Multidisciplinary Optimization using the Successive Response Surface Method

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Topics

- Introduction
- LS-OPT: Application of the Successive Response Surface Method (SRSM)
- Example: Multidisciplinary Optimization (MDO)
Introduction

What is LS-OPT?

- LS-OPT is an environment to explore automatically the design space and find an optimum design
- LS-OPT is a product of LSTC (Livermore Software Technology Corporation)
- LS-OPT is based on the Successive Response Surface Method (SRSM). Statistical approaches (Robustness Analysis) and genetic algorithms (Discrete Methods) will be implemented in near future
- LS-OPT provides a graphical user interface (GUI)
- LS-OPT can be linked to any simulation code, but it is perfect suitable in combination with LS-DYNA
Why Response Surface Method and not Gradient Based Methods?

- Highly Nonlinear Problems
- Local Sensitivities may lead to local optimums
- Difficulties by the Computation of Numerical Gradients
  - If the perturbation interval is too large: loose accuracy
  - If the perturbation interval is too small: find spurious gradients
**LS-OPT: Application of the SRSM**

**SRSM: How does it work?**

- Design surfaces are fitted through points in the design space to form approximate optimization problem

- The idea is to find surfaces with the best predictive capability

![Diagram showing design surfaces and parameter space](image)

- calculated model response for a chosen parameter combination \( p_i \) (experimental point)
- linear approximation surface

**The idea is to find surfaces with the best predictive capability**

*Optimization using the Successive Response Surface Method*
LS-OPT: Application of the SRSM

Design Space, Region of Interest & Experimental Design Points

Optimization using the Successive Response Surface Method
LS-OPT: Application of the SRSM

Feasible Experimental Design

- Design Variable 1
- Design Variable 2
- Constraint $g$
- Constraint $f$
- Feasible Region
- Region of Interest
- Center of Region of Interest (Baseline Design)
- Basis Experiments

Optimization using the Successive Response Surface Method
Optimization using the Successive Response Surface Method

 LS-OPT: Application of the SRSM

Successive Approximation Scheme

Design Variable 1

Design Variable 2

Region of Interest

Start

Optimum

Design Space

Optimization using the Successive Response Surface Method
LS-OPT: Application of the SRSM

The Optimization Process

- DOE
- Preprocessing
- Simulation
- Build response surfaces
- Optimization
- Approximate solution
- Error Analysis
- Sensitivity Analysis
- Trade-Off
- Convergence

Approximation Model
Region of Interest (Move Limits)
Trial Design

Converged?
No

Solution

Model
Design Formulation

Optimization using the Successive Response Surface Method
Optimization using the Successive Response Surface Method

Graphical User Interface

LS-OPT: Application of the SRSM

[Diagram showing a graphical user interface for optimization using the Successive Response Surface Method (SRSM)].
Optimization using the Successive Response Surface Method

### LS-OPT: Application of the SRSM

#### Graphical User Interface

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Optimization using the Successive Response Surface Method
LS-OPT: Application of the SRSM

Graphical User Interface

Optimization using the Successive Response Surface Method
**LS-OPT: Application of the SRSM**

**Advantages of the Method**

- **Global Optimization:**
  Response Surface have a tendency to capture globally optimal regions. Local minima caused by noisy response as well as the step-size dilemma for numerical gradients are avoided.

- **Parallel Computation:**
  Successive Response Surface scheme allows parallel (independent) computation of experimental points within one iteration.

- **Flexible Design Exploration:**
  Design exploration can be changed within the optimization process. Thus, control of the computational time and the quality of the Response Surface is possible.

- **Trade-Off Studies:**
  Since the Response Surface is determined, easy examination of varying constraint bounds is possible (not reliable with linear approximations).
Example: Multidisciplinary Optimization (MDO)

Fully Integrated Optimization - Crash and NVH

Iteration \((k)\)

Multidisciplinary Analysis

- \(x^{(k)}_{\text{CRASH}}\) ➔ Crash Analysis
- \(x^{(k)}_{\text{NVH}}\) ➔ NVH Analysis

Response Surfaces

\[ f(x^{(k)}_{\text{CRASH}}) \]
\[ f(x^{(k)}_{\text{NVH}}) \]

Systems Level Optimizer

Goal: Minimize Mass
Crashworthiness and NVH Constraints
Design \(x^{(k)}\)

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Full Vehicle – Crash Performance (LS-DYNA)

Baseline:
- 30,000 elements
- Displacement = 552mm
- Stage1Pulse = 14.34 g
- Stage2Pulse = 17.57 g
- Stage3Pulse = 20.76 g
Example: Multidisciplinary Optimization (MDO)

Full Vehicle – Crash Performance (LS-DYNA)

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

BIW-Modell - NVH Performance (LS-DYNA)

Baseline:
- 18,000 elements
- Torsional Mode 1
- Frequency = 38.7 Hz

LS-DYNA eigenvalue problem - FORD TAURUS BIW
Time = 38.736
Example: Multidisciplinary Optimization (MDO)

