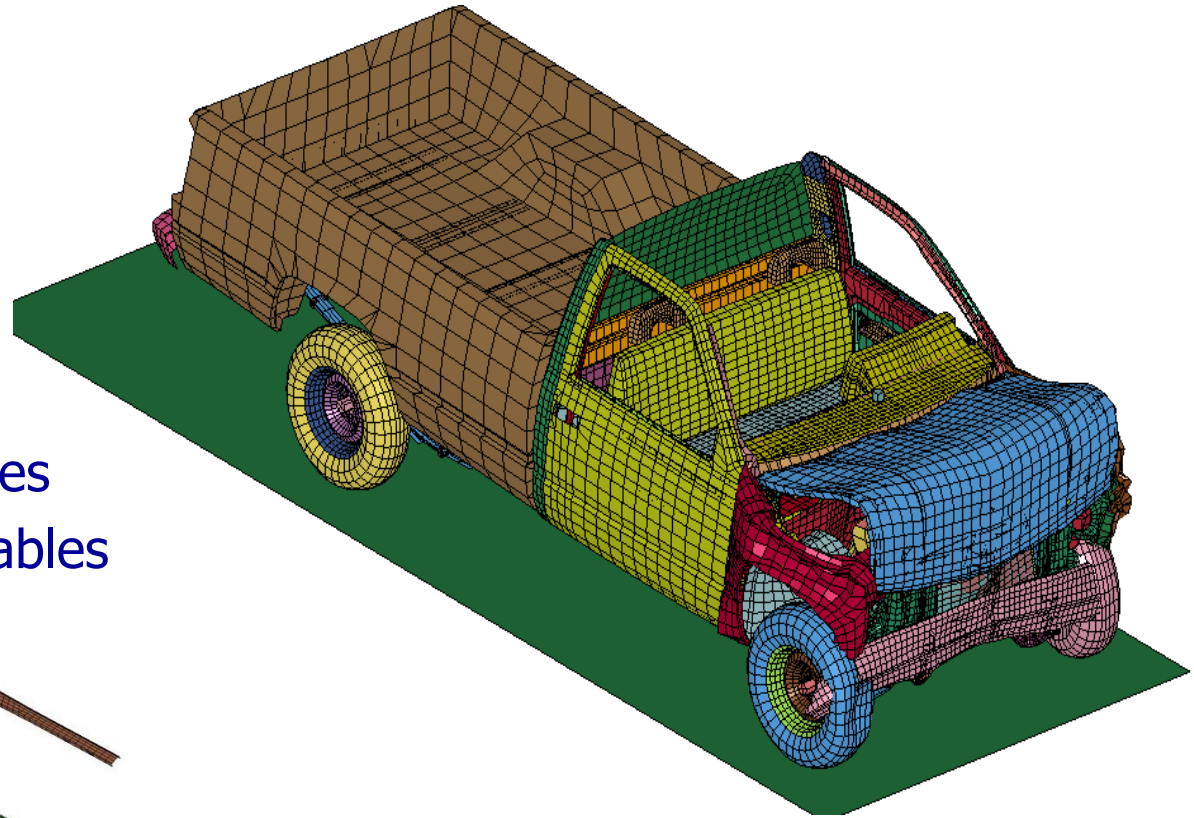
Multi-level Optimization: Applications

◆ Applications:

- ◆ System Optimization (component sublevels)
- ◆ Design of Product families
- ◆ Tolerance optimization
 - (*Basudhar, A. and Stander, N. Tolerance Optimization using LS-OPT, Proceedings of the LS-DYNA Forum, Bamberg, October, 2014*)
- ◆ Robust design using Random Fields
 - (*Craig, K.-J. and Stander, N. Optimization of shell buckling incorporating Karhunen-Loève-based geometrical imperfections, Structural and Multidisciplinary Optimization, 2008, 37:185:194*)
- ◆ Integrated Design and Materials Engineering (e.g. ICME project)
 - Engineer materials at various levels
 - Integrate materials with Forming design

Multi-level Optimization: Example -- Truck

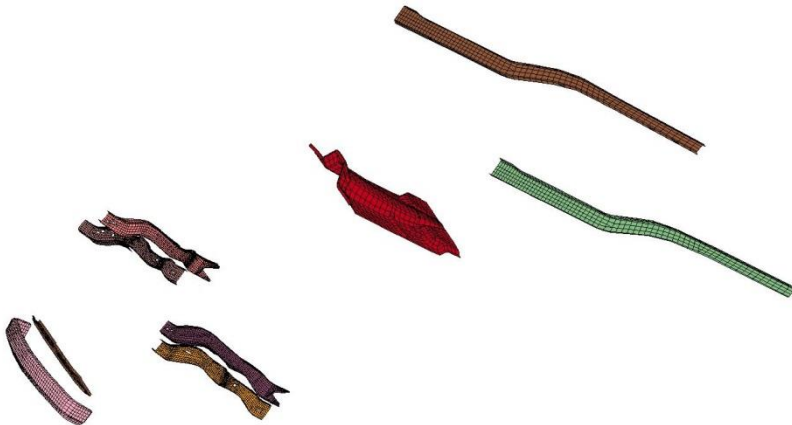
C2500 PICKUP TRUCK MODEL - (MCAC V6)
Time - 0



