

## An Overview of LS-OPT<sup>®</sup> Version 4.1

Nielen Stander, Tushar Goel

Livermore Software Technology Corporation, Livermore CA 94551

### Abstract

*The main focus of the LS-OPT V4.1 development has been to further expand the graphical postprocessor and to significantly improve reliability, usability and transparency when distributing solver jobs across networks. Much of the latter has been accomplished through industrial collaboration. While LS-OPT originated as an LS-DYNA<sup>®</sup> based tool, new features are increasingly being developed to facilitate interfacing with non-LS-DYNA solvers. This is necessitated by the increasing requirement for conducting multidisciplinary optimization, thereby involving more than one solver type. Therefore, in V4.1, LS-OPT now has MSC NASTRAN support for mode tracking and frequency extraction. A generic extractor has also been added to aid result extraction from text files.*

### Introduction

In today's CAE environment it is unusual to make engineering decisions based on a single physics simulation. A typical user conducts multiple analyses by varying the design and uses the combined results for design improvement. LS-OPT [1] provides an environment for design and is tightly interfaced to LS-DYNA[2] and LS-PREPOST with the goal of allowing the user to organize input for multiple simulations and gather and display the results and statistics. More specifically, LS-OPT has capabilities for improving design performance in an uncertain environment and conducting system and material identification. These objectives can be achieved through the use of statistical tools and optimization. The individual tasks that can thus be accomplished are:

- Identify important design variables
- Optimize the design
- Explore the design space using surrogate design models
- Identify sources of uncertainty in FE models
- Visualize statistics of multiple runs
- Design for uncertainty
- Nonlinear topology optimization

The typical applications are: Multidisciplinary Design Optimization [3] (crashworthiness, modal analysis, durability analysis, etc.), system and material identification (biomaterials, metal alloys, concrete, airbag properties, etc.) and process design (metal forming).

The main technologies available in LS-OPT are:

- *Experimental Design (DOE)*. D-Optimal design, Latin Hypercube sampling, Space Filling and others. DOE allows the user to automatically select a set of different designs to be analyzed. The main types mentioned here are each suited to a different type of

analysis: *D*-Optimal for polynomials and sequential optimization, Latin Hypercube for stochastic analysis and Space Filling for Neural Networks and Kriging.

- *Metamodels (approximations)*. Response Surface Methodology (polynomials) and Neural Networks are the most important. With these tools, the user can explore the design space and quantify the predictability of a response, i.e. identify sources of noisy response.
- *Variable screening* [3] provides information on the relative importance of design variables. Screening is now possible using two approaches namely using the gradients of the response surfaces (ANOVA) as well as a new approach: Global Sensitivity Analysis as introduced by Sobol [4].
- *Probabilistic analysis* includes Reliability and Outlier Analysis [5]. The former allows the user to evaluate the probability of failure while the latter allows the identification of parts of a model that contribute to noisy response and therefore affect the predictability of the results. The outlier analysis uses integrated LS-PREPOST features.
- *Optimization*. Used for automated design improvement. The Sequential Response Surface Method (SRSM) [6] is the principal iterative tool for finding a converged optimum. A similar methodology is used for finding a converged result using neural net updating (Feedforward Neural networks, Radial Basis Function networks as well as Kriging). Multi-objective Optimization (MOO) is now a standard feature and can be done either directly or using metamodels. Reliability-Based Optimization has full functionality.

The ability to execute simulations across a network is crucial in the modern day computing environment. LS-OPT interfaces to various queuing systems such as PBS and also allows for exporting environment variable values to the simulation jobs. In Version 4.1, a significant effort has been made to improve the robustness of the runs. Transparency has been added by displaying any solver log at the click of a button.