Design Variables (Thickness)

- Left and right Apron (1)
- Shotgun outer and inner (2)
- Inner and outer rail (2)
- Left and right cradle rails (1)
- Front cradle cross members (1)
Example: Multidisciplinary Optimization (MDO)

Design Formulation – FULLY SHARED VARIABLES

Design Objective:
- Minimize (Mass of components)

Design Constraints:
- Displacement > 551.8mm
- $37.77\text{Hz} < \text{Torsional mode 1 frequency} < 39.77\text{Hz}$
- Stage1Pulse > 14.34g
- Stage2Pulse > 17.57g
- Stage3Pulse > 20.76g

Thickness Design Variables Shared: 7
- Rails (inner and outer), Shotgun (inner and outer), Aprons, Cradle rails, cross member

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Mode Tracking

- During NVH optimization necessary to track mode as mode switching can occur due to design changes

- Search for maximum scalar (dot) product between eigenvector of base mode and each solved mode:

\[
\max_j \left\{ \left( M_0^{\frac{1}{2}} \phi_0 \right)^T \left( M_j^{\frac{1}{2}} \phi_j \right) \right\}
\]
Example: Multidisciplinary Optimization (MDO)

Optimization History: Mass (Objective) – FULLY SHARED VARIABLES

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Optimization History: Maximum Displacement – FULLY SHARED VARIABLES

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Optimization History: Stage Pulses – FULLY SHARED VARIABLES

![Graph showing optimization history with stages and bounds.](image-url)
Example: Multidisciplinary Optimization (MDO)

Optimization History: Torsional Mode Frequency – FULLY SHARED VARIABLES

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Variable Screening

Goal: Remove of less significant variables
Example: Multidisciplinary Optimization (MDO)

Variable Screening

- Methodology: ANOVA (ANalysis Of VAriance)
- $\Delta b_j$ depends on the variance of the simulation points
- Use a 90% confidence level and determine the lower bound

From regression analysis

Coefficient: variable $j$
Example: Multidisciplinary Optimization (MDO)

Variable Screening

- Variables are ranked according to lower bound
- If the lower bound < 0, regression coefficient is insignificant
- In a linear approximation, a variable can be removed if its coefficient is insignificant

Significant

Insignificant

Value which determines significance
Example: Multidisciplinary Optimization (MDO)

Design Formulation – PARTIALLY SHARED VARIABLES

Design Objective:
- Minimize (Mass of Components)

Design Constraints:
- Displacement > 551.8mm
- 38.27Hz < Torsional Mode 1 frequency < 39.27Hz
- Stage1Pulse > 14.34g
- Stage2Pulse > 17.57g
- Stage3Pulse > 20.76g

Crashworthiness Design Variables: 6
- Rails (inner and outer), Shotgun
  (inner and outer), Aprons, Cradle Rails

NVH Design Variables: 4
- Shotgun (inner and outer), Cradle Rails, Cross Member

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Optimization History: Mass (Objective)

Optimization using the Successive Response Surface Method

Reduction: -4.7%
Example: Multidisciplinary Optimization (MDO)

Optimization History: Maximum Displacement

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Optimization History: Stage Pulses

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Optimization History: Torsional Frequency

Optimization using the Successive Response Surface Method
Example: Multidisciplinary Optimization (MDO)

Run Statistics

Run Statistics – Fully Shared MDO
13 experimental points per iteration per discipline
- 7 hours per crash simulation
- 10 minutes per NVH simulation (700MB memory each)
- 9 iterations to converge
- 117 crash simulations and 117 NVH simulations

Run Statistics – Partially Shared MDO
11 experimental points per iteration for crash
8 experimental points per iteration for NVH
- 6 iterations for good compromised solution
- 66 crash simulations and 48 NVH simulations
- More flexibility in using resources (processors and memory)
Example: Multidisciplinary Optimization (MDO)

Starting from Lightest and Heaviest Design

Optimization using the Successive Response Surface Method
Conclusions MDO-Example

Conclusions / Outlook / Remarks

- **Multidisciplinary feasible optimization** of a full vehicle model considering crashworthiness and NVH design criteria is described.
- Almost **5% mass reduction** is achieved while maintaining or improving of the design criteria of the baseline design.
- **Variable Screening** allows the detection of insignificant design variables.
- The capability of **partially or non shared variables for MDO** may reduce the computational effort dramatically.
Conclusions MDO-Example

Conclusions / Outlook / Remarks

- Optimization with current full vehicle crash models (500000-1000000 Elements) is still very time consuming and requires huge hardware resources.

- Gradients of the linear implicit discipline (NVH) may be used for the calculation of the according Response Surface approximation.

- Discrete Methodologies for sheet thickness optimization.

- A two-stage approach with stochastic and deterministic methods, may be very efficient for crash.