6 Thickness design variables

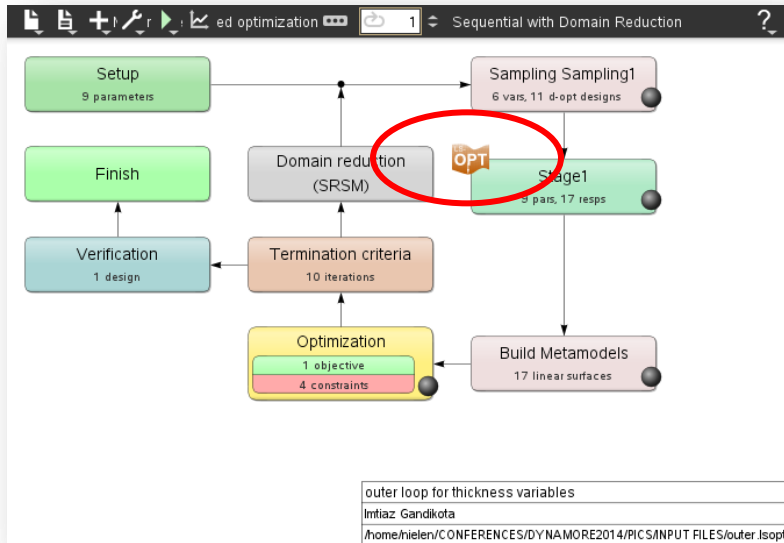
6 Material categorical variables

C2500 PICKUP TRUCK MODEL - (MCAC V6)
Time - 0

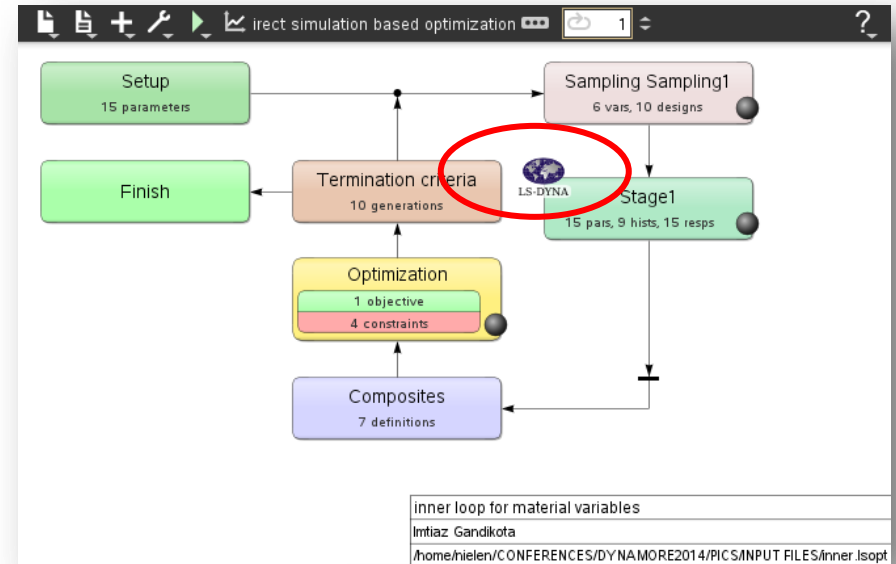


Multi-level Optimization: Example

Outer level: Continuous



Inner level: Discrete/Categorical



Parameter Setup Stage Matrix Sampling Matrix Resources Features

Show advanced options

Type	Name	Starting	Minimum	Maximum	Delete
Continuous	t1	3.137	2.5096	3.7644	🗑️
Continuous	t10	2.7	2.16	3.24	🗑️
Dependent	t2	Definition: t1			🗑️
Continuous	t3	2.997	2.3976	3.5964	🗑️
Dependent	t4	Definition: t3			🗑️
Continuous	t5	3.4	2.72	4.08	🗑️
Dependent	t6	Definition: t5			🗑️
Continuous	t64	1.262	1.0096	1.5144	🗑️
Continuous	t73	1.99	1.592	2.388	🗑️

Add...

OK

Variable setup

Material categories

thickness transfer

Parameter Setup Stage Matrix Sampling Matrix Resources Features

Show advanced options

Edit Input Parameter References

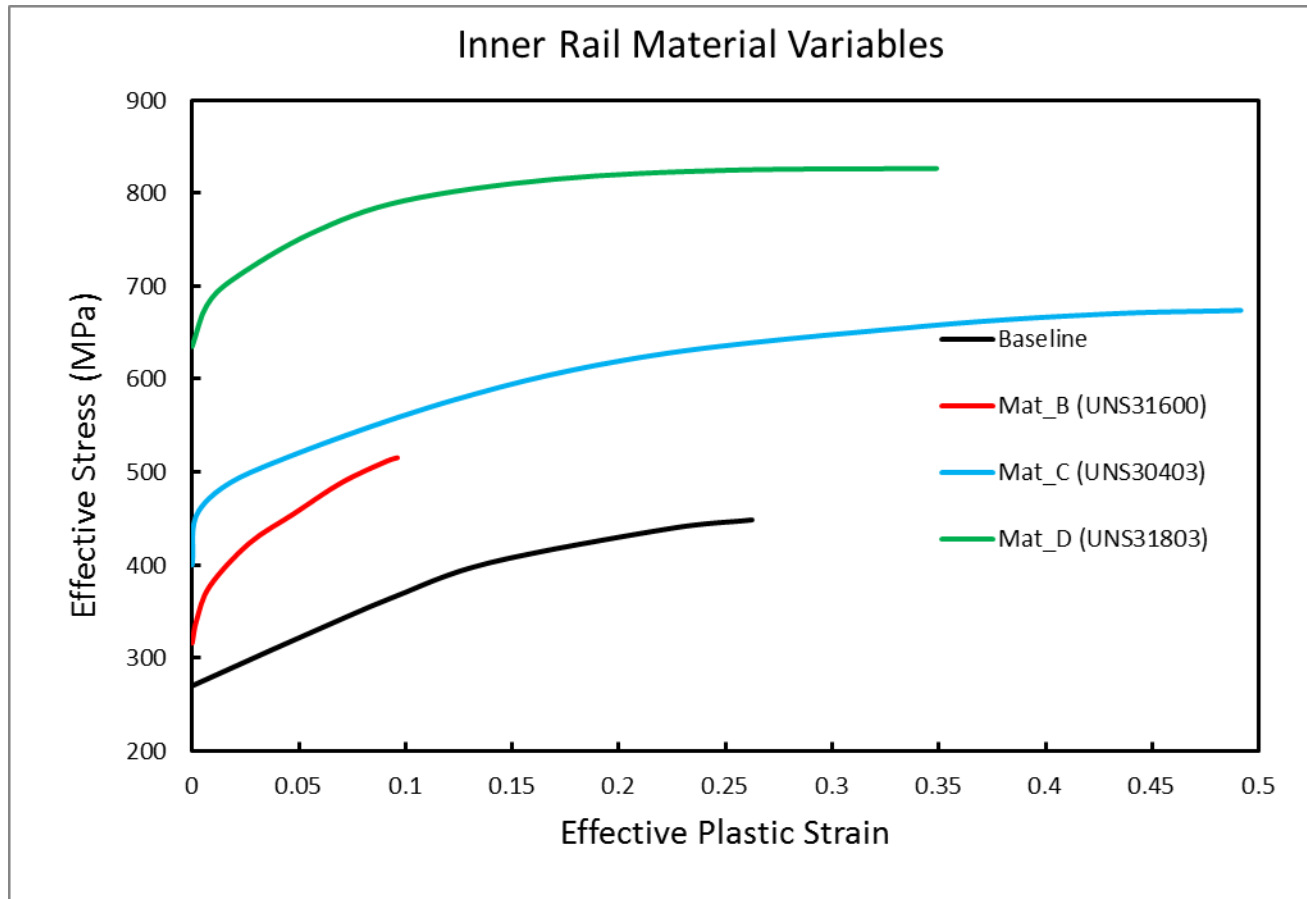
Type	Name	Starting	Minimum	Maximum	Delete
String	mat_BR	mat_BR_c	Values: mat_BR_o, mat_B...	🗑️	
String	mat_IR	mat_IR_c	Values: mat_IR_o, mat_I...	🗑️	
String	mat_OR	mat_OR_c	Values: mat_OR_o, mat_O...	🗑️	
String	mat_bot	mat_bot_c	Values: mat_bot_o, mat...	🗑️	
String	mat_bump	mat_bump_o	Values: mat_bump_b, mat...	🗑️	
String	mat_cab	mat_cab_c	Values: mat_cab_o, mat...	🗑️	
Transfer Variable	t1	3.137		🗑️	
Transfer Variable	t10	2.7		🗑️	
Transfer Variable	t2	3.137		🗑️	
Transfer Variable	t3	2.997		🗑️	
Transfer Variable	t4	2.997		🗑️	
Transfer Variable	t5	3.4		🗑️	
Transfer Variable	t6	3.4		🗑️	
Transfer Variable	t64	1.262		🗑️	
Transfer Variable	t73	1.99		🗑️	

Add...

