Advanced Modeling, Visualization, and Data Mining Techniques for a New Risk Landscpape

Lee Smith, FCAS, MAAA, and
Lilli Segre-Tossani

Casualty Actuarial Society Call for Papers
2003 Risk and Capital Management Seminar • July 28-29, 2003

ERM & DFA Modeling:
Risk Correlation, Integration, Dependency and Concentration

Advanced Modeling, Visualization and Data Mining Techniques for a New Risk Landscape

Submitted by Lee Smith and Lilli Segre Tossani

Abstract

The risk landscape that confronts financial institutions in the 21st century presents an unprecedented departure from past experience. Traditional mathematical tools based in linear statistical mathematics are failing actuarial science by not being able to deliver credible analyses in an environment characterized by issues such as multiple correlations, extreme events and cascading risks.

Complexity science, an area of scientific investigation that has been largely limited to powerful laboratory environments until recent decades, offers new tools and methodologies with which to address this new environment. *InsuranceWorld©* is an adaptive agent-based simulator designed through application of complexity science to allow an individual company to see how markets will evolve under various catastrophe scenarios. This paper describes this tool and its scientific and mathematical foundations.

Navigating the Global Risk Landscape

Contemporary global financial institutions are facing a risk landscape of unprecedented peril. Events for which there is no credible historical data, correlations that were previously undetected, products of increasing complexity and a rapidly changing information universe: all these lead to the need for tools of unprecedented sophistication. Terrorist behavior, in particular, is non-linear by nature, and not amenable to traditional modeling techniques.

Traditionally, actuaries have been able to use linear[1] statistical models to analyze the problems in their domain. The classical case is in pricing life insurance, where large historical databases have been built. The Law of Large Numbers allows for convergence of results as observations increase, given assumptions about the nature of the universe from which the data comes.

---

[1] Throughout this paper, the authors use the word "linear" in its scientific sense; that is to say, as implying parallelism between the magnitude of a cause and the magnitude of its effect. One of the characteristics of complex systems is that they are non-linear. Non-linear systems exhibit unpredictable but non-random cause and effect relationships. Edward Lorenz' "butterfly effect" provided an illustration of this behavior by postulating that a butterfly flapping its wings in Brazil might cause a tornado in Kansas. In complex systems, even a very small change in initial conditions can rapidly lead to changes in the behavior of the system that appear counter-intuitive in both nature and magnitude.

Statistical modeling has been at the heart of risk management for the past century. Most actuarial methodologies rely on the availability of a reasonably credible amount of historical data. Future activity is then estimated by evaluating historical patterns and determining how they should be adjusted to give a reasonable assessment of future patterns.

Data requirements are even greater when risk classification calculations are required. It is one thing to develop needed premium levels for an entire line of business, but then the rates need to be determined for various categories of risk. There is a traditional trade-off between what is known as homogeneity and credibility, where the actuary must decide how finely to divide up the databases available.

Actuarial Modeling

Actuaries develop elaborate modeling formulae or programs that are applied to historical data and resolve to describe a probable future to which a current dollar price tag can be attached. One reason that there is an almost infinite variety of actuarial models is that each model necessarily incorporates an element of judgment or intuition or speculation in the definition and weighting of probable future events. As if that weren't complicated enough, data must be segregated by size of loss so that policy limit and reinsurance rate calculations can be made. This is becoming an ever more difficult part of the data collection and analysis process because the changing nature of risk magnifies the effect on losses at the high end of the scale.

Actuaries work at the intersection of nature and society, contingencies and financial impacts. They are to the financial world what physicists are to the physical. Tools being used in actuarial work hold much promise in rationalizing the way public policy issues are resolved. Actuaries take aspects of mathematics, law, economics, accounting, probability, demographics, regulation, modeling and finance, and analyze the financial impact of contingent events. There is a conjunction of understanding in actuarial science, economics, and finance that that parallels that of the emerging paradigms in other areas of thought

Physics and Modeling

Physicists can make predictions about the behavior of large numbers of atoms, electrons, photons, and other small objects, but not about individual events, which are probabilistic by nature. Similarly, an actuary can make predictions about large numbers of contingencies, deaths, accidents, or catastrophes, but not about individual events or incidents.

The mathematics behind actuarial science is the same mathematics physicists use in modeling the behavior of subatomic particles and classical matter and energy. Solution of differential equations is a major component of analyzing the phenomena with which scientists and actuaries deal. Curve fitting and error analysis are key aspects of the toolbox of both professions.

One interesting analogy is the Schrodinger wave equation, which, along with Heisenberg's matrix framework, forms the mathematical foundation for key aspects of quantum mechanics. By giving a probability structure to the location of ethereal subatomic entities that eventually emerge into the matter of our world, Schrodinger's equation allows scientists to make calculations about location, energy and momentum of events in superposition.

