



Guest Editorial

Sensitivity Analysis of Model Output: SAMO 2004

The Fourth International Conference on Sensitivity Analysis of Model Output (SAMO 2004) was held from March 8 through March 11, 2004, in Santa Fe, New Mexico. The previous SAMO conferences were held in Belgirate, Italy (September 25–27, 1995), Venice, Italy (April 19–22, 1998), and Madrid, Spain (June 18–19, 2001). The SAMO conferences are single-track meetings that promote in-depth technical discussions of issues related to the uncertainty and sensitivity analysis of model predictions. In the context of the SAMO conferences, uncertainty analysis refers to the determination of the uncertainty in model predictions that results from uncertainty in model inputs, and sensitivity analysis refers to the determination of the contributions of the uncertainty in individual model inputs to the uncertainty in model predictions. Here, *model* is used broadly enough to include large analyses that involve multiple individual models that are linked together, and *model input* is used broadly enough to include designators for alternative models or modeling assumptions.

Topics considered at the SAMO conferences include innovative methods for uncertainty and sensitivity analysis, experimental design and sampling plans for computer experiments, model calibration and validation, probabilistic and nonprobabilistic structures for the representation of uncertainty in model inputs and outputs, and decision-making under uncertainty. The uncertainty and sensitivity analysis of model predictions is important in all areas of modeling and specific modeling topics that have been considered in the SAMO conferences include problems from economics, engineering, ecology, nuclear safety, and physics.

The novelty of simply being able to carry out a complex calculation is past. Now, the relevant question with respect to an analysis is not “What is the answer?” but rather “What is the uncertainty in the outcomes of the analysis and what gives rise to this uncertainty?”. Or, put another way, “How much confidence should be placed in the results of the analysis?”. Answering these questions requires the performance of an uncertainty and sensitivity analysis and is essential to drawing properly informed insights from an analysis. Large numerical analyses are now often used to support important societal decisions. Appropriately informed decisions cannot be made on the basis of such

analyses without knowledge of the uncertainty associated with their results [1–16]. The SAMO conferences provide a forum for the presentation and discussion of both techniques for and results obtained in uncertainty and sensitivity analyses. By providing this forum, the goal of the SAMO conferences is to encourage and enhance the use of uncertainty and sensitivity analysis in the assessment of model predictions.

In support of this goal, the SAMO conferences have a tradition of publishing an associated special journal issue [17–20]. Consistent with this tradition, the present issue of *Reliability Engineering and System Safety* contains selected papers from the SAMO 2004 conference.

The SAMO 2004 conference involved both invited presentations of a general and usually tutorial nature and contributed presentations that tended to be more focused on a specific technique or application. The invited presentations, in the order delivered, were:

1. Input Screening: Finding the Important Model Inputs on a Budget (Max Morris)
2. Sensitivity Analysis Practices. Strategies for Model-Based Inference (Andrea Saltelli)
3. Sensitivity Analysis When Model Outputs Are Functions (Michael McKay)
4. Bayesian Analysis of Computer Code Outputs: A Tutorial (Anthony O'Hagan)
5. Statistical Calibration of Computer Simulations (Katherine Campbell)
6. Calibration, Validation, and Sensitivity Analysis: What's What (Timothy Trucano)
7. Probabilistic Inversion for Chicken Processing Lines (Roger Cooke)
8. Survey of Sampling-Based Methods for Uncertainty and Sensitivity Analysis (Jon Helton).

To avoid confusion, the listed titles are the titles for the corresponding papers in the special issue, which in some cases are slightly different from the titles used at the conference. As described below, the papers based on the invited presentations often have coauthors in addition to the indicated individual actually making the presentation.

The special issue is organized on the basis of the invited presentations. Specifically, the papers based on the invited

presentations are dispersed through the special issue and immediately followed by related papers based on contributed presentations. However, as the contributed papers often touch on topics covered by more than one invited presentation, the resultant organization of the special issue is certainly not unique. As described below, the issue contains a total of 35 papers, of which 8 are based on the invited presentations indicated above and 27 are based on contributed presentations made at the conference.

