UNDERSTANDING SENSITIVITY ANALYSIS FOR COMPLEX FIRE MODELS

W. W. Jones, R. D. Peacock, P. A. Reneke, C. L. Forney, M. M. Kostreva
USA

Analytical models for predicting fire behavior have been evolving since the 1960's. These analytical tools have progressed to the point of providing predictions of fire behavior with an accuracy suitable for most engineering applications. Two questions arise concerning the use of these models for engineering calculations:

- How precise do the inputs to the model need to be (How do changes in the inputs effect the predictions)?
- How accurate is the output of model (How close are the actual conditions to those predicted by the model)?

Several methods of sensitivity analysis have been applied to fire models. These range from explicit evaluation of the equations used in simple models such as ASET[1] to pointwise evaluation of complex models from numerous computer runs of the model[2]. For simple models like the ASET model, analytical techniques can be readily applied. For more complex fire models, obtaining an overall assessment of model sensitivity increases with the complexity of the model, requiring evaluation of numerous model inputs and outputs.

In a report for the Electric Power Research Institute[3] on validation of power plant plume models, a number of statistical techniques were presented for assessing the uncertainty of predictions based on comparing the residuals betweens measured and predicted values. Examples are

- A time series of the residuals should appear as Gaussian noise and of the residuals should form a symmetric distribution.
- The mean value of the residuals should be zero, and unusually large residuals (outliers) should be rare.
- When plotted against other exogenous variables, the residuals should be random in magnitude and sign.
- A co-plot of residuals and predicted values should show no pattern.

Although these tests were applied to the comparison of measured and predicted values, the identical problem exists in sensitivity analysis.

Iman and Helton[4,5,6] studied the sensitivity of complex computer models developed to simulate the risk of severe nuclear accidents which may include fire and other risks. Three approaches to uncertainty and sensitivity analysis were explored:

- response surface methodology where the inputs are determined from a fractional factorial design, a
- Latin hypercube sampling where carefully chosen random sampling is used to determine model inputs, and
- differential analysis used to evaluate sensitivity for small perturbations about a single set of model inputs.

Khoudja[2] has studied the sensitivity of an early version of the CFAST model with a fractional factorial design involving two levels of 16 different input parameters. His analysis showed a particular sensitivity to the inclusion of conduction in the calculations and lesser sensitivity to the number of compartments included in a simulation.

We examine these questions, requirements and methodologies using an example fire model to point out the strengths and weaknesses of our current level of understanding[7,8], and present a number of these alternatives for analyzing the sensitivity of both simple and complex room fire models and show how they can be used in practice.

1. Jarvis, J. P., Kostreva, M. M., Forney, C. L., Tools for Validation and Analysis of Fire Models, Combustion Institute/Eastern States Section. Chemical and Physical Processes in Combustion. 20th Fall Technical Meeting. Abstracts. November 2-5, 1987, Gaithersburg, MD, 103/1-4 pp. 1987.

2. Khoudja, N., Procedures for Quantitative Sensitivity and Performance Validation of a Deterministic Fire Safety Model. Ph.D. Dissertation, Texas A&M University, NBS-GCR-88-544, Natl. Inst. Stand. Technol. 1988.

3. Validation of Plume Models Statistical Methods and Criteria, EPRI EA-1673-SY, Electric Power Research Institute, Palo Alto (1980).

4. Iman, R. L. and Helton, J. C., An Investigation of Uncertainty and Sensitivity Analysis Techniques for Computer Models, Risk Analysis, Vol. 8, No. 1, 71-90 (1988).

5. Iman, R. L. and Conover, W. J., A Distribution-Free Approach to Inducing Rank Correlation Among Input Variables. Communications in Statistics **B11**(3), 331-334 (1982).

6. Iman, R. L. and Shortencarier, A FORTRAN 77 Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models. NUREG/CR-3624, SAND83-2365, Sandia National Laboratories, Albuquerque, New Mexico (1984).

7. Peacock, R. D., Jones, W. W., and Bukowski, R. W., Verification of a Model of Fire and Smoke Transport, Fire Safety J. **21**, 89-129 (1993).

8. Beard, A., Evaluation of Fire Models: Part I – Introduction. Fire Safety J. **19**, 295-306 (1992).