Application of Neural Networks in LS-OPT: Parametric Study and Guidelines

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3rd German LS-DYNA Users Meeting
Bamberg, Germany
October, 2004

Overview

- **Metamodeling Methods**
  - Goals
- **Optimization**
  - Technologies
- **Examples**
  - Frontal Crash: full vehicle
  - Knee Impact
  - Analytical Benchmarks
- **Conclusion**

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How are metamodels used in crash ?

- **Surrogate model for design**
  - Approximations critical for design modeling in nonlinear dynamics (LS-DYNA)
  - Global approximation: Optimization & Tradeoff
- **Model for any number of simulation runs**
  - Given: number of simulation runs
    Required: Surrogate model
  - Different polynomial orders require discrete numbers of runs (e.g. 10var: L=11+, Q=66+)
  - Adding points to a simple model (linear) does not significantly improve the prediction accuracy
- **Local improvement**
  - Refine regionally, but maintain global relevance

Technologies for Optimization

- **Metamodels**
  - Response Surface Methodology
  - Feedforward Neural Networks
- **Point selection:**
  - RSM: *D*-Optimal
  - NN: Updated Space Filling (Maximize Min. Distance between any two points) Johnson (1990)
- **Subdomain Reduction**
  - Reduce the region of interest for each iteration
  - Heuristics: Roux/Stander *et al* (*MA&O* 1996, *IJNME* 1998, Crash & Benchmarking: *EC* 2002)
  - RSM: Necessary for low order polynomials: regional approximation
  - NN: Necessary for regional refinement. Start with full design space
- **Simulation (LS-OPT)**
  - Parallel or distributed
  - Automated

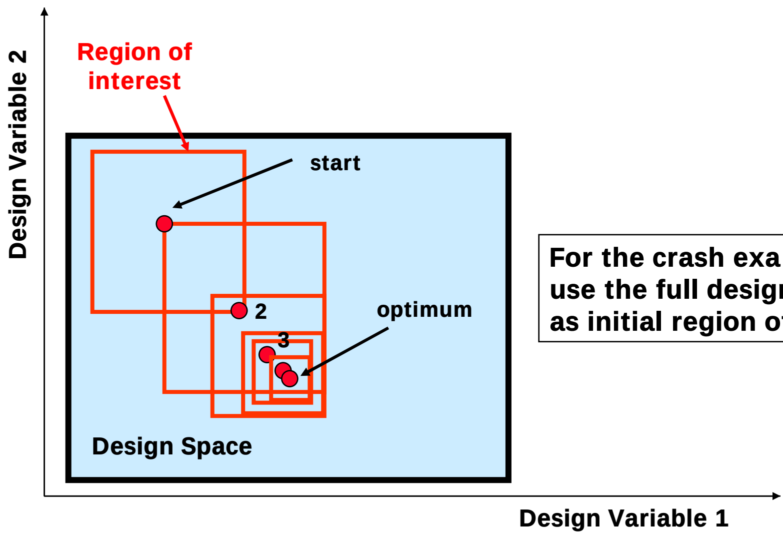
Metamodeling
Methodology

- **Response Surface Methodology (RSM)**
  - Polynomial-based (only linear in this study)
  - Point selection: *D*-Optimality
  - Regional (midrange) approximation
- **Neural Nets**
  - Simulation of a biological network
  - Nonlinear Regression (Levenberg-Marquardt, BFGS,…)
  - Point Selection: Updated Space Filling

Point Selection

- **NN**
  - Space Filling
  - Simulated Annealing to locate new points
  - Max. Min. distance between
    - new points
    - new points + fixed points
  - New points bounded by sub-region
  - $1.5(n+1)$ points per iteration: relatively sparse
- **Response Surface Method**
  - Use D-Optimality (GA)
  - linear approximations
  - $1.5(n+1)$ points per iteration

Successive Approximation Scheme
Converges to an Optimum



For the crash examples, use the full design space as initial region of interest

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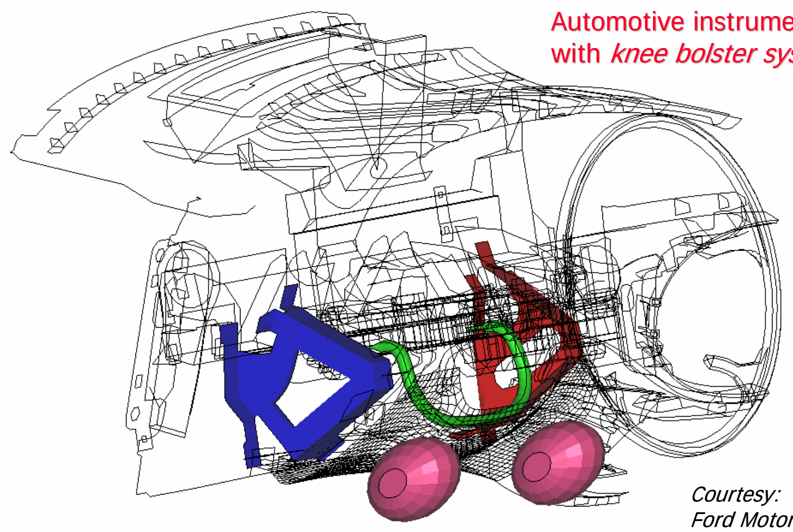
Components to Be Designed

Automotive instrument panel with *knee bolster system*



Courtesy: Ford Motor Company

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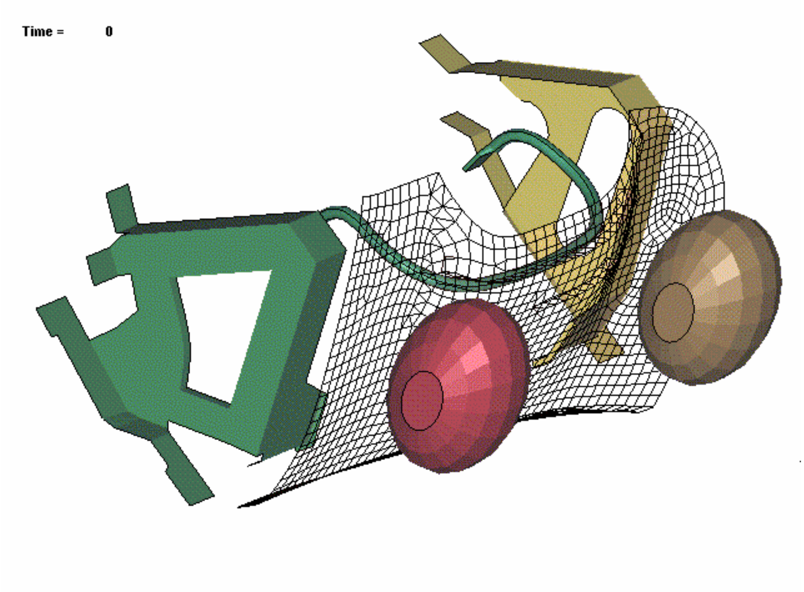
40ms Impact: LS-DYNA Simulation