The post-processor (Viewer) has been significantly modernized and expanded in recent years. Firstly, the postprocessor provides features for viewing the simulation results using Scatter plots, Parallel Coordinate plots, Correlation matrix, Histories and various Statistical tools. The approximation results require Surface plots, Interpolation and Sensitivity Analysis displays. For MOO Scatter plots, Parallel Coordinate plots, Hyper-Radial Visualization and Self-Organizing Maps are available. Since Stochastic Analysis is an integral LS-OPT feature, various statistical tools are provided to visualize results based on either direct or metamodel-based simulation.

## General Features

**Design Sampling:** *Discrete sampling* can now be done on a variable-by-variable basis. This feature allows the user to flag those discrete variables which require sampling with the exact discrete values, e.g. number of ribs in a vehicle part. The *D*-Optimality criterion, Space Filling, Full Factorial and Monte Carlo schemes are supported under this feature.

The .csv text format for a user-defined point selection table, has been added.

**Job distribution:** Because the logistics of job distribution plays a crucial role in simulation-based optimization/analysis, the relevant modules have been reworked to improve reliability and

diagnostics for distributing solver jobs across a network. For convenience the user can now specify environment variables to be exported to the solver job (e.g. running on a cluster). This feature is convenient for setting up a job configuration which can be mobilized using a simple file with *name=value* type variable definitions or a more convenient GUI customized by the user/system administrator. Job monitoring has also been made more transparent by labeling each progress bar with the Iteration number, Case name and Job number. During and after runtime, the solver log (e.g. LS-DYNA<sup>®</sup> output) can be easily displayed for each job, allowing error terminations to be diagnosed immediately. As in the past, jobs can be distributed through a number of standard queuing interfaces that allow automatic monitoring and file transfer with minimal user effort or a so called *Blackbox* interface for systems with firewalls in which the user is responsible for job monitoring/file transfer.

**Result interfaces:** A full mode tracking and frequency extraction interface has been added for the MSC NASTRAN solver. Mode tracking is required for frequency constraints because vibration modes may switch between designs. The procedure operates the same as the current LS-DYNA mode tracking feature, i.e. it allows the user to identify any mode (e.g. twisting mode or bending mode) of interest and then to automatically track the selected mode for all the designs being simulated for optimization or reliability.

For the purpose of vehicle safety design, various vehicle injury criteria have been added, namely the Viscous Criterion, Chest Compression criterion and A3ms criterion. More criteria are being added to Version 4.2

Users can now extract SPH (for fluid structure interaction) and acoustics related responses.

**Extraction of results from text files:** GenEx is a generic extractor packaged with LS-OPT to enable extraction of response quantities from text output files. The tool enables the user to create a template in which the location (anchor points) of the numeric fields of interest are defined. The extractor is useful when running a simulation package which produces text output files, but for which a dedicated LS-OPT interface is not yet available. The selected responses are automatically imported in the LS-OPT GUI.

**\*CASE support and multi-stage analysis:** Multiple cases can be defined in a LS-DYNA keyword file using the \*CASE keyword. LS-OPT supports the extraction of responses for a specific LS-DYNA case, thereby facilitating multi-stage analysis.

**Parameter Identification:** Radial Basis Function Networks are now supported in addition to polynomials for the history-based Mean Squared Error composite function. The accuracy of parameter identification has also been improved by the addition of *Virtual Histories*, i.e. histories interpolated from response surface approximations. Virtual Histories (as e.g. displayed in Figure 6) are available based on linear or quadratic polynomials or Radial Basis Function networks.

## Viewer Features

The purpose of the LS-OPT Viewer is to provide an integrated visualization aid for making design decisions. The new Viewer, which was first released in Ver. 4, has now been significantly expanded through the addition of six options (see Plot Selector in Figure 1). These are a Parallel Coordinate plot for simulation results, history plots (for both computed and predicted histories),

a 2-Dimensional Interpolator, Global Sensitivity Analysis and Variable Values/Confidence intervals (for parameter identification problems). The window on the left allows the selection of previously saved setups. These can be saved from any multi-window display.