OK

Multi-level Optimization

Categorical variables: Material levels



Multi-level Optimization: Design Criteria

Variables

- ◆ Outer level: 6 thickness variables of main crash members
- ◆ Inner level: 4 material types (levels) for 6 main crash members

◆ Minimize

- ◆ Mass

◆ Criteria

- ◆ Intrusion < 721
- ◆ Stage 1 pulse < 7.5g
- ◆ Stage 2 pulse < 20.2g
- ◆ Stage 3 pulse < 24.5g

Multi-level Optimization: *SRSM/GA* vs. *GA* only

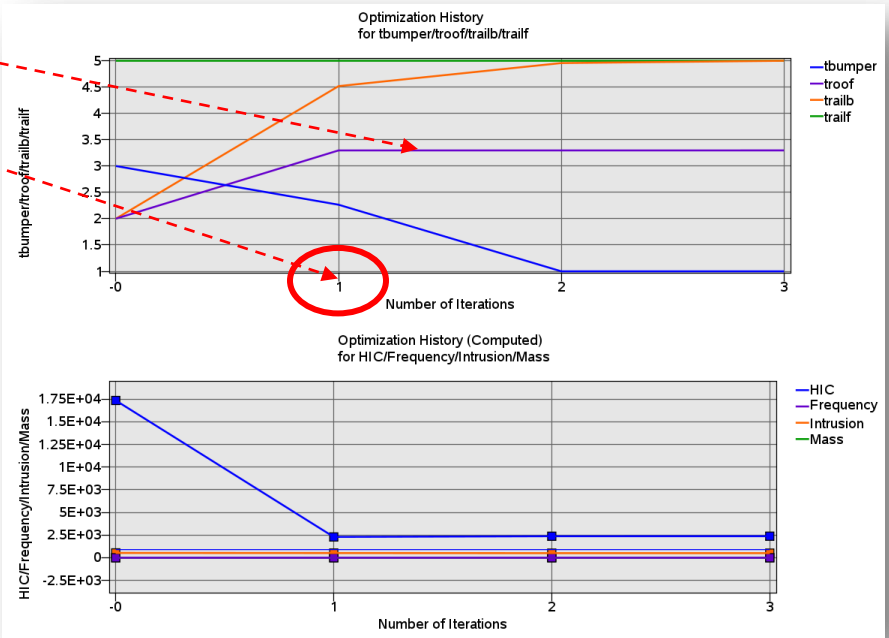
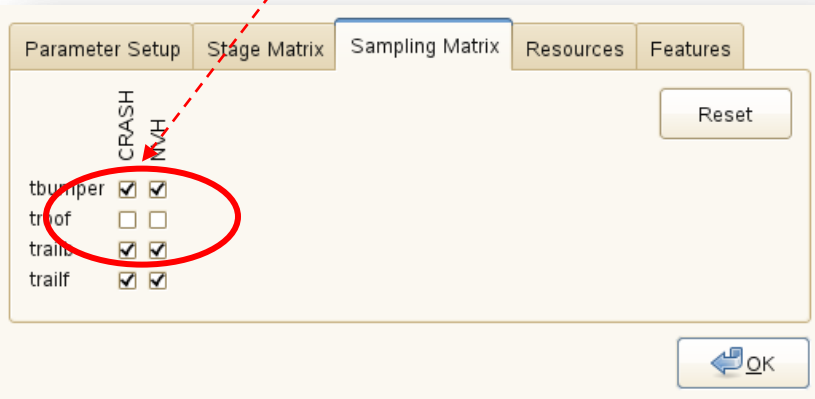
Analysis Type	No. of DVs	Mass (Kg)		Reduction (%)	Cost (LS-DYNA runs)
		Baseline	Optimum		
Multilevel Optimization with thickness and discrete material variables	6 (thickness) + 6 part materials (4 discrete levels) = 12	138.1	122.2	11.6	9340
Direct optimization with both thickness and material variables (population size: 30)	6 (thickness) + 6 part materials (4 discrete levels) = 12	138.1	130.5	5.5	3000
Direct GA with thickness and discrete material variables (population size: 100)	6 (thickness) + 6 part materials (4 discrete levels) = 12	138.1	121.9	11.8	5000

Multilevel Optimization: Observations

- ◆ Multilevel more robust (possibly).
 - ◆ GA population size can significantly influence global optimality
- ◆ Multilevel allows metamodel creation for continuous variables
 - ◆ E.g. can apply robustness, tolerance optimization etc.
- ◆ Disadvantage: Multilevel more expensive.
 - ◆ Optimization could be streamlined, e.g. by adapting starting points for sublevel optimization. Hybridization of optimizer.
- ◆ Multilevel useful in other applications such as tolerance optimization: *Tolerance Optimization Using LS-OPT (Basudhar). Proceedings of this forum*
 - ◆ Also, Collaborative Design Optimization, Design of Product Families

Variable deactivation (iterative methods)

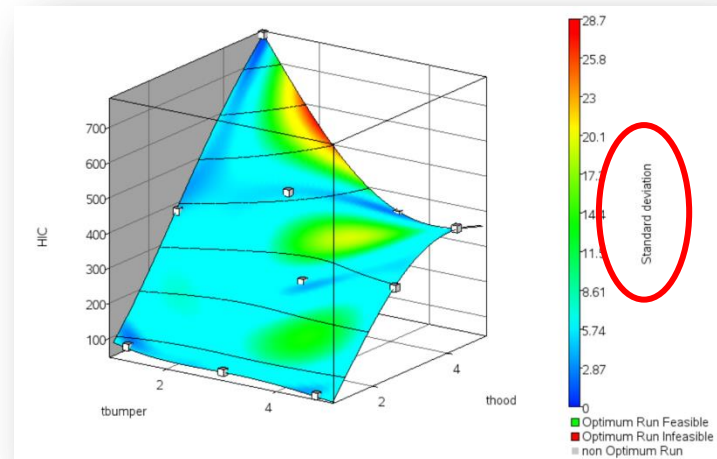
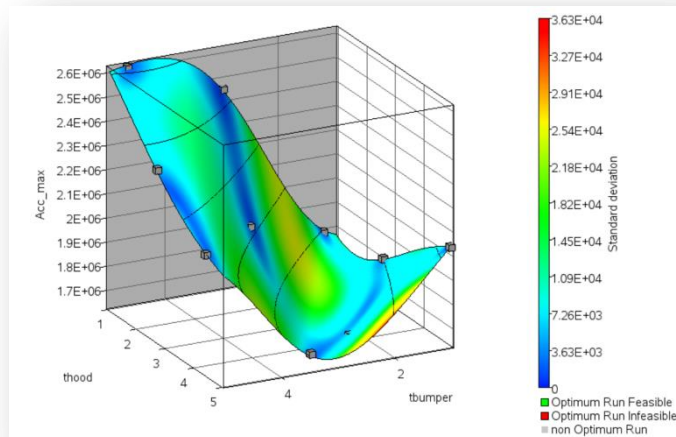
- ◆ Optimization: large number of function evaluations, especially in multi-level setup
- ◆ Variables can be manually de-activated
 - ◆ Save computational effort (variable screening)
 - ◆ Variable is frozen
 - ◆ Seamless restart