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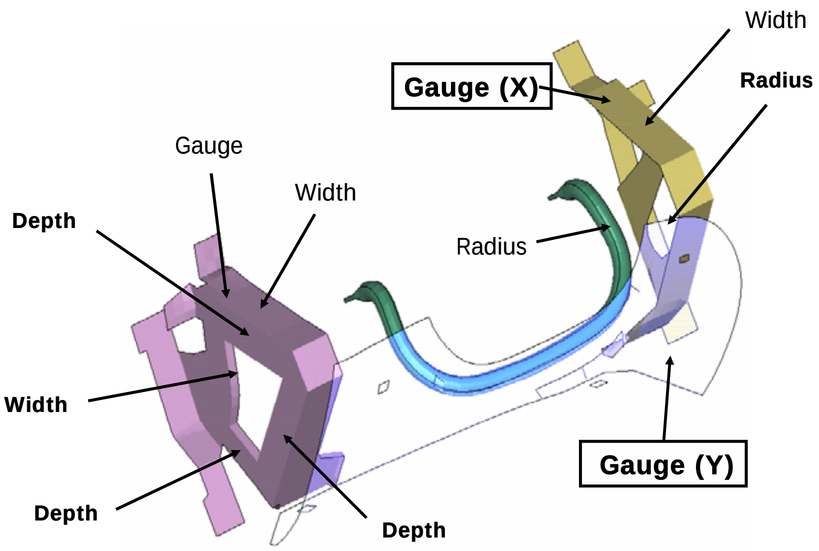
Two Design Variables



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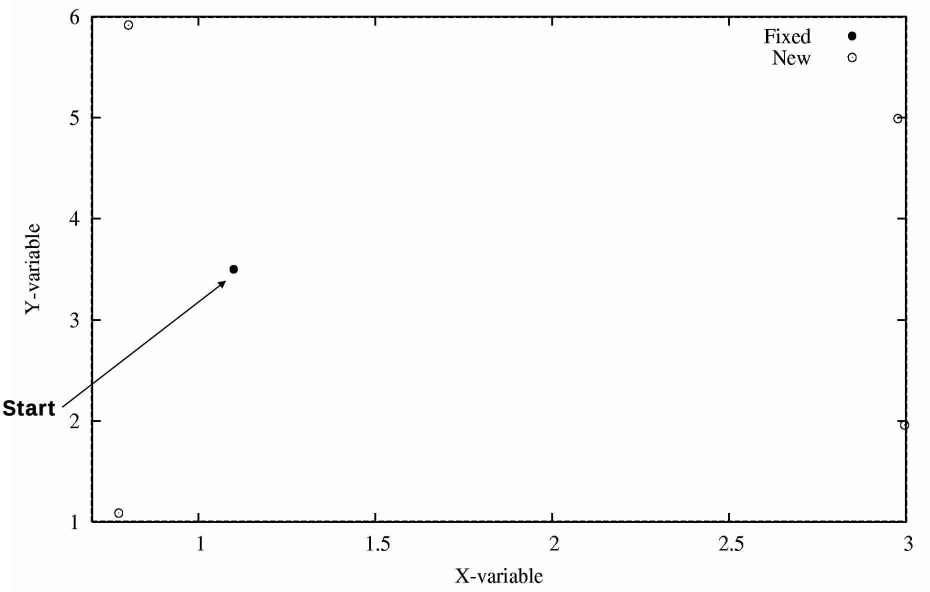
Experimental Design: Space Filling Method

Knee Impact: Iteration 1



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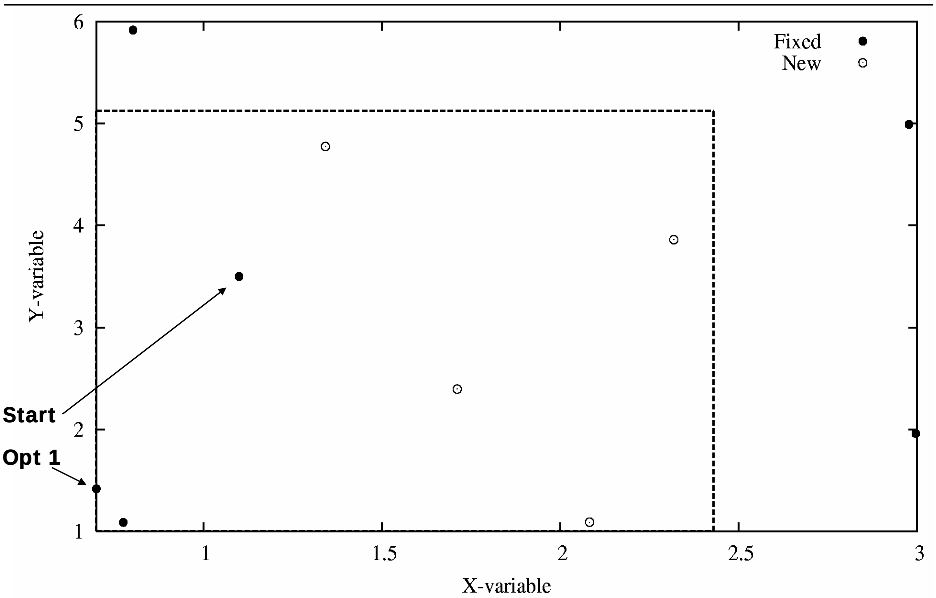
Experimental Design: Space Filling Method

Knee Impact: Iteration 2



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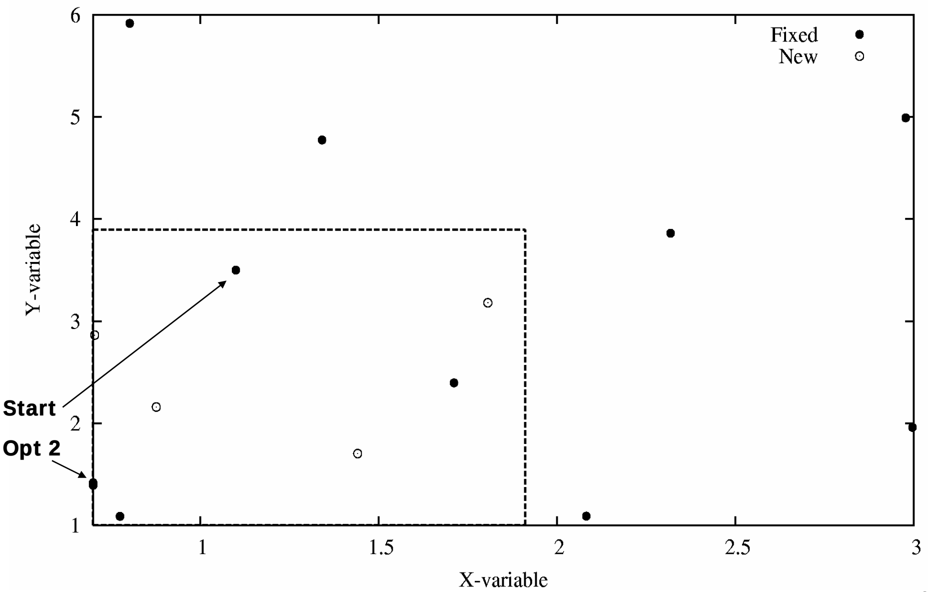
Experimental Design: Space Filling Method