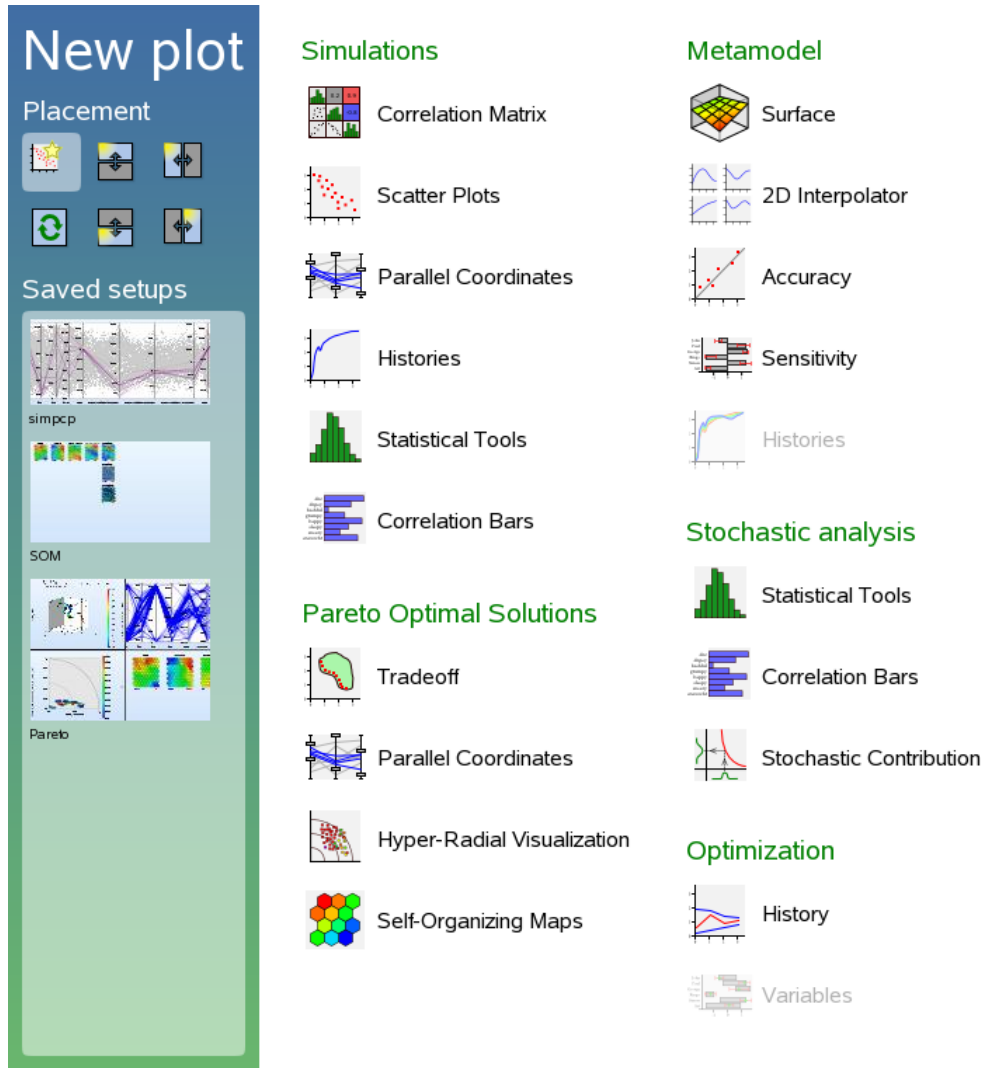
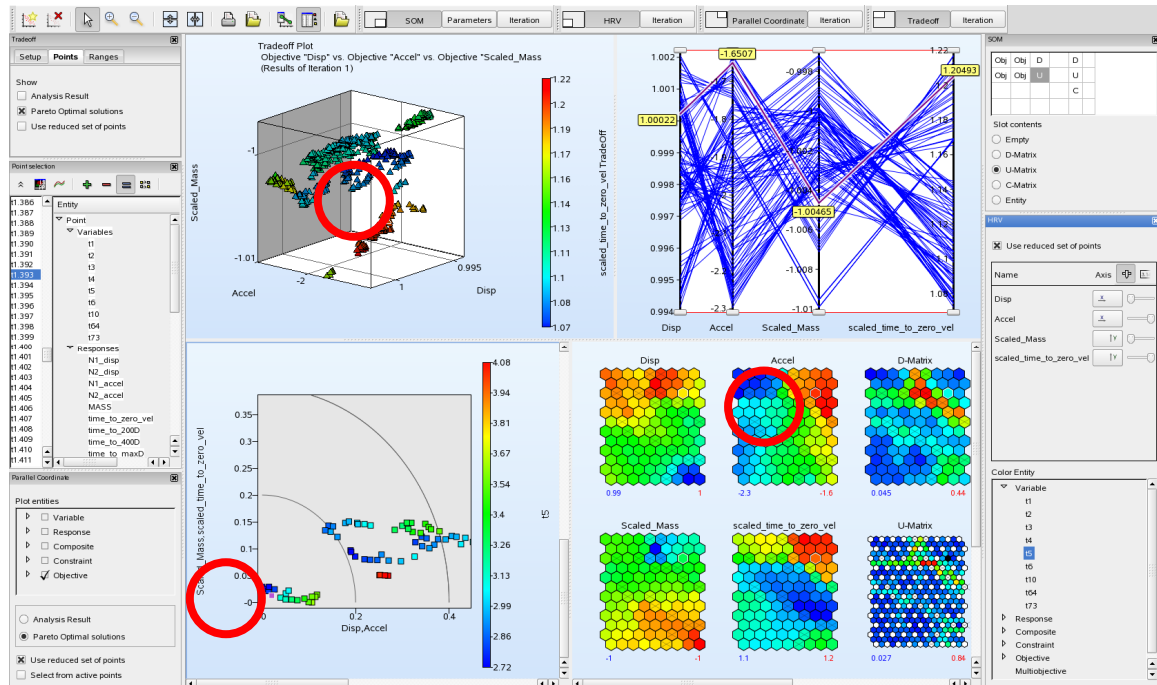