The special issue begins with the paper based on the invited presentation by Andrea Saltelli and coauthored with Marco Ratto, Stefano Tarantola and Francesca Campolongo. This paper describes the important role that sensitivity analysis plays in well-planned modeling studies and places special emphasis on sensitivity analysis procedures based on variance decomposition. This paper and several related papers comprise the first group of papers in the special issue and are listed below:

1. Sensitivity Analysis Practices. Strategies for Model-Based Inference (A. Saltelli, M. Ratto, S. Tarantola, F. Campolongo)
2. Sensitivity Analysis in Presence of Model Uncertainty and Correlated Inputs (J. Jacques, C. Lavergne, N. Devictor)
3. A New Estimator for Sensitivity Analysis of Model Output: An Application to the e-Business Readiness Composite Indicator (S. Tarantola, M. Nardo, M. Saisana, D. Gatelli)
4. Global Sensitivity Analysis for Calculating the Contribution of Genetic Parameters to the Variance of Crop Model Prediction (D. Makowski, C. Naud, M.-H. Jeuffroy, A. Barbottin, H. Monod)
5. The Importance of Jumps in Pricing European Options (F. Campolongo, J. Cariboni, W. Schoutens)
6. Hydrocarbon Exploration Risk Evaluation Through Uncertainty and Sensitivity Analyses Techniques (P. Ruffo, L. Bazzana, A. Consonni, A. Corradi, A. Saltelli, S. Tarantola)
7. Accounting for Components Interactions in the Differential Importance Measure (E. Zio, L. Podofillini).

The unifying theme that brings these papers together is the use of variance decomposition procedures.

The issue next contains a paper based on the invited presentation by Jon Helton and written in conjunction with Jay Johnson, Cedric Sallaberry and Curtis Storlie. This paper provides a survey of sampling-based methods for global sensitivity analysis. This paper and several related papers constitute the next grouping of papers in the issue:

8. Survey of Sampling-Based Methods for Uncertainty and Sensitivity Analysis (J.C. Helton, J.D. Johnson, C.J. Sallaberry, C.B. Storlie)
9. An Approximate Sensitivity Analysis of Results from Complex Computer Models in the Presence of Epistemic and Aleatory Uncertainties (B. Krzykacz-Hausmann)

10. The Use of Global Uncertainty Methods for the Evaluation of Combustion Mechanisms (A.S. Tomlin)
11. Local and Global Uncertainty Analysis of Complex Chemical Kinetic Systems (J. Zádor, I.G. Zsély, T. Turányi)
12. Response Surfaces and Sensitivity Analyses for an Environmental Model of Dose Calculations (B. Iooss, F. Van Dorpe, N. Devictor).

The unifying theme in these papers is the consideration of global sensitivity analysis, often in conjunction with some form of sampling-based uncertainty propagation.

The next grouping of papers begins with the paper based on the invited presentation by Max Morris on efficient methods for initial screening sensitivity analyses. This grouping contains the following papers:

13. Input Screening: Finding the Important Model Inputs on a Budget (M.D. Morris)
14. Refinement Strategies for Stratified Sampling Methods (C. Tong)
15. Comparison of Pure and “Latinized” Centroidal Voronoi Tessellation Against Various Other Statistical Sampling Methods (V. J. Romero, J.V. Burkardt, M.D. Gunzburger, J.S. Peterson)
16. Combined Array Experiment Design (L.M. Moore, M.D. McKay, K.S. Campbell).

The common theme in these papers is the use of experimental design in uncertainty and sensitivity analysis.

The paper based on the invited presentation by Anthony O’Hagan on Bayesian analysis of model predictions follows next in the issue and is the first paper in the grouping:

17. Bayesian Analysis of Computer Code Outputs: A Tutorial (A. O’Hagan)
18. Case Studies in Gaussian Process Modelling of Computer Codes (M.C. Kennedy, C.W. Anderson, S. Conti, A. O’Hagan)
19. Sensitivity Estimations for Bayesian Inference Models Solved by MCMC Methods (C. Pérez, J. Martín, M.J. Rufo)
20. Comments on Generalised Likelihood Uncertainty Estimation (R.J. Romanowicz, K.J. Beven)
21. A Response-Modeling Alternative to Surrogate Models for Support in Computational Analyses (B. Rutherford).

These papers are united in sharing various aspects of a Bayesian perspective.