Knee Impact: Iteration 3



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Feedforward Neural Networks

- **Construct *ensemble* of architectures (different numbers of hidden nodes)**
  - Single layer architectures (0 – 10 nodes)
  - Select the "best" net
  - Selection criterion: Min. Generalized Cross Validation (GCV)
- **Some properties of NN Variance Modeling**
  - NN's have variance due to local minima associated with training
  - Net variance is bigger for noisy functions and for extrapolation

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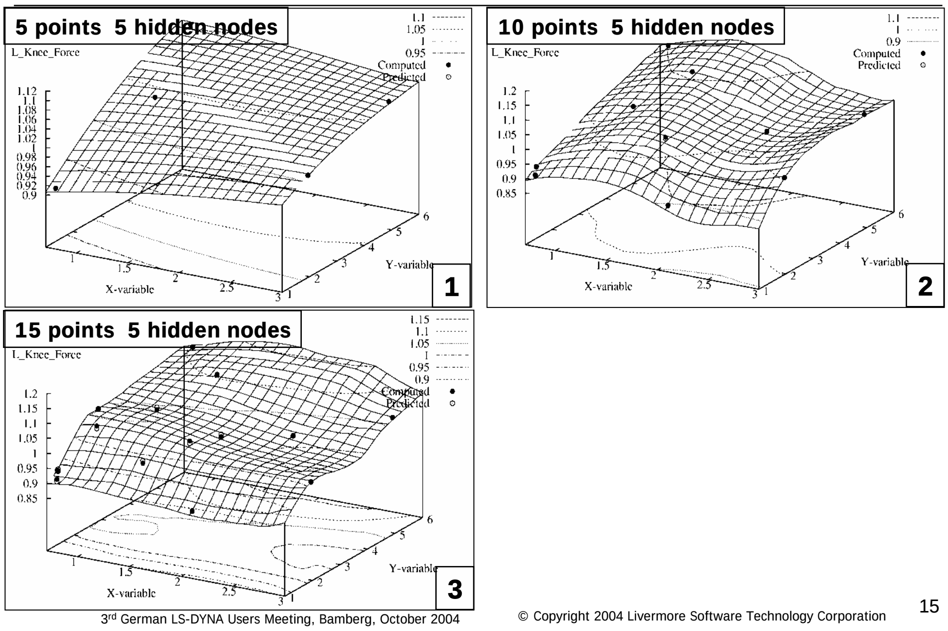
Neural Network Updating

Knee Impact: Left Knee Force



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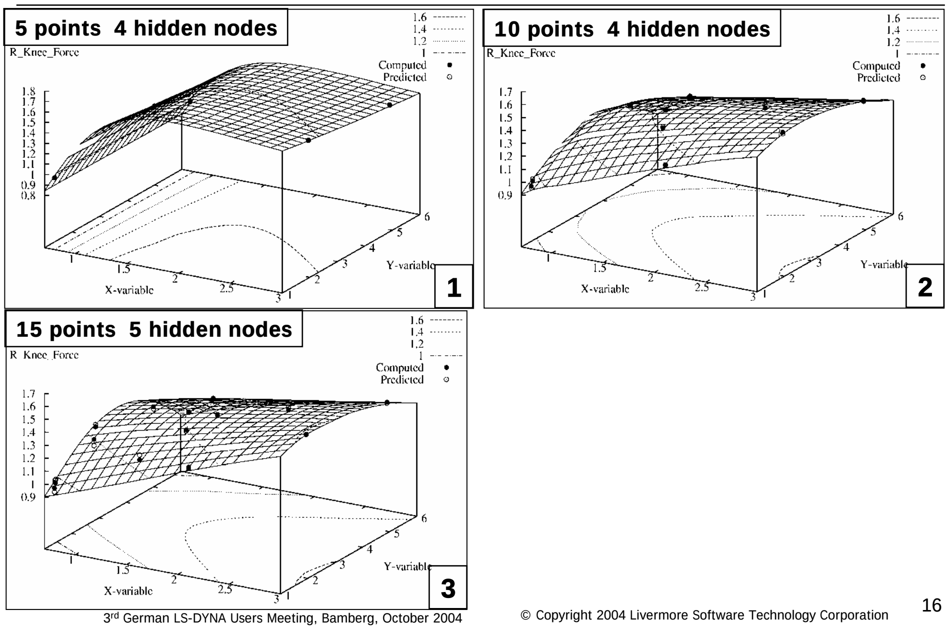
Neural Network Updating

Knee Impact: Right Knee Force



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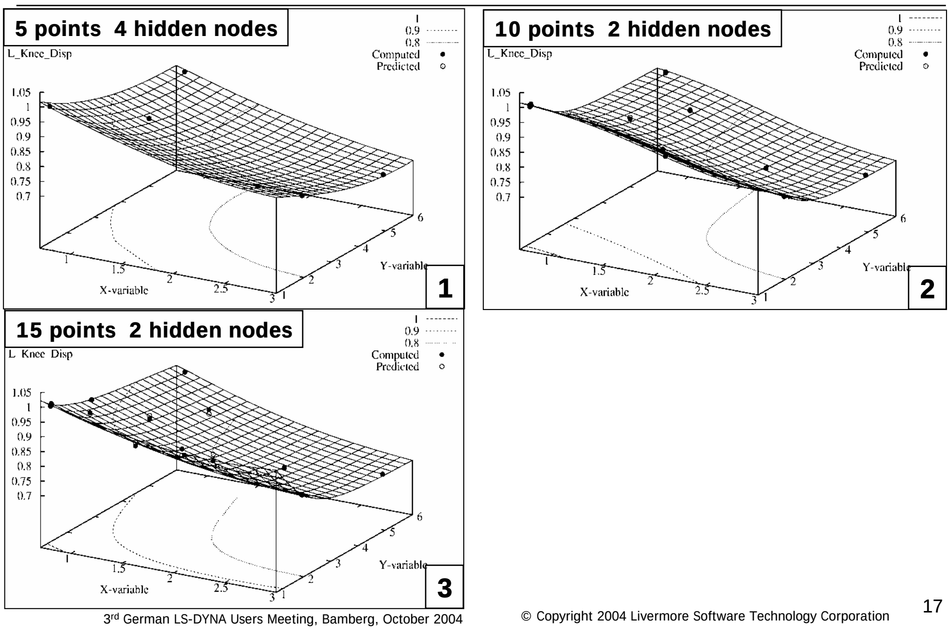
Neural Network Updating