Figure 1: Plot selector showing the various plot categories, placement options and saved setups.

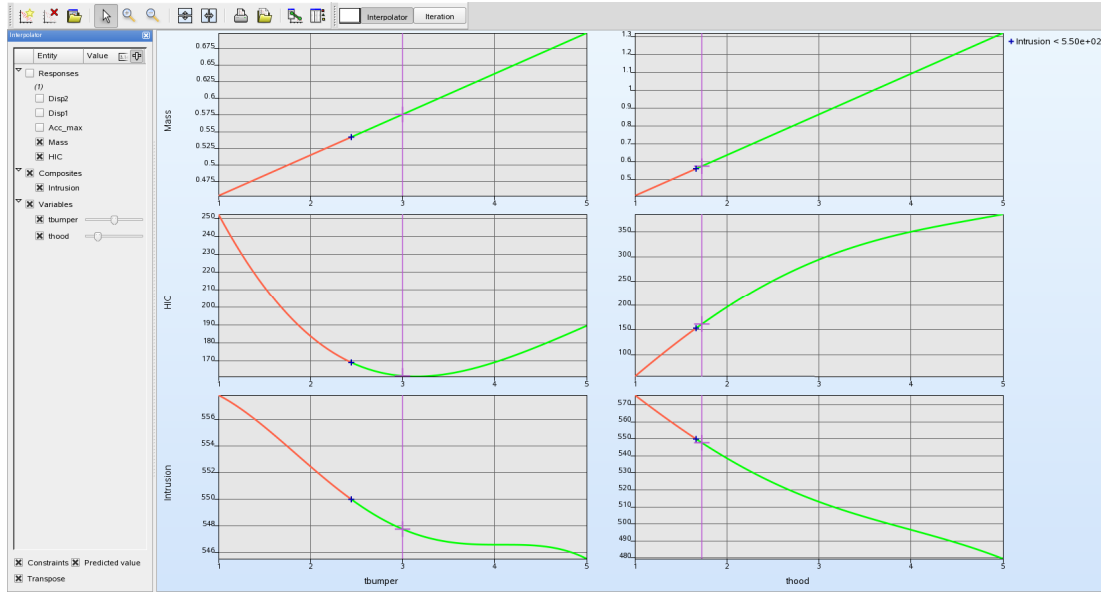
1. *Integration of Self Organizing Maps (SOM) with the Pareto Optimal Frontier (POF) tools.* The Pareto set is a set of optimal points generated by solving a *multi-objective optimization* problem and is typically displayed in the objective function space. After computing the POF, it is still up to the user to select the best design from the set. Because of the possibility of having more than 3 objectives, visualization of the Pareto set can be problematic. LS-OPT therefore provides four different types of Pareto displays offering different visualization perspectives of the POF. The methods are integrated in the sense that selecting a group of points in the one type also highlights the same group in the other types. *SOM* has been added in V4.1 because it allows the user to simultaneously visualize the tradeoff properties for all objectives, constraints, variables and any other response defined by the user. The selected