Multiple entity plot

Parallel Neural Networks: Motivation

- ◆ High metamodel accuracy required. Even with screening, appropriate metamodeling tools needed
- ◆ Feedforward Neural Networks
 - ◆ High accuracy global approximation. Good bias-variance compromise. Variance information available (illustrated below)
 - ◆ Expensive. Vehicle crash often 100+ responses. Solved independently due to nonlinearity. Reduction (as when linear) not possible.
 - *Ensembles* (sorting through hidden nodes to get the right order)
 - ◆ *Committees* (Monte Carlo method to improve prediction)
 - ◆ Ensembles and Committees are suitable for parallelization



Parallel Neural Networks: Interface

Sampling & Metamodel Settings | Active Variables | Features | Constraints | Execution

Execution options for FFNN calculation

Resources

Resource	Units per job	Global limit	Delete
FFBUILDER	1	120	x

[Create new resource](#)

Use Queuing
SLURM

Use LSTCVM proxy

Command: [Browse](#)

[OK](#)

Show status for: Metamodel Sampling1

Job ID/PID	Component	Iter	RespID	Nodes	Status
30195	Sampling1	1	3	1	Normal Termination
30198	Sampling1	1	3	2	Normal Termination
30225	Sampling1	1	3	3	Normal Termination
30228	Sampling1	1	3	4	Normal Termination
30231	Sampling1	1	3	5	Running...
30235	Sampling1	1	4	1	Normal Termination
30239	Sampling1	1	4	2	Normal Termination
30260	Sampling1	1	4	3	Normal Termination
30283	Sampling1	1	4	4	Running...
30287	Sampling1	1	4	5	Running...
30291	Sampling1	1	5	1	Normal Termination
30294	Sampling1	1	5	2	Running...
30297	Sampling1	1	5	3	Running...
30303	Sampling1	1	5	4	Running...
30307	Sampling1	1	5	5	Running...
0	Sampling1	1	6	1	Waiting...
0	Sampling1	1	6	2	Waiting...
0	Sampling1	1	6	3	Waiting...

Tools: [View log](#), [Open folder](#), [LS-PREPOST](#), [Kill](#), [Accelerated Kill](#)

Show plot

Dialog

- ◆ Functionality similar to solver job monitoring.
- ◆ Jobs can be distributed

Log

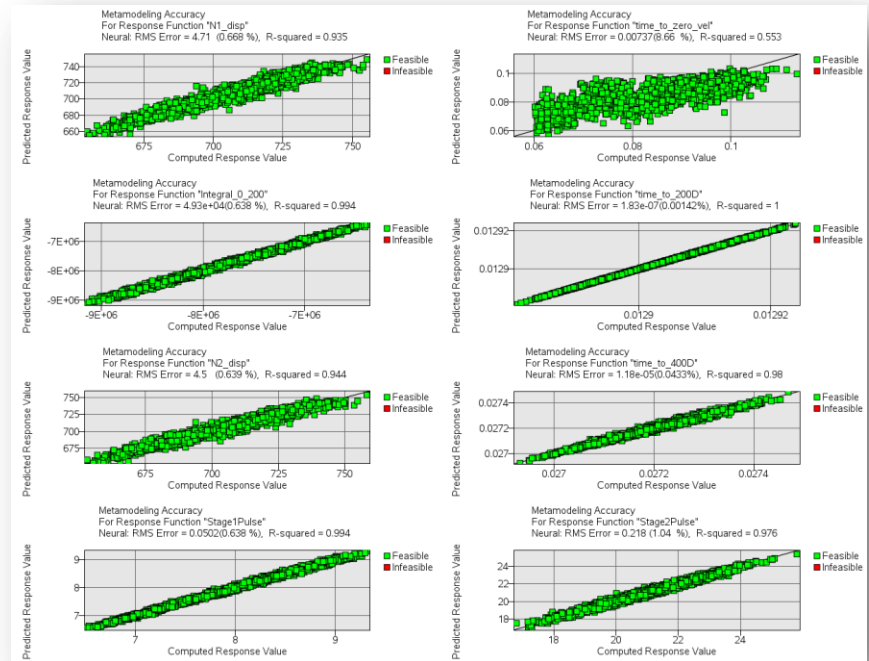
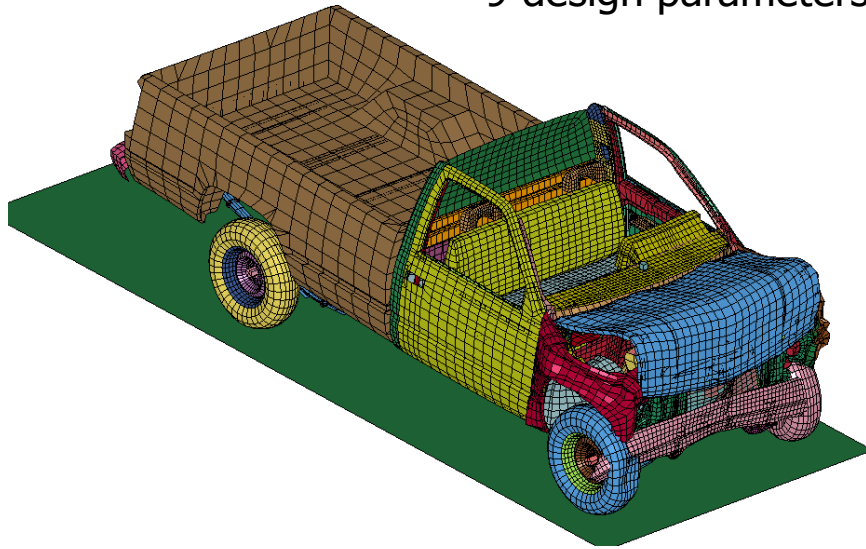
```
[STDOUT] Response name : "Acc_max"
[STDOUT] -----
[STDOUT]
[STDOUT] Number of data points = 10
[STDOUT] Threshold for RMS Error = 0 %
[STDOUT] 1 Hidden Layer
[STDOUT] 9 Members
[STDOUT] 2*2 discarded nets
[STDOUT] Averaging type: Mean using 5 remaining nets
[STDOUT]
[STDOUT] Found input data file: S_AnalysisResults
[STDOUT]
[STDOUT] Response # 3
[STDOUT]
[STDOUT] Training primal net # 1 (3 layers, Neurons: 2 -> 2 -> 1 )
[STDOUT] Training primal net # 2 (3 layers, Neurons: 2 -> 2 -> 1 )
[STDOUT] Training primal net # 3 (3 layers, Neurons: 2 -> 2 -> 1 )
[STDOUT] Training primal net # 4 (3 layers, Neurons: 2 -> 2 -> 1 )
[STDOUT] Training primal net # 5 (3 layers, Neurons: 2 -> 2 -> 1 )
[STDOUT] Training primal net # 6 (3 layers, Neurons: 2 -> 2 -> 1 )
[STDOUT] Training primal net # 7 (3 layers, Neurons: 2 -> 2 -> 1 )
[STDOUT] Training primal net # 8 (3 layers, Neurons: 2 -> 2 -> 1 )
```