Knee Impact: Left Knee Displacement



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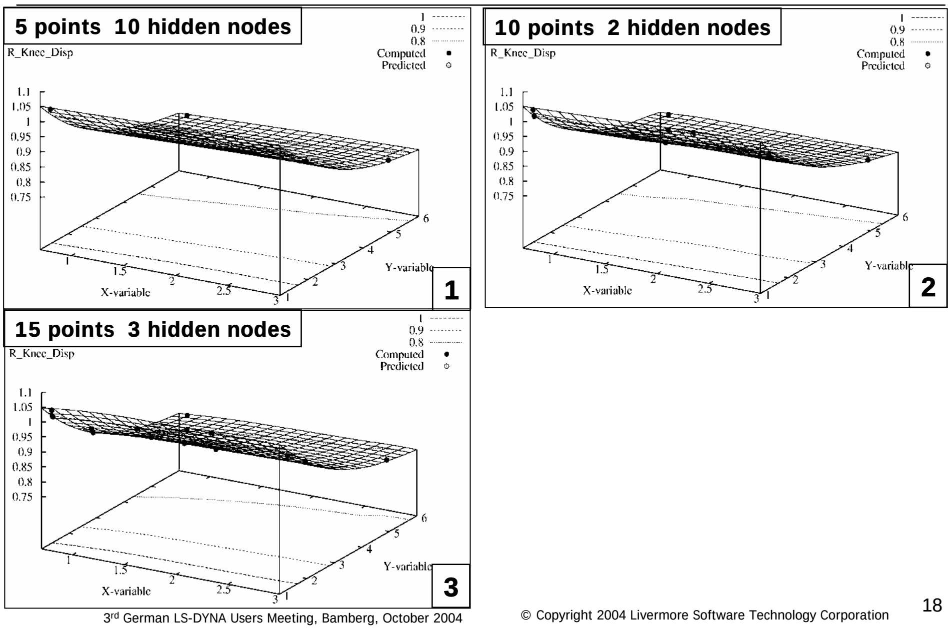
Neural Network Updating

Knee Impact: Right Knee Displacement



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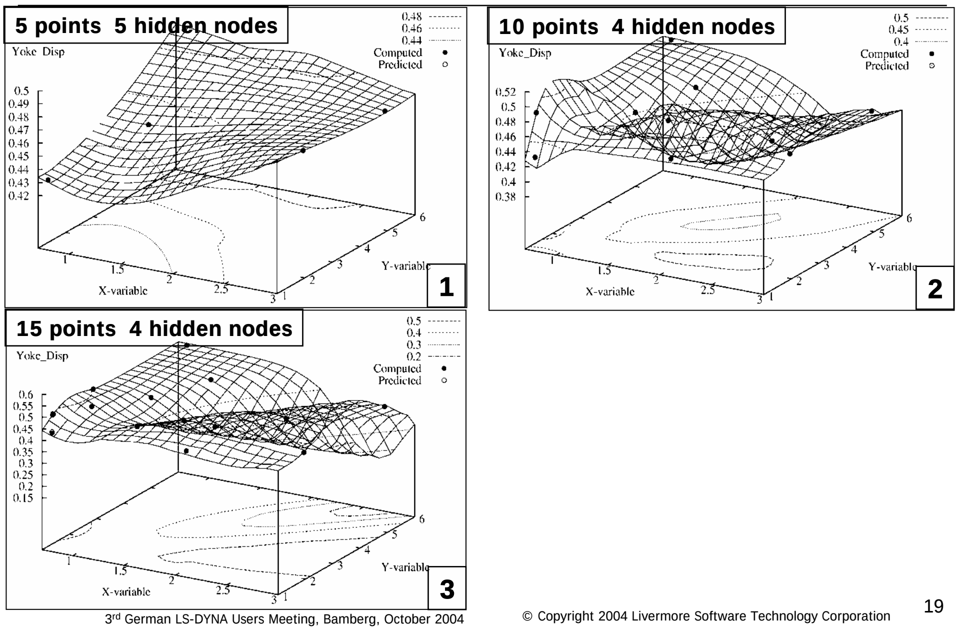
Neural Network Updating

Knee Impact: Yoke Displacement



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Crash Performance of Base Design