points can be exported in the form of a simulation-ready .csv file. The four methods are shown in Figure 2 with SOM at the bottom right. These can of course be displayed individually.



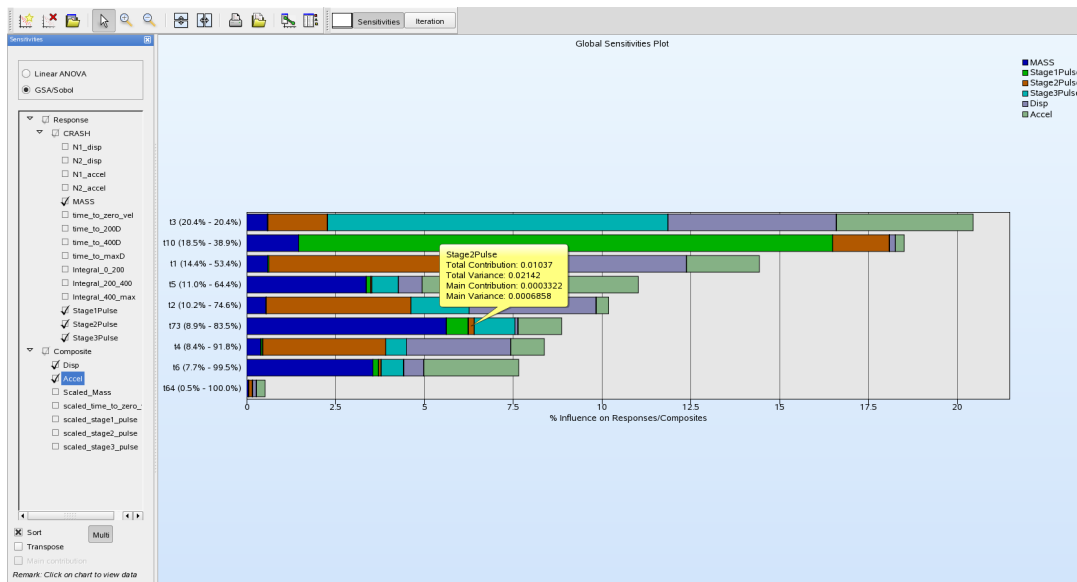
**Figure 2: Integrated Visualization of the Pareto Optimal Front.** A selected point (circled in red) is highlighted on all the plots to facilitate selection of a suitable point. The plot types are (clockwise from top left) (i) 4D Scatter plot (ii) Parallel Coordinate plot, (iii) Self Organizing Maps (new) and (iv) Hyper-Radial Visualization (HRV).