The roles played by calibration, verification and validation in successful uncertainty and sensitivity analyses constitute a theme addressed in three of the invited presentations. In particular, the presentations by Timothy Trucano, Katherine Campbell, and Roger Cooke and the associated papers written in conjunction with colleagues

address various aspects of these important components of successful analyses. Several contributed papers also address these issues. The result is the following grouping of papers in the issue:

22. Calibration, Validation, and Sensitivity Analysis: What's What (T.G. Trucano, L.P. Swiler, T. Igusa, W.L. Oberkampf, M. Pilch)
23. Statistical Calibration of Computer Simulations (K. Campbell)
24. Probabilistic Inversion for Chicken Processing Lines (R.M. Cooke, M. Nauta, A.H. Havelaar, I. van der Fels)
25. Our Calibrated Model Has Poor Predictive Value: An Example from the Petroleum Industry (J.N. Carter, P.J. Ballester, Z. Tavassoli, P.R. King)
26. Simulation Error Models for Improved Reservoir Prediction (A. O'Sullivan, M. Christie)
27. Validation and Error Estimation of Computational Models (R. Rebba, S. Mahadevan, S. Huang)
28. Application of MCMC–GSA Model Calibration Method to Urban Runoff Quality Modeling (A. Kanso, G. Chebbo, B. Tassin)
29. Estimation Procedures and Error Analysis for Inferring the Total Plutonium Produced by a Graphite-Moderated Reactor (P.G. Heasler, T. Burr, B. Reid, C. Gesh, C. Bayne).

The unifying theme in the preceding papers is the role of calibration, verification and validation in modeling.

The use of nonprobabilistic structures for the representation of uncertainty is an area of study that is gaining rapidly increasing attention in the uncertainty and sensitivity analysis community. None of the invited presentations dealt with nonprobabilistic representations for uncertainty. However, several of the contributed presentations did. The result is the following grouping of papers:

30. Sensitivity Analysis in Conjunction with Evidence Theory Representations of Epistemic Uncertainty (J.C. Helton, J.D. Johnson, W.L. Oberkampf, C.J. Sallaberry)
31. Sensitivity Analysis Using Probability Bounds (S. Ferson, W. T. Tucker)
32. Uncertainty-Based Sensitivity Indices for Imprecise Probability Distributions (J.W. Hall)
33. On a Strategy for the Reduction of the Lack of Knowledge (LOK) in Model Validation (P. Ladevèze, G. Puel, T. Romeuf)
34. Varying Correlation Coefficients Can Underestimate Uncertainty in Probabilistic Models (S. Ferson, J.G. Hajagos).

The commonality in these papers is the use of non-probabilistic structures such as belief and plausibility in evidence theory in the representation of uncertainty.

The special issue ends with the paper based on the invited presentation by Michael McKay and coauthored with Katherine Campbell and Brian Williams:

35. Sensitivity Analysis When Model Outputs Are Functions (K. Campbell, M.D. McKay, B.J. Williams).

This paper considers the common and very important situation in which the analysis result under study in a sensitivity analysis is a function rather than a single uncertain number.

The papers contained in this special issue provide a current perspective on a broad cross section of the procedures, applications and challenges in uncertainty and sensitivity for computer modeling applications. It is the Guest Editors' belief that the papers contained in this issue and their associated references form a valuable resource for individuals wishing to gain entry into this important and rapidly growing area of study.

The next SAMO conference will be held in Budapest in 2007 (date to be established) and will be announced at the sensitivity analysis website <http://sensitivity-analysis.jrc.ec.eu.int/>. Those with an interest in uncertainty and sensitivity analysis of model predictions are encouraged to participate. The past SAMO conferences have been enjoyable and productive. The forthcoming SAMO conference in Budapest will undoubtedly be the same.

The success of the SAMO 2004 conference resulted from the support and efforts of many individuals and institutions. Special thanks and recognition are extended to the conference scientific committee (Members: J. Cavendish, K.M. Hansen, T. Homma, M.J.W. Jansen, H.-M. Kim, and S. Tarantola) and the local organizing committee (Members: S.W. Doebling, K.M. Hansen, F.M. Hemez, R.J. Henninger, M.D. McKay, and K. Womack). Primary institutional sponsorship was provided by Los Alamos National Laboratory. Additional sponsorship was provided by the Joint Research Center of the European Commission, the American Statistical Association, and the Society for Industrial and Applied Mathematics.

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