Statistical Approach to Complex Systems in the Presence of Uncertainty

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The optimization of engineering systems often inappropriately assumes deterministic input parameters. The effect of such assumptions is generally unknown particularly for complex systems. We address this problem using a probabilistic framework accounting for parametric uncertainties and allowing for quantification in system response or performance. In this framework the performance functions of interest are random, and their optimization is performed with respect to the design variables. We adapted and implemented an advanced statistical learning technique, sequential importance sampling (SIS), to make predictions about the response of complex uncertain systems, including an HE-detonation model and an energy policy model, and their sensitivity to variations of the variables.

Project Goals

The purpose of the project is to establish a stochastic framework that enables the efficient calculation of response statistics over the entire variable space. The framework consists of two components.

First, directly parallelizable advanced sampling techniques are used to evaluate the system response as a function of design and random variables using the least number of deterministic simulations. Second, the output of this sampling process is statistically classified using robust probit regression and boosting schemes to derive the dependence of the performance statistics as functions of the variables.

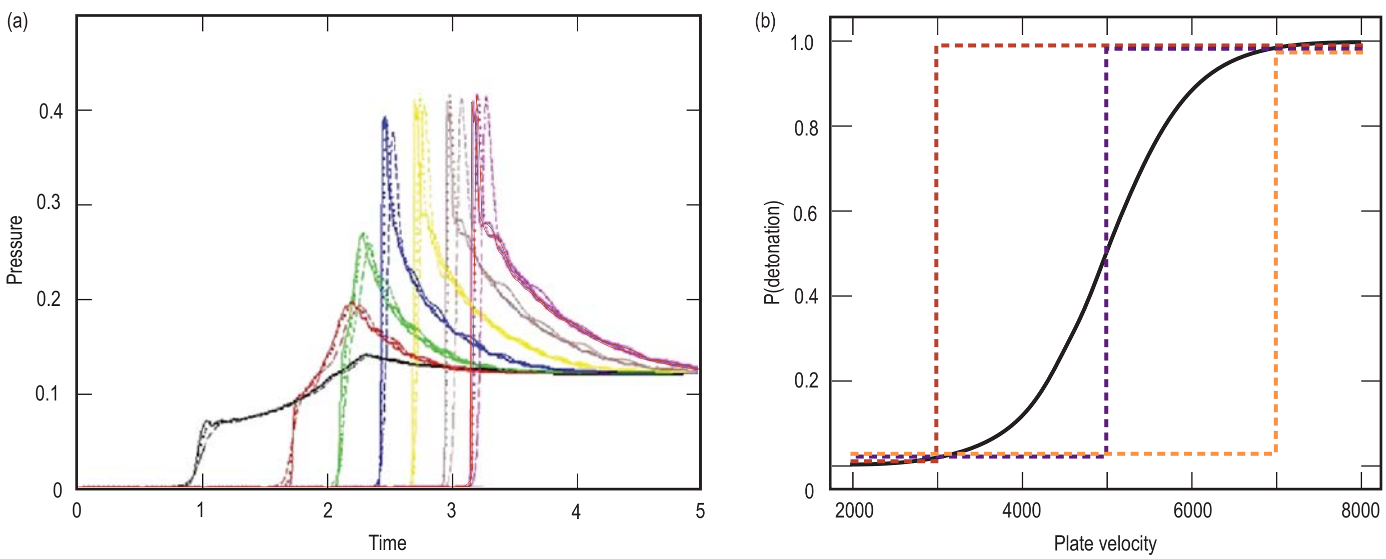

Figure 1. (a) Pressure vs. time at different gages for a deterministic ALE3D detonation simulation. (b) Probability of detonation as a function of plate velocity for three spatially fixed HE mass-fraction values (dotted lines) and accounting for zonal HE mass-fraction uncertainty using SIS (solid line).

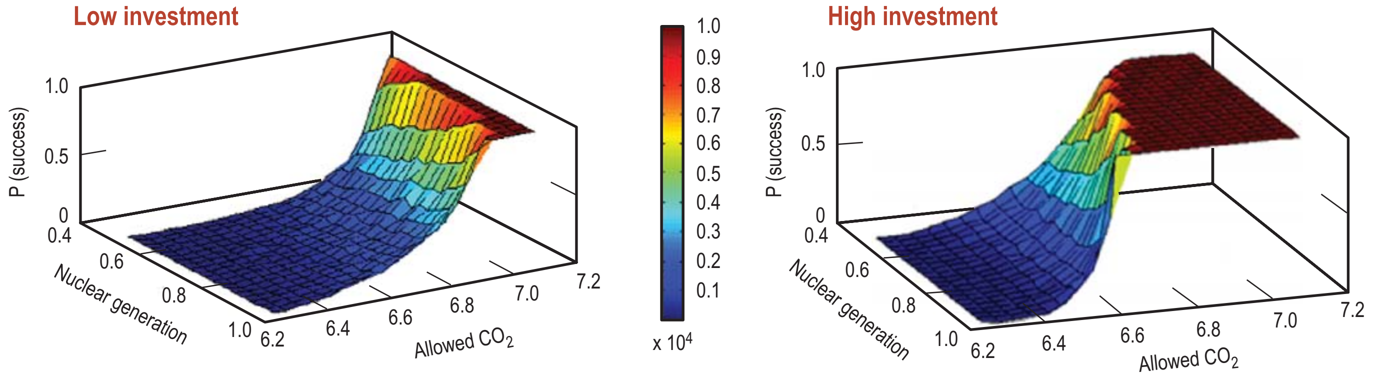

Figure 2. Probability of policy success as a function of three variables.

Relevance to LLNL Mission

Our project addresses the need for uncertainty quantification and sensitivity analysis of complex systems and enhances LLNL's ability to apply advanced stochastic techniques to existing deterministic codes. The advocated techniques increase efficiency and predictive ability of existing computational codes and are applicable to problems in infrastructure protection, energy security, and national security.

FY2007 Accomplishments and Results

Our accomplishments have been in the area of detonation modeling and energy policy.

Modeling HE detonation is potentially a multivariate nonlinear problem with uncertainty in several parameters. The ALE3D hydrodynamics code deterministically predicts detonation based on peak overpressure, assuming a spatially fixed HE mass-fraction ratio as a function of flyer plate velocity (Fig. 1a). Using SIS we efficiently compute and optimize the likelihood of detonation accounting for uncertainty in the zonal HE mass fraction. Illustrated in Fig. 1b is one possible response space using SIS along with three deterministic, *i.e.*, spatially fixed HE mass-fraction, ALE3D simulations.

The mathematical modeling of energy systems is used to optimize policy strategies but is hampered by large uncertainties associated with several key parameters. Policy decisions made in the presence of uncertainty work best with a probabilistic objective function, *e.g.*, the probability that the cost will not exceed a certain threshold.

In this example we use MARKAL, a deterministic model for energy systems that accounts for a very large number of uncertain parameters. We consider two random variables (gas and oil prices) as well as three design variables (national R&D investment, nuclear generation, and CO_2 allowance) and predict the probability of successfully attaining a cost-effective CO_2 emission reduction. Figure 2 depicts the probability of success as a function of the three design variables.

Related References

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