Crash model

30 000 elements

Intrusion = 552mm

Stage1Pulse = 14.34g

Stage2Pulse = 17.57g

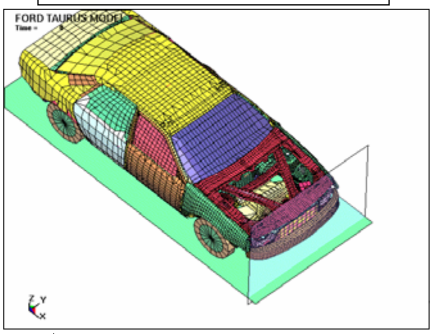
Stage3Pulse = 20.76g

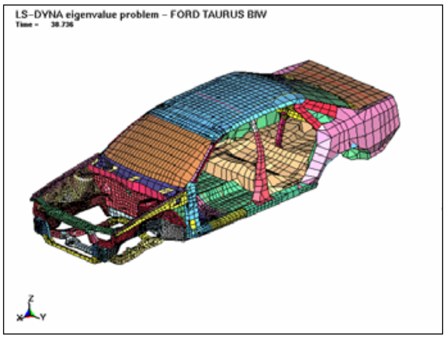
BIW model

18 000 elements

Torsional mode 1

Frequency = 38.7Hz





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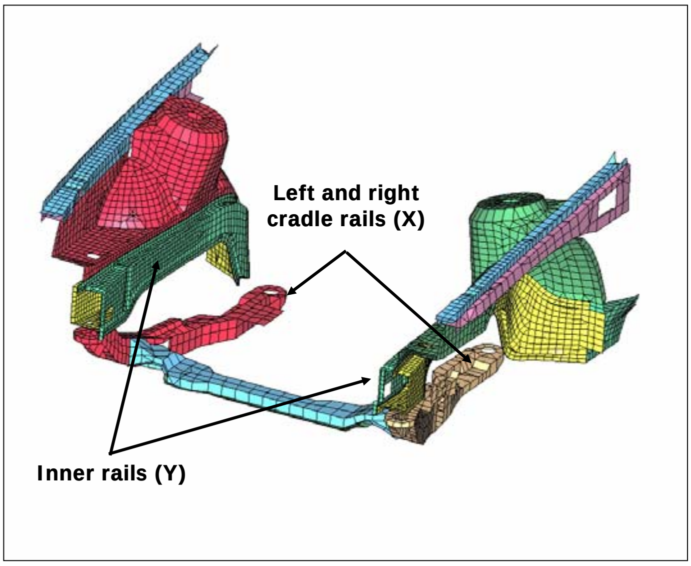
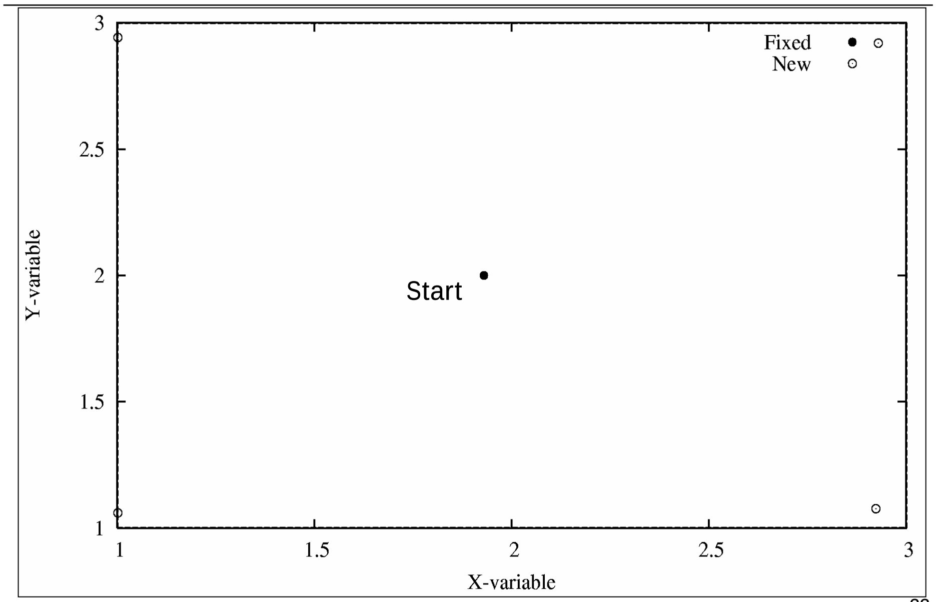
Two Design Variables (Thickness)

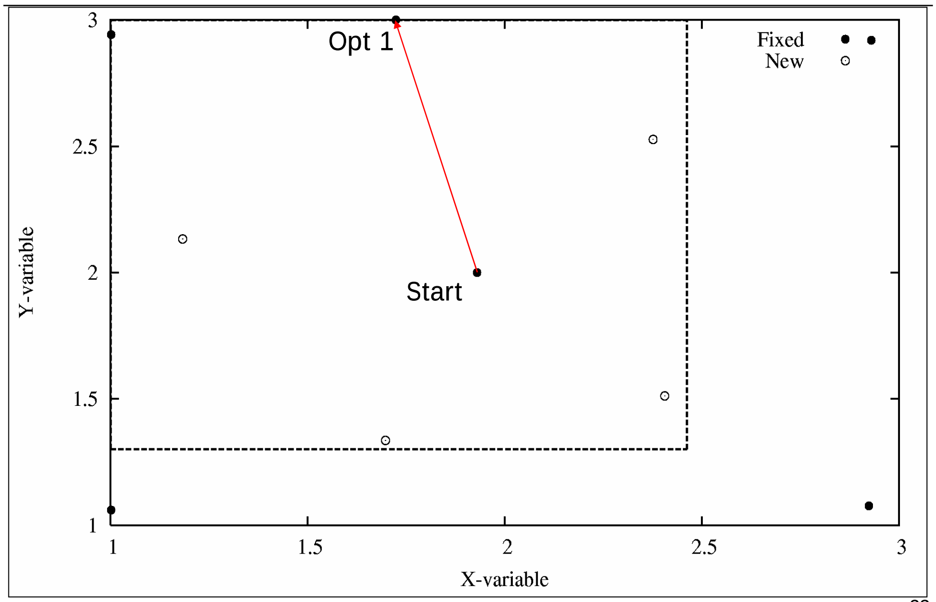


Experimental Design: Space Filling Method

Iteration 1



Experimental Design: Space Filling Method
Iteration 2



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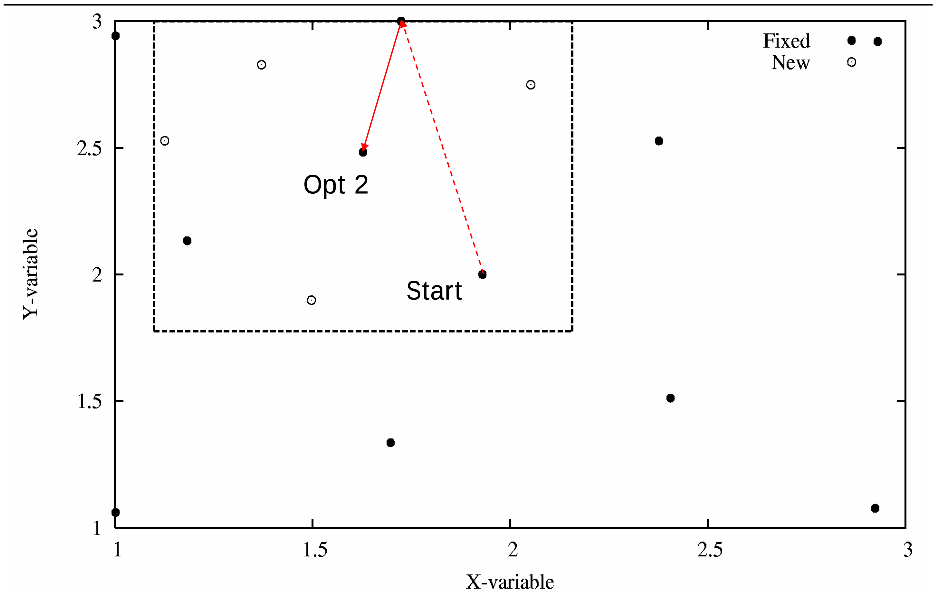
Experimental Design: Space Filling Method
Iteration 3