2. *Interpolation Matrix (2D)*. The 2D Interpolator displays cross-sections of the metamodels. This display is in the form of a matrix, here shown with variables in the columns and the responses represented by the rows. A slider control can be used to adjust the variable values (vertical purple line). To enable the user to move the design within a feasible region, the feasibility is displayed by coloring the plot in green for the feasible range and red for the infeasible range.



**Figure 3: 2D interpolation matrix showing cross-sections at selected variable values for three responses and two variables. Green represents the feasible region**

3. *Global Sensitivities.* Global response sensitivities are computed using the Sobol Sensitivity Index method [4] and can be used to screen design variables, thereby accelerating the optimization procedure with only those variables which are deemed significant. The sensitivity bar charts represent the variability of each response with respect to each variable and can be plotted either with each bar representing a variable and showing the responses (Figure 4) or each bar representing a response/composite and showing the relative importance of the variables.



**Figure 4: Global Sensitivity Analysis (GSA) plot showing the sensitivity of 6 responses as a function of 9 variables. The x-axis shows the fraction of influence of each variable. The balloon shows Total and Main contributions and variance values.**

4. *Histories*. Both computed (Figure 5) and predicted (i.e. interpolated) histories (Figure 6) can be displayed. The histories can be color-highlighted with variable values, feasibility and iteration number. Clicking a history plot will bring up the parameter list for the selected design.

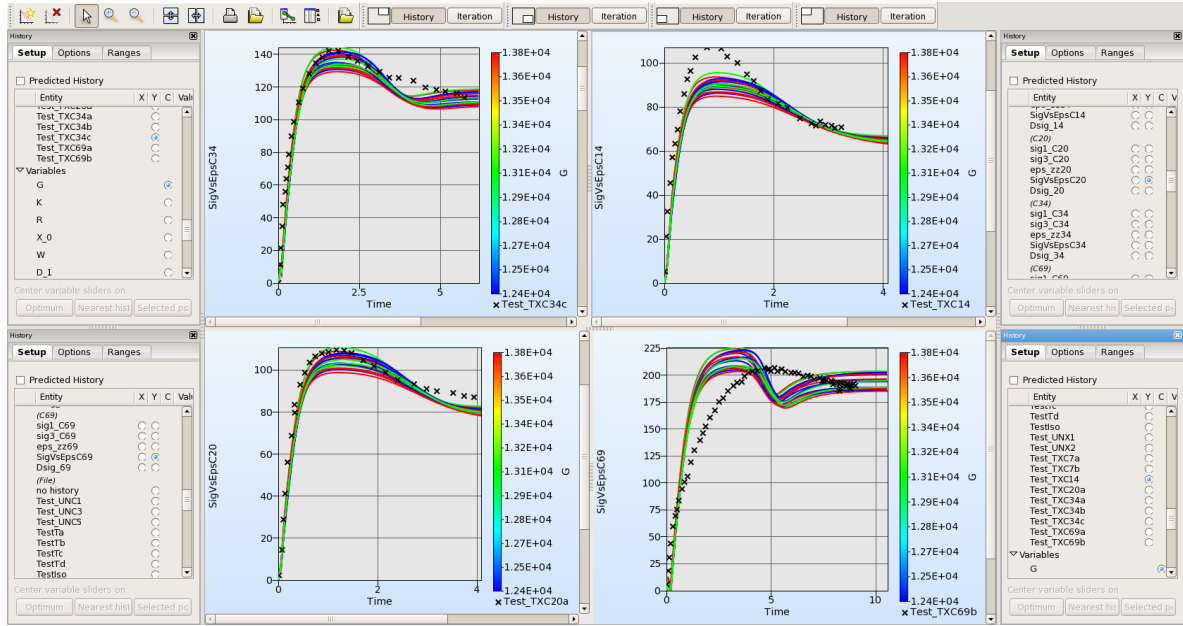


Figure 5: Multi-window plot of computed histories for a parameter identification problem (selected iteration). The test values are shown as black crosses.