[Search](#) [Dismiss](#)

Progress

Parallel Neural Networks: Results

9 design parameters



Predicted vs. Computed

Statistics

Parameters	9
Simulations	1997
Responses	15
Processors	8

Calculation times

Type	Order	MC	Time (min.)
Min	3	9	2.8
Default	5*	9*	10.6
Max	10	19	99.6



Excel stage type (substitution)

Inputs from LS-OPT to
Excel fields

Stage Stage2

Setup Parameters Histories Responses File Operations

General

Package Name: Excel

Excel File: data.xlsx

Input definitions

Sheet	Cell	Type	Value	Fill direction	Delete
Sheet1	A3	Parameter	x1	Vertical	
Sheet1	Param2	Parameter	x2	Vertical	
Sheet2	nodout1	Response	NODOUT1	Vertical	
Sheet2	nodout2	Response	NODOUT2	Vertical	
Sheet2	xaccel_432	History	xaccel_432	Vertical	

Execution

Resources

Resource	Units per job	Global limit	Delete
EXCEL	1	1	

OK

Design variables

Histories/
Responses
of previous
stages

data - Microsoft Excel

File Home Insert Page Layout Formulas

Param2

	A	B	C	D
1	Stage 2 Design variables			
2	x1	x2		
3	2	4		
4				

data - Microsoft Excel

File Home Insert Page Layout Formulas Data Review

H5

	A	B	C	D	E	F
1	Stage1_lsopt_output => Stage2_excel_input					
2						
3						
4	nodout1	nodout2		xaccel_432		
5						
6	-736.719	-26.1055		0	0	
7				0.009999	-155.516	
8				0.019992	-305.94	
9				0.029999	-452.651	
10				0.039994	-595.531	
11				0.049999	-736.719	
12						

Excel stage type (extraction)

	intrusion		xaccel_432_mod	
13				
14		Stage2_Isopt_output		
15				
16				
17	intrusion		xaccel_432_mod	
18				
19	-710.614		1	0
20			2	-53.4974
21			3	-105.243
22			4	-155.712
23			5	-204.863
24			6	-253.431
25				

Dialog box: Edit history

Name: xaccel_432_mod

Subcase: [dropdown]

File: data.xlsx [Browse]

Worksheet: Sheet2 [Refresh]

X/time range: [dropdown]

Y/value range: xaccel_432_mod

Auto increment

[OK] [Cancel]

Dialog box: Edit response

Name: intrusion_dist

Subcase: [dropdown]

Multiplier: n/a

Offset: n/a

Not metamodel-linked

File: data.xlsx [Browse]

Worksheet: Sheet2 [Refresh]

Value cell: intrusion_dist

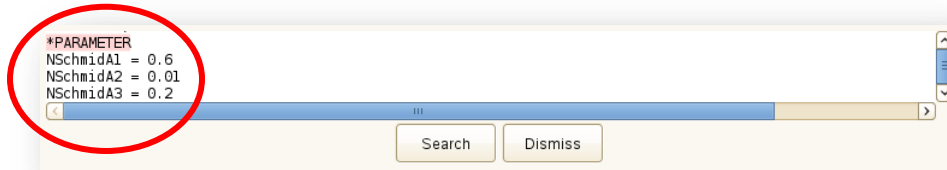
[OK] [Cancel]

Excel fields as LS-OPT histories/responses

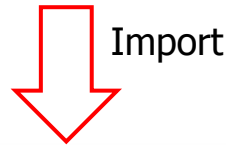
Third Party solvers: Example

Courtesy: Aboozar Mapar, MSU

```
*PARAMETER
NSchmidA1 = 0.6
NSchmidA2 = 0.01
NSchmidA3 = 0.2
```



Parameter definition
(solver input file)



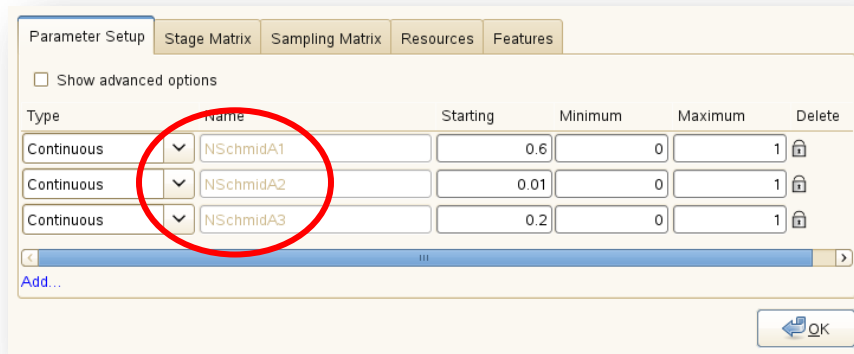
Parameter Setup | Stage Matrix | Sampling Matrix | Resources | Features

Show advanced options

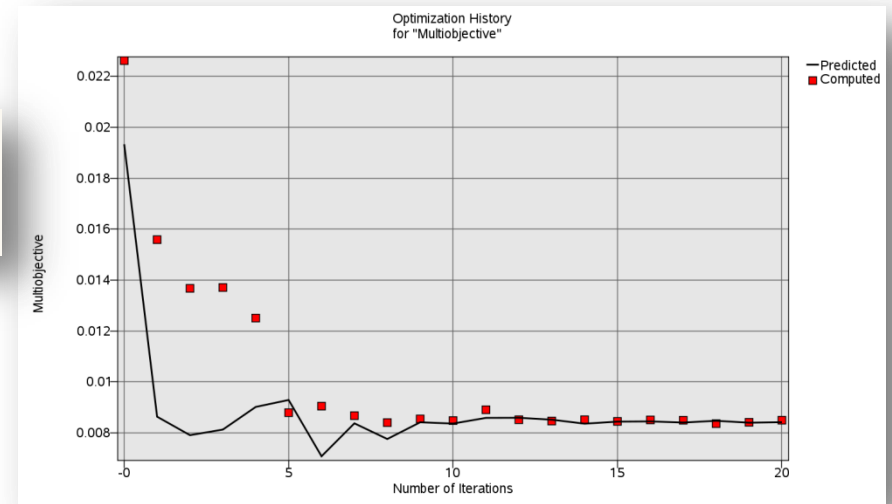
Type	Name	Starting	Minimum	Maximum	Delete
Continuous	NSchmidA1	0.6	0	1	🔒
Continuous	NSchmidA2	0.01	0	1	🔒
Continuous	NSchmidA3	0.2	0	1	🔒

Add...