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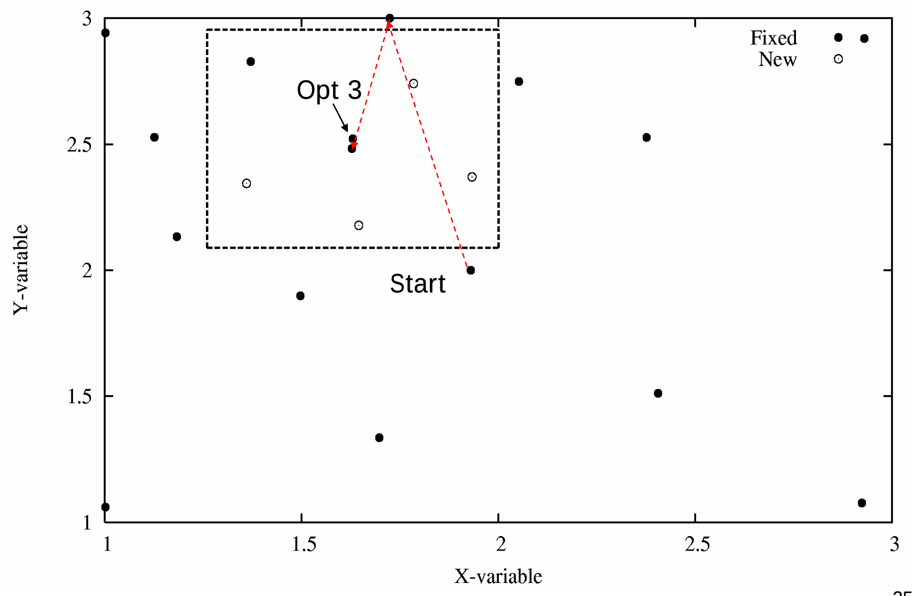
Experimental Design: Space Filling Method

Iteration 4



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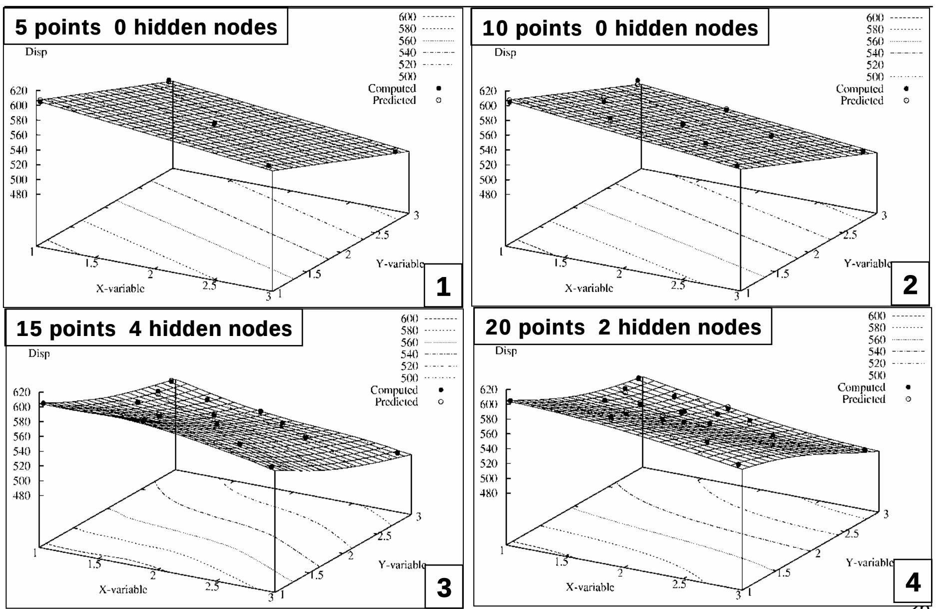
Neural Network Updating

Vehicle Crash: Intrusion



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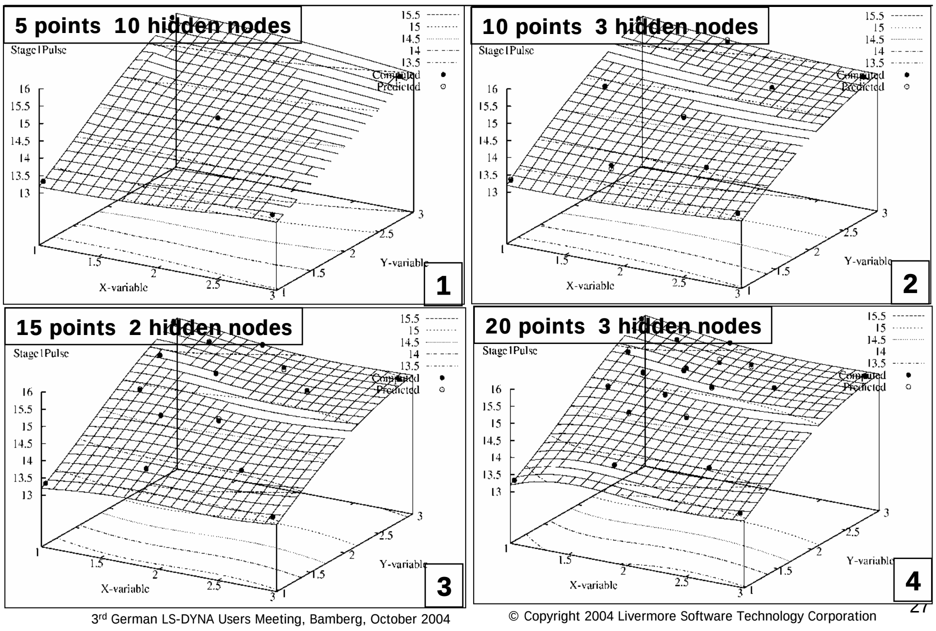
Neural Network Updating
Vehicle Crash: Stage 1 Pulse



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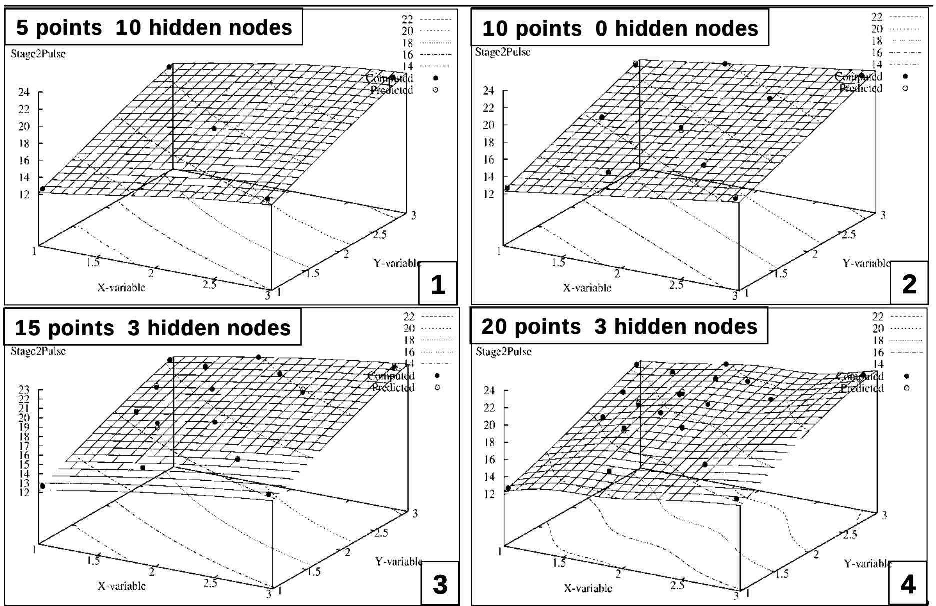
Neural Network Updating
Vehicle Crash: Stage 2 Pulse



