Information Integration Technology

IIT Project Partners

- Nuclear Weapons Program
- Procter & Gamble
- U.S. Army Aviation and Missile Command/Research, Development and Engineering Center
- Missile Defense Agency and U.S. Army Space and Missile Defense Command
- U.S. Air Force Seek Eagle Office and F-22 System Program Office
- Security Division, Los Alamos National Laboratory

Overview

In this age of exponential growth in science and technology, the capability to evaluate the performance, reliability, and safety of complex systems with very limited full-system test data presents new challenges that require new methodology. This new methodology must respond to the ever increasing demands for such evaluations to provide key information for decision and policy makers at all levels of government and industry. Information Integration Technology (IIT) is being developed at Los Alamos National Laboratory in the Statistical Sciences Group to provide a new methodology to meet these challenges. IIT is a framework of processes, methods, and tools that combines diverse information types (experiments, computer simulations, expert knowledge) from diverse sources (scientists, engineers, decision-makers) to assess quantitative performance, reliability, and safety metrics that can aid decision-making under uncertainty.

Traditional statistical methods for these problems were developed for industrial, mass-produced products such as electronics and consumer goods. Everything works quite nicely provided we have coherent system representations and clean, typically single, sources of quantitative data about the system. However, problems today are much more complex and include systems such as nuclear weapons, infrastructure networks, super computer codes, jumbo jets, etc. These systems demand more of the scientists charged with the responsibility of system assessment than our current methodology allows. In many instances it is not possible to mount vast numbers of full system tests, and frequently none are available. System assessment is complicated by the need to consider more than what has been traditionally considered, because a system's *ability to perform* is intertwined with other concepts such as its age, reliability, safety, and surety. In addition, our ability to do assessments may be severely constrained by policy, cost, and schedule. Therefore we must expand our definition of the *system* to include all aspects that affect its performance and all constraints (e.g., test schedule) that affect the confidence we have in the assessment. The end result should be an assessment that is an expression of our complete state of knowledge about the system. The complexities of "big science" problems demonstrate the impossibility of static coherent system solutions. Today the overall assessment process is more about "decision-making" than "modeling."

This new IIT methodology continues to evolve; however, it has already made important contributions to challenging problems from both government and industry. The following examples of IIT applications illustrate both the challenges and the approach's unique blend of statistics and knowledge management.

Safety, Reliability, and Performance of the Nuclear Weapons Stockpile

From its earliest days, Los Alamos National Laboratory has had a prominent role in the development and evaluation of the United States nuclear weapons stockpile, but the end of the Cold War brought significant changes to how this mission could be carried out. There have been significant reductions in the number of weapons, leading to a smaller, "enduring" stockpile. The United States is no longer manufacturing new-design weapons, and it is consolidating facilities across the nuclear weapons complex. In 1992, the United States declared a moratorium on underground nuclear testing; in 1995, the moratorium was extended, and President Clinton decided to pursue a "zero yield" Comprehensive Test Ban Treaty. However, the basic mission of Los Alamos National Laboratory remains unchanged: Los Alamos National Laboratory must evaluate the weapons in the aging nuclear stockpile and certify their safety, reliability, and performance even though the live test data that has traditionally been used for this evaluation can no longer be collected.

To complete this mission, a two-pronged approach of experiments and computational modeling was adopted. The experimental approach is exemplified by the Dual-Axis Radiography for Hydrotesting facility, which enables experimenters to better understand the nature of explosions. The computational modeling effort is exemplified by the Accelerated Strategic Computing Initiative, which uses supercomputers to model the types of complex nuclear experiments that are no longer performed. Alongside the efforts at experimentation and modeling, the Statistical Sciences Group at Los Alamos National Laboratory has been working to integrate historical data and to quantify the vast resources of expert judgment in such a way as to facilitate their inclusion. The Information Integration Technology approach allows us to integrate

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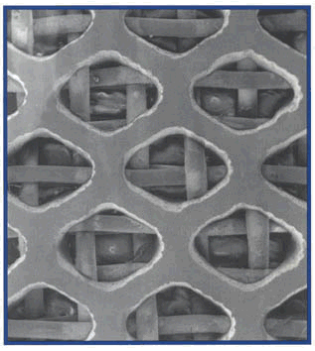
experimental data, computational models, past tests, subsystem tests, and the expert judgment of subject-matter experts to provide a rigorous, quantitative assessment, with associated uncertainties, of the safety, reliability, and performance of the stockpile.