QK



Variable setup

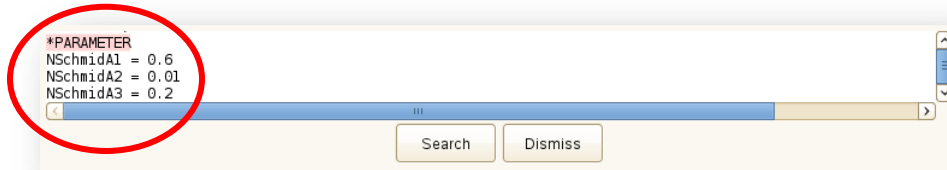


Minimization of residual

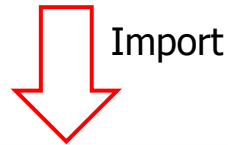
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Courtesy: Aboozar Mapar, MSU

```
*PARAMETER
NSchmidA1 = 0.6
NSchmidA2 = 0.01
NSchmidA3 = 0.2
```



Parameter definition
(solver input file)



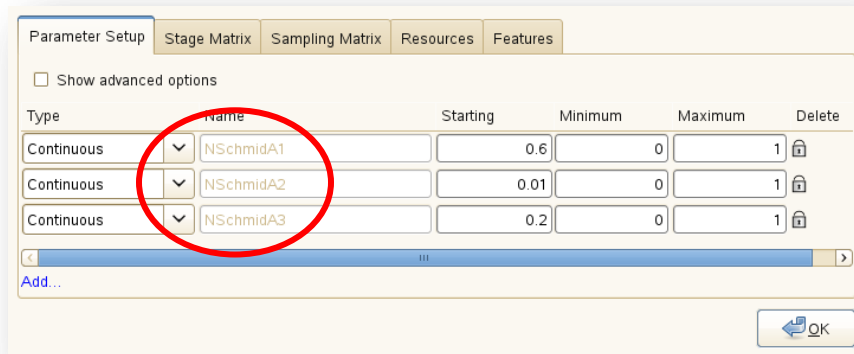
Parameter Setup | Stage Matrix | Sampling Matrix | Resources | Features

Show advanced options

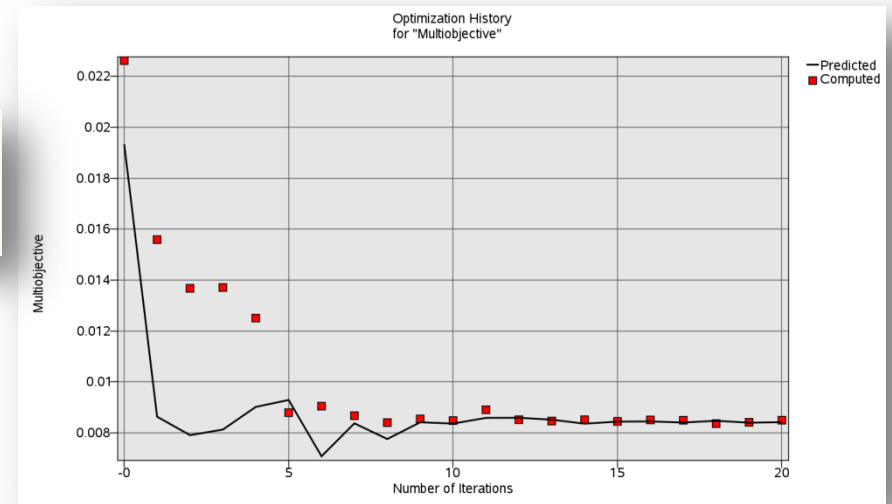
Type	Name	Starting	Minimum	Maximum	Delete
Continuous	NSchmidA1	0.6	0	1	🔒
Continuous	NSchmidA2	0.01	0	1	🔒
Continuous	NSchmidA3	0.2	0	1	🔒

Add...

QK



Variable setup

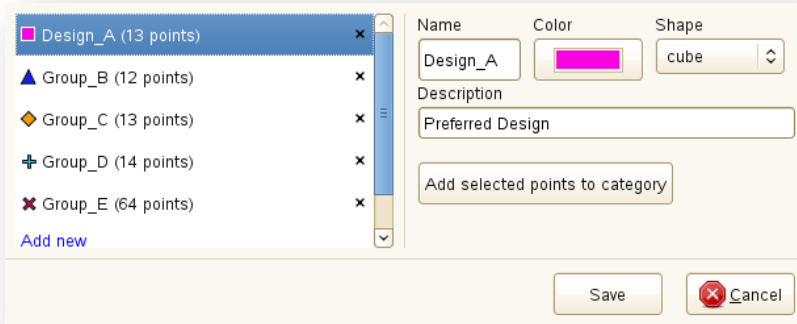


Minimization of residual

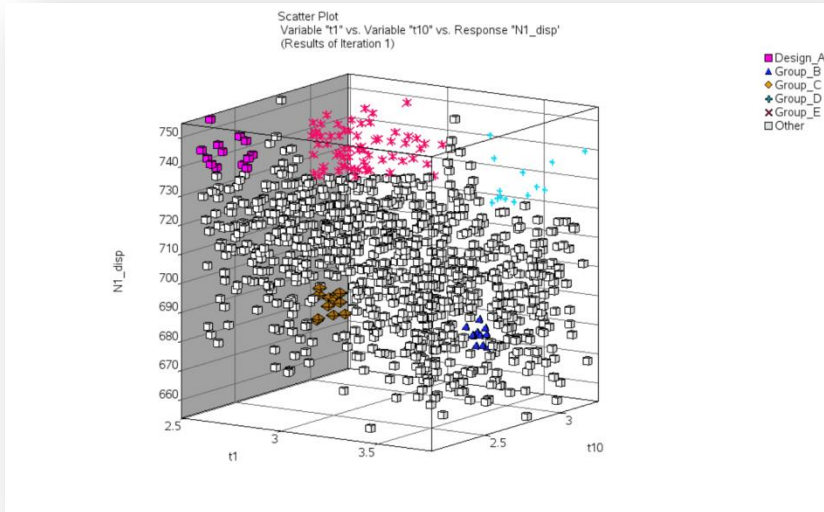
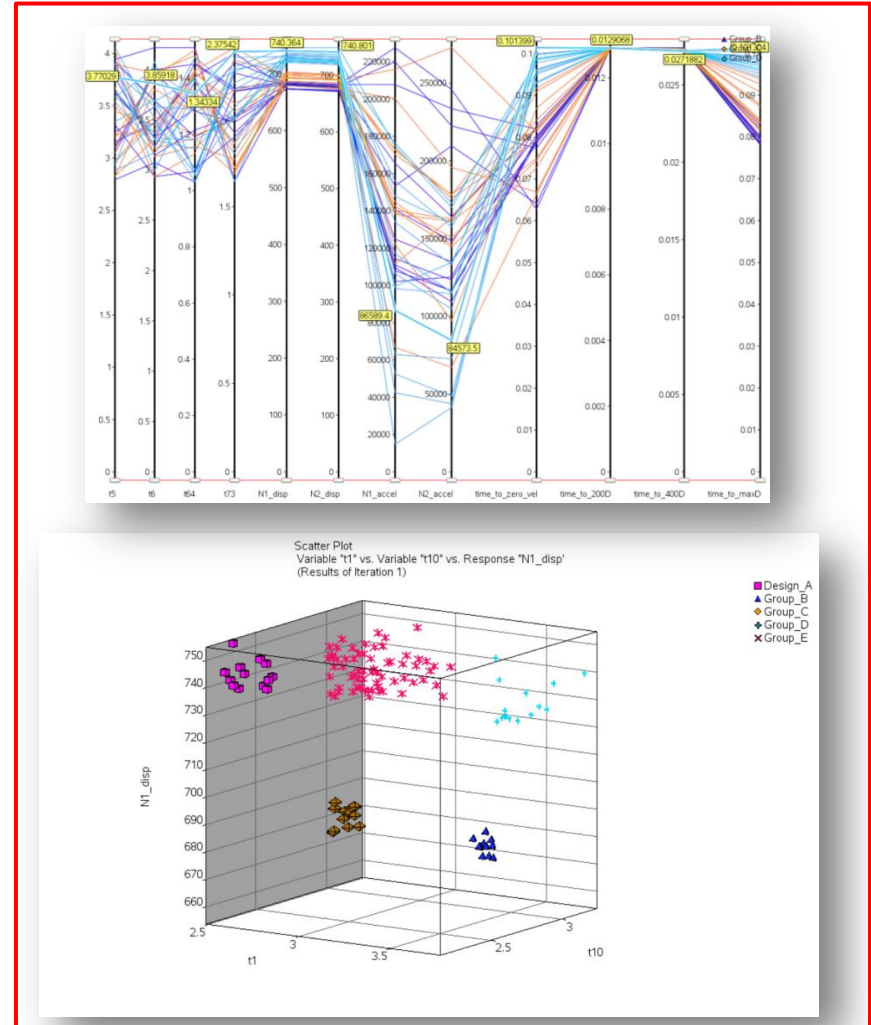
Graphical Features (Viewer)