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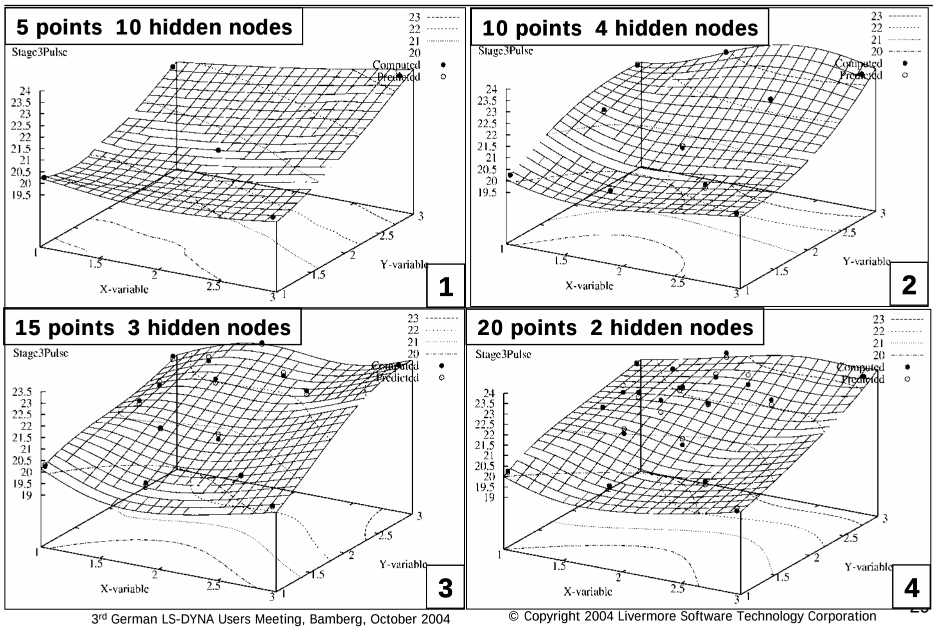
Neural Network Updating
Vehicle Crash: Stage 3 Pulse



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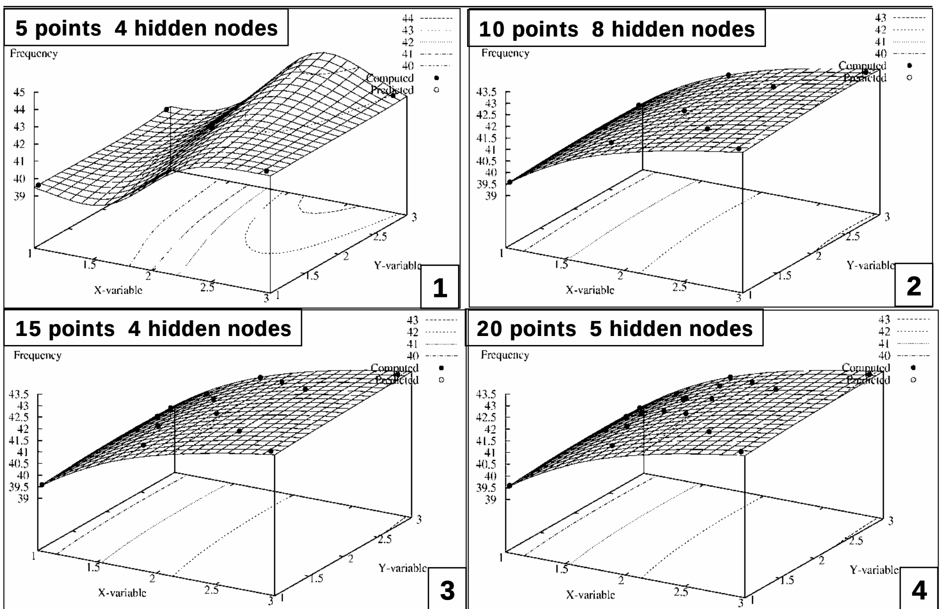
Neural Network Updating
Torsional Mode: Frequency



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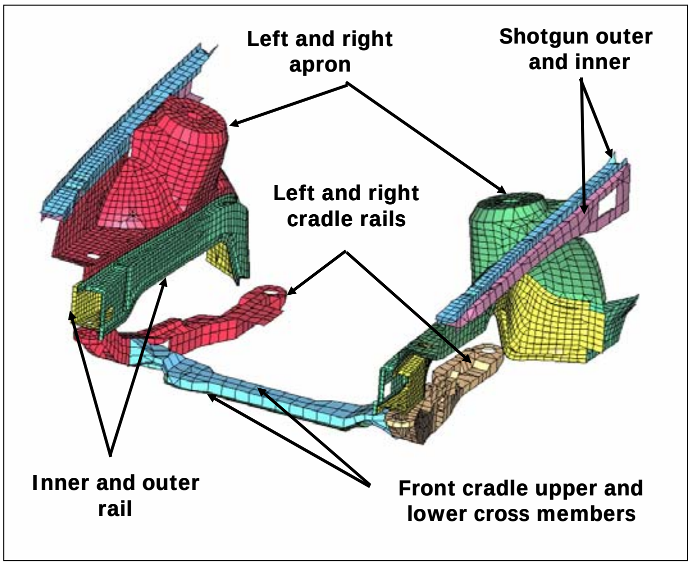
Optimization
Design Variables (Thickness)



Design Formulation
(MDF partially shared variables)

Design Objective:

Minimize (Mass of components)

Design Constraints:

Intrusion < 552.38mm

Stage1Pulse > 14.58g

Stage2Pulse > 17.47g

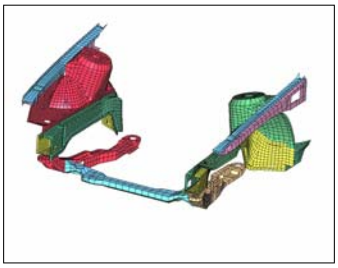
Stage3Pulse > 20.59g

41.38Hz < Torsional mode 1 frequency < 42.38

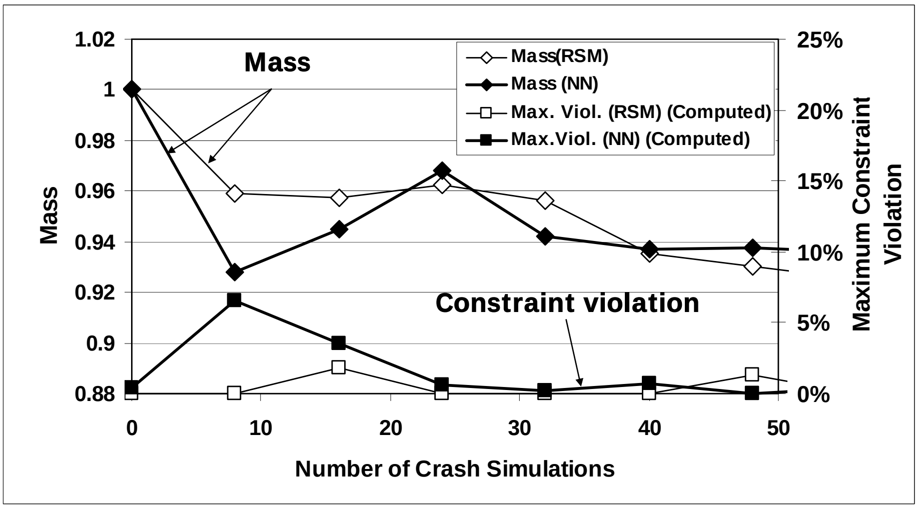
Crashworthiness design variables: 4

Rails (inner and outer); Aprons; Cradle rails

NVH design variables: 7 (all)