New Product Development and Manufacturing Improvements for Procter & Gamble

Procter & Gamble is a long-time industrial collaborator with the Statistical Sciences Group at Los Alamos National Laboratory. There have been several project focuses, including the improvement of the reliability of complex manufacturing processes; the combination of information from experimentation and computer modeling to optimize new product development; the improvement of Research & Development processes by using knowledge elicitation and modeling techniques to identify and quantify sources of uncertainty; and the development of "hybrid" experimental plans, where plans are chosen across possible computational and physical data.

Some of the jointly developed technologies in the projects with Procter & Gamble have been commercialized, and parties interested in those and more of the work products of this partnership may contact the Los Alamos National Laboratory Industrial Business Development Office at (505) 665-9719.



Munitions Stockpile Surveillance for the U.S. Army Aviation and Missile Command (AMCOM)/Research, Development and Engineering Center (RDEC)

Work with AMCOM/RDEC has been funded through the Joint DOD/DOE Munitions Memorandum of Understanding, and has focused on the development of methodology for assessing the reliability of aging stockpiles. Stockpile surveillance gathers many kinds of data, including full-system tests, component and subsystem information, and non-destructive evaluation. In addition, there are computer codes that can predict properties of materials aging. The Information Integration Technology approach focuses on combining this information to support decisions about stockpile life extension programs.

Risk Mitigation for the Missile Defense Agency (MDA) and the U.S. Army Space and Missile Defense Command (SMDC)

SMDC is charged by MDA to develop representative systems that emulate flight characteristics of foreign missile threats. These flights are expensive and politically visible, and risk mitigation is an important element of the program. These flight tests are also very difficult, because these are "one-of-a-kind" events with many complex factors. The Statistical Sciences Group is working with SMDC to apply the Information Integration Technology approach to help develop a predictive reliability and performance model for an upcoming flight. The goal is to allow SMDC staff to pinpoint risk areas and to make clearly informed decisions about resource allocation to mitigate risks.

Flight Envelope Assessment for the U.S. Air Force Seek Eagle Office and F-22 System Program Office

This project focuses on development of methodology to combine data from different sources to predict safety during stores separation for the F-22 aircraft. It involves combining information from wind tunnel, computational fluid dynamics, flight test, and expert judgment. The goal of the project is an analysis system that allows analysts to investigate the safety of stores separation at different aircraft configurations anywhere within the flight envelope. Once this system is in place, additional work will consider its use to do test plan development and optimization for flight and wind tunnel tests.

Improve Security at Los Alamos National Laboratory

The Security Division is charged with maintaining physical and information security at Los Alamos National Laboratory. The Statistical Sciences Group is working to help the Security Division characterize systems of security resources at specific facilities.

Like many complex systems, security resources are not fully testable, and information comes from a variety of sources, including computer simulations, operational tests, and training. These characterizations help the Security Division understand the complexities of how their systems may react to attack and help them characterize the reliability of security plans to oversight agencies.

The *Statistical Sciences Group* at Los Alamos National Laboratory was formed in 1967 to provide the Laboratory with a center of expertise in statistics. The group consists of 21 statistical scientists and 4 knowledge modelers, plus supporting personnel, visiting faculty, graduate students, and post-doctoral fellows. It offers challenging opportunities in statistical research and applications for individuals eager to participate in multidisciplinary scientific activities. The group currently has expertise in a range of methodologies, including Bayesian methods, biomathematics, computer model evaluation, environmental statistics, Monte Carlo and computer-intensive methods, reliability analysis, spatial modeling, statistical graphics and visualization, and stochastic processes.

Statisticians and knowledge modelers work in partnership with world-class scientists in a variety of application areas, including material science; computer science applied to modeling of weapon performance, traffic flow and congestion, disease outbreaks, and ecological phenomena; physics; engineering; geology; military strategy and analysis; industrial problems; and genetics, microbiology, and chemistry.

Research Areas

Knowledge Representation

Statisticians are often asked to provide predictive risk and reliability assessments for a wide range of research and development projects. When these projects are very innovative, however, the statistician may be faced with the dilemma of minimal data for the system under scrutiny. Complicating such situations is the increasing ubiquity of multidisciplinary and multinational research teams: statisticians often find themselves asked to contribute to complex, emergent projects that challenge their ability to build predictive models capable of integrating multiple types of data, information and knowledge from a wide range of sources.

The Statistical Sciences Group at Los Alamos National Laboratory has developed a multidisciplinary approach to knowledge elicitation, representation, and transformation. This approach meshes techniques from cultural anthropology, computer science, and statistics to address the complexities of multidisciplinary research. Specifically, elicitation techniques derived from cultural anthropology are used to elicit tacit problem-solving structures from the "natives"–generally, the scientists and engineers collaborating on difficult Research & Development problems. The elicited information, in turn, is used to develop ontologies that represent the problem space in the "native language" of the research team, but which are more mathematically tractable to the computer science and statistical communities. Iterative cycles of representational refinement and quantification lead to the emergence of predictive statistical models that make intuitive sense to all parties: the scientists, engineers, elicitation experts, knowledge modelers and statisticians. Important methodological areas include conceptual graphs, statistical graphical models, and the translation from qualitative to quantitative representations.