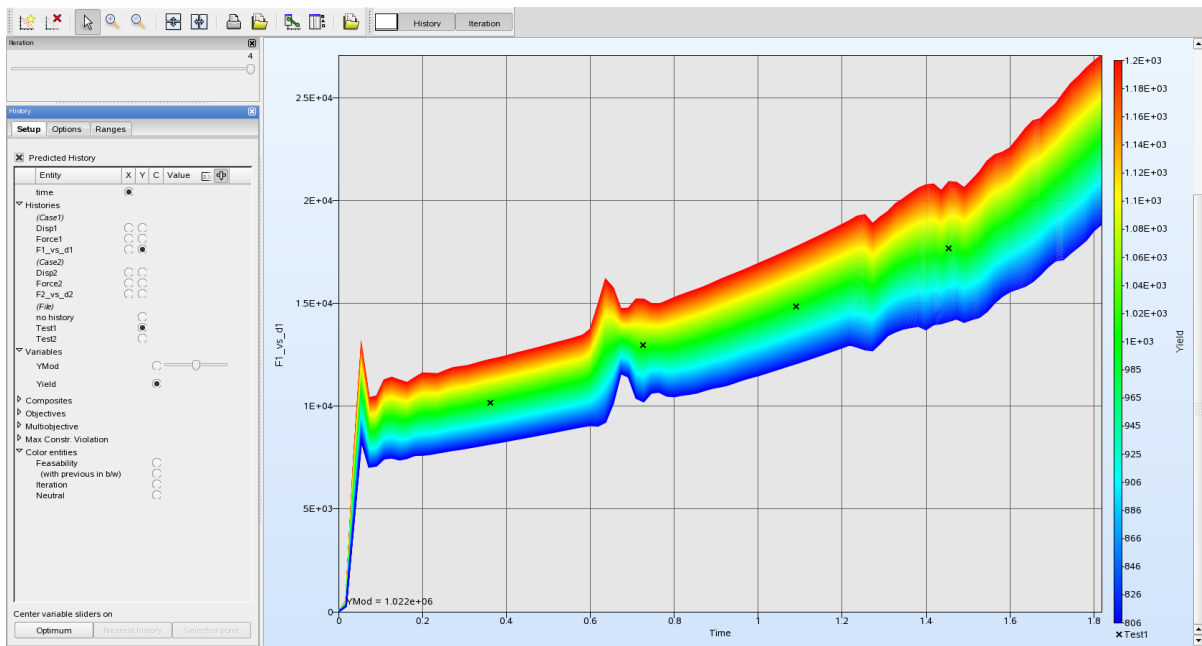
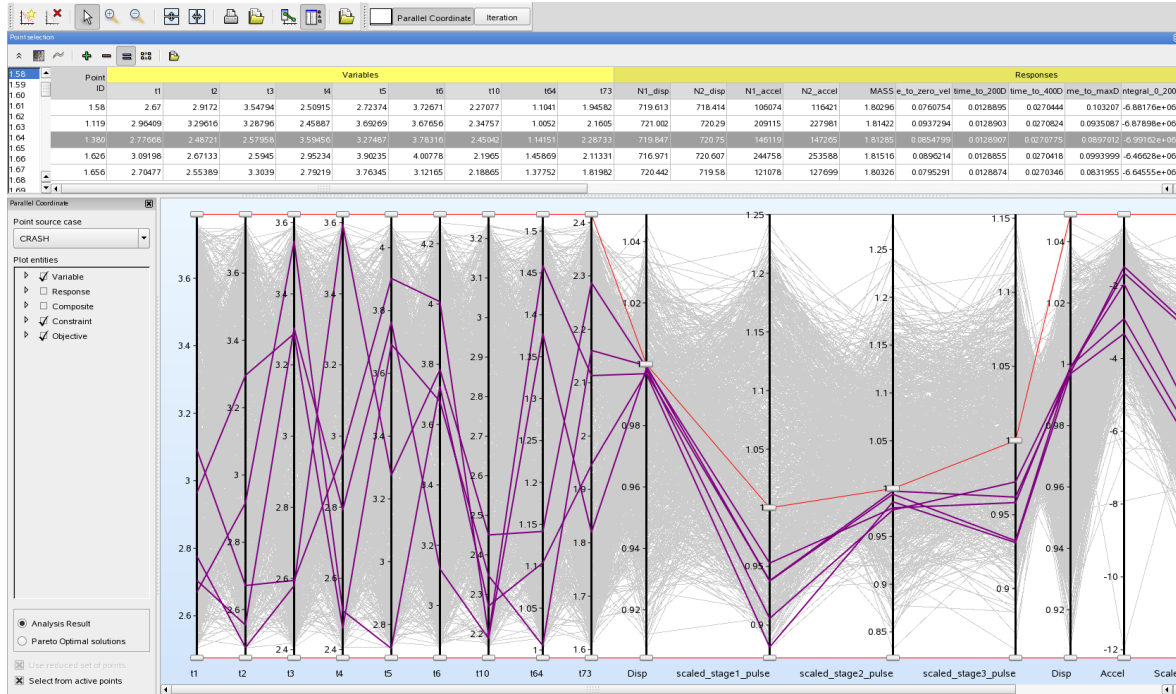