Design Point Categories

◆ Picking, displaying and saving designs of interest



Dialog



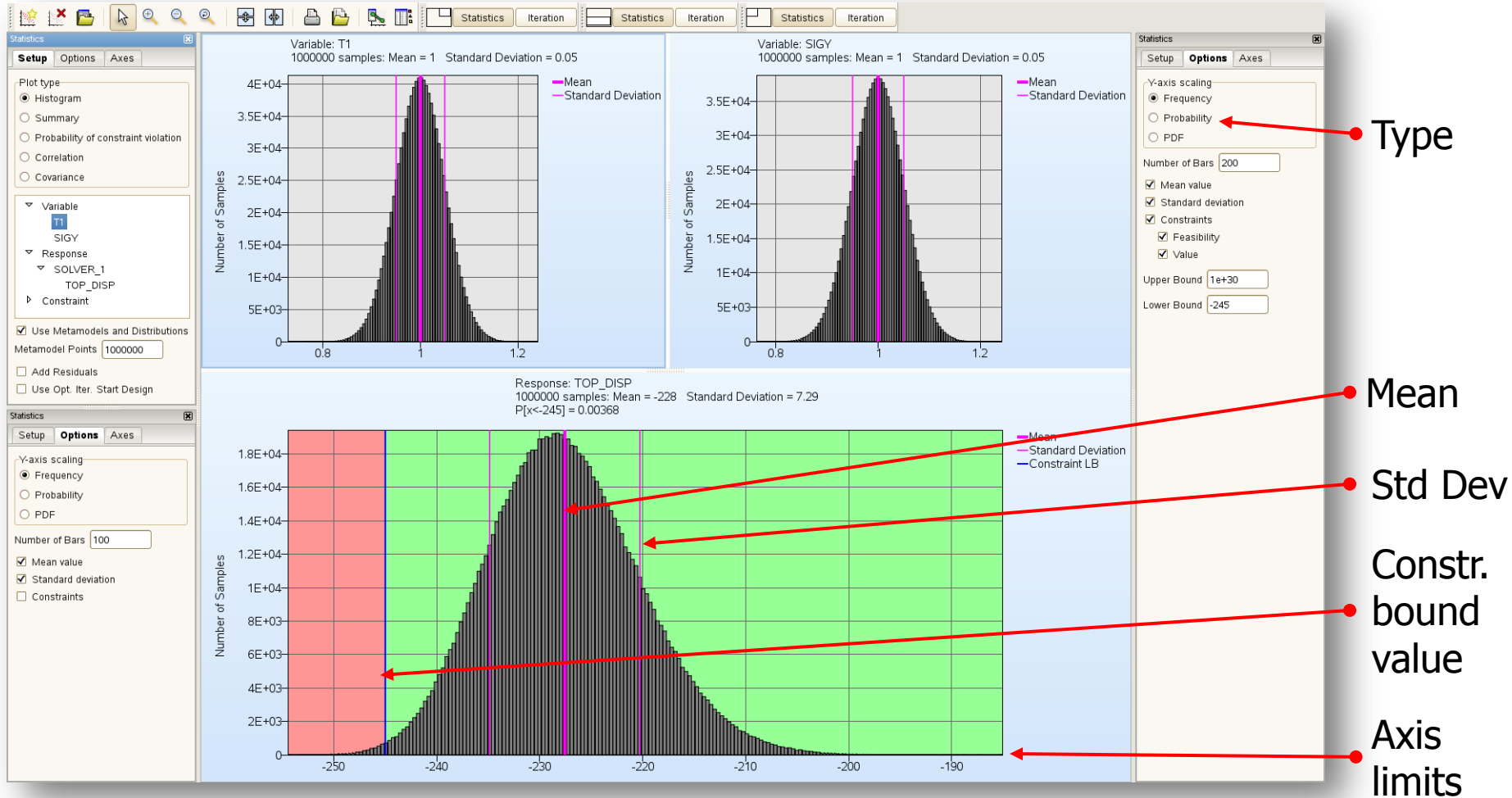
Categories + Other

"Other" points hidden

Histogram visualization

- ◆ Manual axis control of the region of interest
 - ◆ Range, step size
 - ◆ Graphical visualization of properties (mean, std dev, feasibility range)
 - ◆ Additional histogram types
 - ◆ Frequency
 - ◆ Probability / Relative Frequency = $\frac{\text{Frequency}}{\text{Sample size}}$
 - ◆ Probability Density Function (PDF)
/ Relative Frequency per Unit Width = $\frac{\text{Probability}}{\text{Bin width}}$
- (standard representation)

Histogram visualization – attributes



Global Sensitivity Analysis (subregion)

- ◆ Sensitivities within specific design *proximity*
- ◆ Can set up *multiple* sub-regions interactively

Number of Points for Integration
10000 (default)

Overwrite global computations

Subregion definitions

Name	Active	Overwrite	Delete
Subregion1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Edit x
subregion2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Edit x

Add...