Statistical Methods

The statistical methodologies that the Statistical Sciences Group develops are driven by the projects and partners for Information Integration Technology. Methodological focuses include Bayesian inference, Bayesian hierarchical models, and computational methods for reliability and lifetime estimation; system reliability and lifetime analysis; computer model evaluation; failure time regression models; methods for accelerated life testing; models for degradation data; and demonstration testing.

Data from Expert Judgment

There is a body of work that looks at various aspects of expert judgment, from the construction of priors for statistical models, to the development of utility functions and decision analyses within economics, to the anthropological and psychological work on elicitation strategies. Ongoing work includes the development of a conceptual framework for utilizing "statistical" information elicited from experts. When presented with a dataset containing experimental data, statisticians have a "toolkit" of methods and a set of canonical examples to use when deciding how to analyze the data. This "toolkit" is still absent from the realm of expert judgment. The Statistical Sciences Group is actively exploring probabilistic as well as non-probabilistic (e.g., Dempster-Shafer and fuzzy set) representations of uncertainty through the development of a common foundation for the methods.

Data from Computer Models

Another source of data used in the Information Integration Technology approach is that derived from computer simulations. These computer models are often highly complex themselves, and there are many research challenges associated with the calibration and validation of these models under the conditions of limited real world data. Simulation data are often limited as well, because the models require many hours, days, or even months to run. Another challenge to the evaluation of these simulation data is the high dimensionality of the output. The Statistical Sciences Group has a very active research effort in the area of complex computer model evaluation, applying techniques from sensitivity analysis, Bayesian interpolation methods, and extensions of techniques from spatial statistics. These techniques are being applied to a range of models to understand performance of accelerators, nuclear weapons, and ground water remediation methods.

Hybrid Experimental Design

Traditional experimental design is concerned with allocating trials within a single experiment. Suppose, however, that data is available from many diverse kinds of experiments including different types of physical experiments (e.g., destructive or non-destructive) and runs of a computer code. Hybrid experimental design considers the allocation of test resources across different types of experiments by trading off the costs of performing any particular trial with the information gained. Applications include optimizing new manufacturing processes and designing test programs for complex systems.

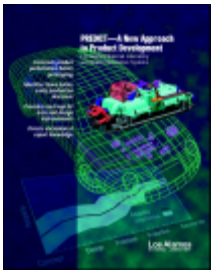
Knowledge Management

There are a variety of tools required to capture information, organize it, and make the results available for subsequent analysis to the distributed communities working on a problem. The research in knowledge management focuses on the development of these tools both for the statistical and knowledge modeling researchers and for the problem owners.

SCIENCE SERVING SOCIETY

An Early Application

In 1999, the collaboration between Delphi Automotive Systems and Los Alamos National Laboratory won an R&D 100 Award. The project, named PREDICT, applied Information Integration Technology to Delphi's problems of predicting the reliability of new products in development. PREDICT starts performance and reliability analysis of new products ahead of both prototyping and production, which can result in large savings by finding problems early in the product life-cycle and reducing or eliminating manufacturing problems and product recalls.



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What We Do In Information Integration Technology

The goal of Information Integration Technology (IIT) is to develop a framework of processes, methods, and tools useful for evolving R&D to support decision-making under uncertainty. In many disciplines, integration of the science with data, modeling, and analysis either occurs through some "test" event or in the mind of the decision-maker. We build on what is already being done and create an analysis framework to facilitate integration of scientific knowledge. The framework allows support of a wide range of objectives and has the following characteristics.

Flexibility: We make use of information from a variety of sources, including theoretical models, test data, computer simulations, expertise, and expert judgment (from scientists, field personnel, decision-makers, etc.). The nature of the information is also diverse, i.e., not only do we have information about how the system performs, we also have information about the system, its structure and behavior, decision constraints, options, and preferences, etc.

Mathematical Rigor: IIT merges techniques from statistics and probability, graph theory, knowledge management and representation, computer science and simulation, and decision theory. We use IIT to integrate diverse sources of information and associated uncertainties to develop full distributions for performance metrics that can aid decision-making under uncertainty.

We are applying IIT in collaboration with partners from the weapons community here at Los Alamos National Laboratory, from industry, and from the DOD.

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