Full vehicle
Optimization History



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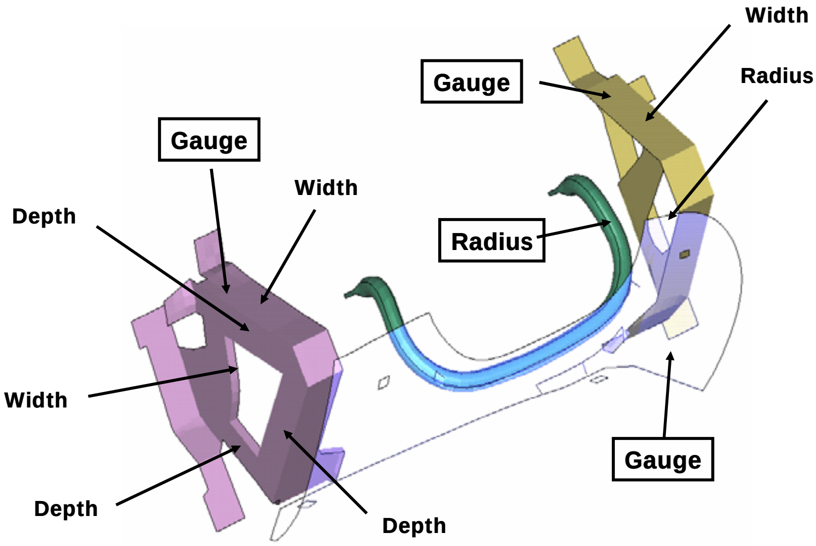
Design Variables



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Design Formulation

Design Objective:

min (max (Knee_F_L, Knee_F_R))

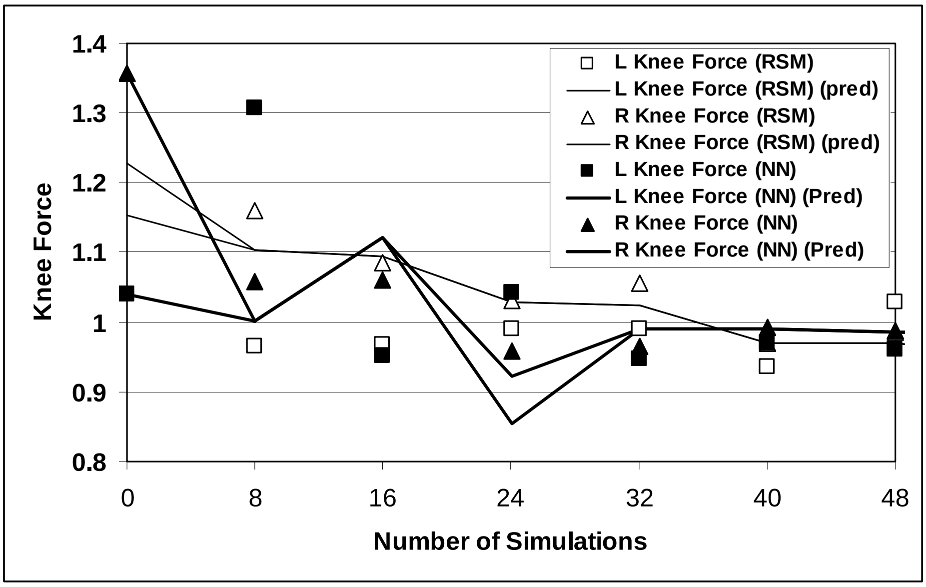
Design Constraints:

Left Knee intrusion	**<**	**115mm**
Right Knee intrusion	**<**	**115mm**
Yoke intrusion	**<**	**85mm**

Design variables

Reduced from 11 to 4 (ANOVA)

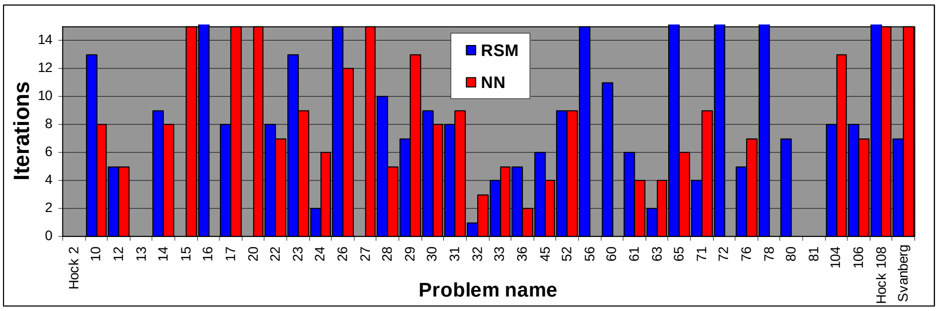
Optimization Convergence



Additional Benchmarks for Testing NN
37 Hock & Schittkowski, Svanberg Polytope

- Polynomials of various orders
- Exponential functions
- Svanberg Polytope (21 var.)
- 2 – 21 variables

- Number of iterations for 1 % accuracy
- Omission: not converged within 15 iterations



Guidelines for Optimization with NN

- **Use full design space as initial region of interest by simply omitting initial range (in "Variables" panel)**
- **Iterative updating: Use same number of points per iteration as linear response surface.**
- **Use Space Filling sampling method (default)**
- **Make sure that "Updated" Neural Net Option is set ("Sampling" panel) (default).**
  - Effect: Points will be placed in Maxi-min. Positions
  - Metamodeling will be done using all available points

Advantages of NN

- **Global approximation**
  - Avoids inaccuracy for small range – does regional refinement
  - Can apply trade-off study or robustness analysis after optimization run
- **Do not have to choose between different orders of polynomials.**
  - Choice of NN architectures is automated
  - Independent of number of points chosen (so can choose minimum, e.g. as for linear)
- **Do not have to choose initial range**
  - Start with full design space
- **A regression method – not interpolation**
  - Filters noise