All active All overwrite

OK

Name
Subregion1

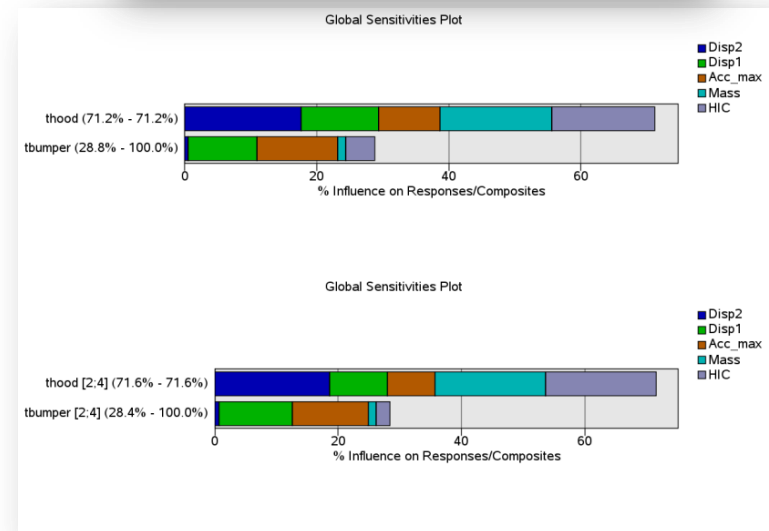
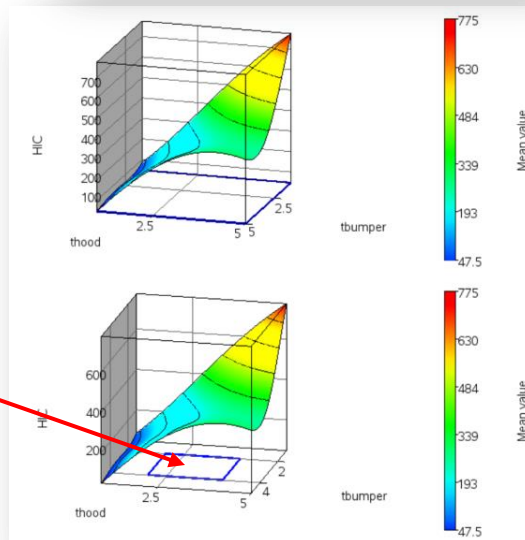
Active
 Overwrite

Bounds - Global bounds used for variable if not specified below

Variable	Lower bounds	Upper bounds	Delete
tbumper	2	4	x
thood	2	4	x

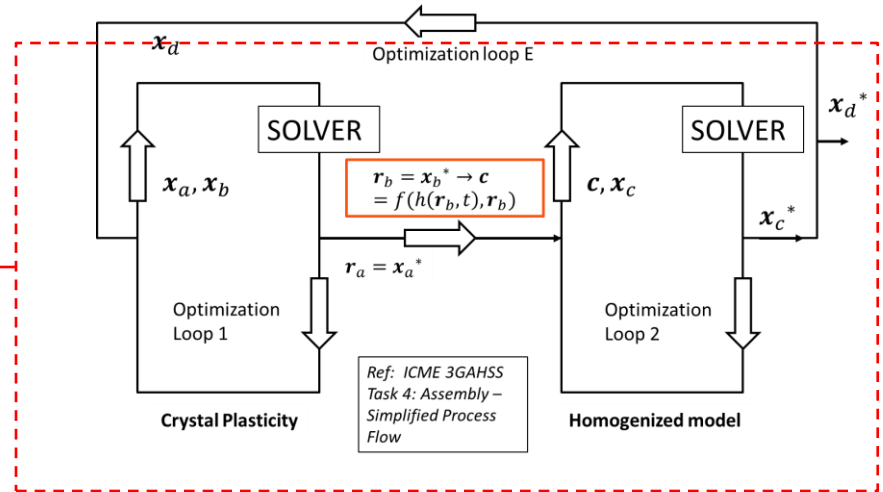
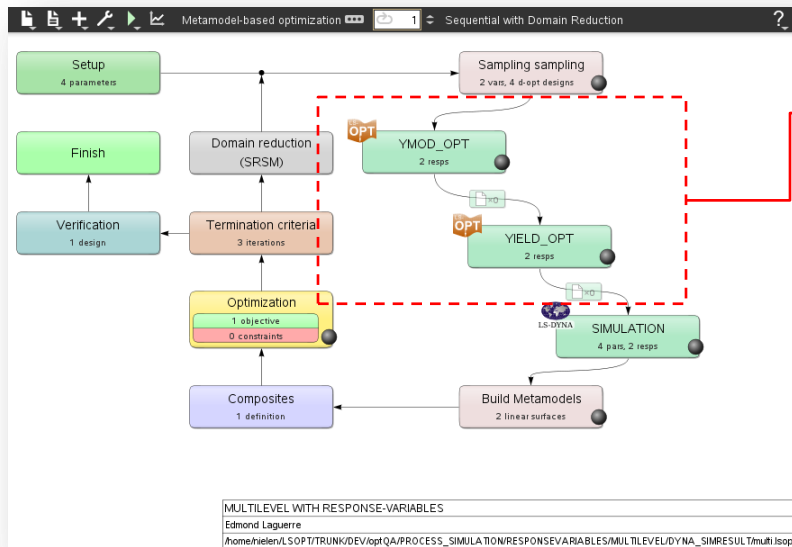
Add...

OK



Response-variables (development version)

- ◆ Transfer variables between design stages
- ◆ Responses are substituted in successor stage input



Parameter Setup Stage Matrix Sampling Matrix Resources Features

Show advanced options

Type	Name	Starting	Minimum	Maximum	Delete
Response Variable	YModRV	YMod_OPT_EXPR			
Response Variable	YieldRV	Yield_OPT_EXPR			
Continuous	tbumper		3	1	5
Continuous	thood		1	1	5

Add...

OK

Outlook

Outlook

- ◆ Multi-level Optimization
 - ◆ Funded by US Department of Energy
 - ◆ *Analytical Target Cascading* as a logical development path to provide a collaborative capability
- ◆ Viewer (post-processing, data mining)
 - ◆ Result table manipulation: integration of *categories* into tables, etc.
 - ◆ Speed improvements to Viewer displays
 - ◆ Virtual design displays: generate cluster of surrogate results
- ◆ Reliability
 - ◆ Probability Density Function approximation from empirical data
 - Kernel density approximation
 - ◆ Sequential reliability analysis
 - Convergence of probability of failure value
 - Adaptive sampling
 - ◆ Tolerance-based optimization – See paper by *Anirban Basudhar*

Outlook

- ◆ New applications for approximations
 - ◆ Domain reduction approaches for multi-objective optimization (MOO)
 - Extend work done for User's Conference 2012
 - Classification-based Decision Boundaries
 - ◆ Support Vector Machines
 - ◆ Application in domain definition for binary and discontinuous responses
 - ◆ Multi-response metamodels
 - Spatial distribution of response locations
 - Biomechanical applications, e.g. using MRI spatial data for heart muscle calibration

- ◆ Metamodels: performance and usability
 - ◆ Multiple metamodel type displays: comparison of metamodels

Outlook

◆ Job scheduler

- ◆ LS-OPT job scheduler handles/monitors ~ 330 jobs in parallel (Linux limitation).
- ◆ With MPP (e.g. 64 nodes/job) $\sim 21,000$ but capacity is now typically $\sim 20,000$ nodes

◆ More solver types

- ◆ Matlab
- ◆ *LS-TaSC*

Other papers at this conference

- ◆ Tolerance Optimization Using LS-OPT (Basudhar)
- ◆ LS-OPT Current development: A perspective on multilevel optimization, MOO and classification methods (Stander, Basudhar) (Developers Forum, Sweden)