Figure 6: Plot of a predicted history for a parameter identification problem (selected iteration). The plot shows the variation of the history over the design range of a selected variable (see legend on right).

*Parallel Coordinate Plot:* A Parallel Coordinate plot feature has been added for the simulation points (see Figure 7). The plot opens with pre-set constraint bounds, thereby highlighting the feasible points. Selected point sets (such as is highlighted in Figure 7) can be exported to a simulation-ready text file (in .csv format).



**Figure 7: Parallel Coordinate Plot of 1000 simulation points. The red line represents the constraint bounds, in this case leaving only five feasible points (highlighted). An exportable table is shown above the chart.**

5. *Variable Bar Chart.* This chart (not depicted) shows the values of the variables at a selected iteration. For parameter identification, error bars are used to display confidence intervals.

### Closure

With the release of the advanced features in Version 4.1, LS-OPT has achieved a mature status, offering most of the features required for an LS-DYNA-based design environment. Features have also been added to accommodate users using NASTRAN for the tracking and computation of modal frequencies. These features have been tested in an industrial setting. In addition, industrial demand has contributed to significant enhancements for solver job distribution. The Viewer has been significantly extended to provide a full complement of post-processing features for CAE. A brief outlook of Version 4.2 will be given in the presentation.



**References**

1. Stander, N., Roux, W.J., Goel, T., Eggleston, T. and Craig, K.J. LS-OPT Version 4.1 User's Manual, Livermore Software Technology Corporation, March 2010.
2. LS-DYNA<sup>®</sup> Keyword User's Manual, Version 971.
3. Craig, K.J. and Stander, N., Dooge and Varadappa, S. Automotive crashworthiness design using response surface-based variable screening and optimization, *Engineering Computations*, Vol. 22:38-61, 2005.
4. Goel, T. and Maurath, C. Variable Screening Using Global Sensitivity Analysis. Proceedings of the 11<sup>th</sup> LS-DYNA<sup>®</sup> Users' Conference, Dearborn, MI, June 10-11, 2010.
5. Roux, W.J., Stander, N., Günther, F and Müllerschön, H. Stochastic analysis of highly nonlinear structures, *International Journal for Numerical Methods in Engineering*, Vol. 65:1221-1242, 2006.
6. Stander, N. and Craig, K.J. On the robustness of a simple domain reduction scheme for simulation-based optimization, *Engineering Computations*, Vol. 19:431-450, 2002.