Actuarial events can also be said to be in superposition. Until an event occurs (e.g., a terrorist attack), the actuary is estimating which of a number of possibilities of frequencies and severities may arise from a cloud of uncertainty. By using the mathematical and technological developments created by the scientific community in the past few years, actuaries can move their models forward enormously in robustness and accuracy. With its probabilistic and demographic perspective, actuarial science can model the complex nature of the physical and social worlds in new ways. This will provide a system of metrics that can incorporate the deeper knowledge that has emerged into the calculus of decision making.

Why Traditional Actuarial Tools Fail

In the past hundred years, foretelling has moved from the realm of the intuitive to the realm of the scientific, focusing on the use of mathematics and the "law of large numbers" to provide a statistical confidence that actual results would be close to expected results. For a period of time, the technology of mathematics sufficed to provide a high level of confidence in actuarial calculations. Today, however, they have demonstrated their inadequacy to the task of pricing/valuing extreme events and highly-correlated risks.

Statistical modeling has been at the heart of risk management for the past century. Industry actuaries develop elaborate modeling formulae or programs that are applied to historical data and resolve to describe a probable future to which a current dollar price tag can be attached. One reason that there are an almost infinite variety of actuarial models is that each model necessarily incorporates an element of judgment or intuition or speculation in the definition and weighting of probable future events.

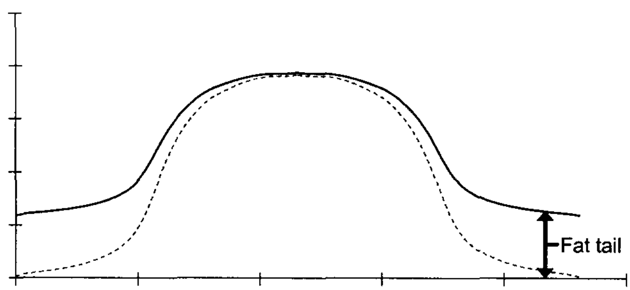
Current modeling techniques present several drawbacks. One drawback is that they do not do a good job of dealing with simultaneous changes to multiple variables in complex environments. In risk theory, for example, a portfolio distribution of risk is obtained by convoluting frequency and severity distributions. Historical data is used to determine the likelihood (frequency) of a loss arising from a given policy. (i.e., what is the likelihood this policy-holder will have one, two or x number of losses during the policy period.). Historical data is also used to determine the severity of losses (i.e., given that a loss occurs, what is the likelihood it will be $0, $1,000, $10,000, $50,000, etc.). Losses for a portfolio of risks are then estimated as the convolution of the frequency and severity distributions. So convolutions do take into account pair-wise correlations—but this is not enough. In fact, we know that in today's environment all risks are potentially cascading risks and that any individual risk will be affected by many more than one pair of correlations of varying degrees of strength.

Another drawback of current modeling techniques is that, when they are applied to large complex systems such as the national economy, there is no way to validate or test them without incurring additional, unacceptable risk. Is one, for instance, willing to force people out of their jobs in order to test the effect of unemployment on credit card delinquency?

In the past decade, the discomfort around traditional tools has escalated. We can list defining events such as Hurricane Andrew and the attack on the World Trade Center that have brought to light the potential impact of the inadequacy of traditional risk valuation and management techniques. Traditional risk-management tools were never intended to work with the expanded risks of today's global market environment.

Fat Tails

It has become clear that statistical modeling simply cannot measure the non-linear dynamics that now resonate throughout this new era of risk exposures. If there is one indicator that we can point to for validation of this failure of traditional statistical modeling, it is the emerging prevalence of "fat tails." A fat tail is a particular distortion of the classic bell curve in probability distributions. When there are fat tails, the curve looks like the solid line in the diagram below rather than the true bell curve represented by the dashed line. Complexity scientists call fat tails the signature of unrecognized correlation. Fat tails are an indicator that cascading risks are influencing the probability distribution.



Specifications for the Development of New Actuarial Tools

Thus, in the new century, actuaries are challenged daily to bring their expertise to seemingly intractable problems. A recent example is the *2002 Practice Note for Statements of Actuarial Opinion*, which directs that actuarial opinions now must consider the impact of terrorism exposure on a company's financial condition. Included in the list of things to be considered is consideration of major risk factors, coverages involved, reinsurance exposure and claim procedures.

The insurance process itself is a complex system composed of contingencies, customers, providers and financial markets all interacting to produce an insurance system that moves money based on contractual agreements. Unlike philosophers, physicists and economists, actuaries work beneath the surface of society, in arcane areas of commerce. Their tools, however, being multi-dimensional and fuzzy, may prove to be among the most useful in unraveling some of the deeper issues now being faced by society.

As the complexity and sophistication of its tools increases, actuarial science can help uncover the deep connections between nature, human behavior, institutions, finance and mathematics that drive social reality. It can help design structures by which to handle the contingencies of existence that intersect with economics and commerce.

"New" Tools Tied to Old Paradigms

Over the past decade, actuarial science has made some important attempts to incorporate new tools to meet the new challenges. The introduction of Enterprise Risk Management and Dynamic Financial Analysis into the actuarial toolbox is a good example. It may be helpful to briefly describe several of these tools in the context of the discussion that forms the topic of this paper. It is the position of the authors that these new tools, as useful as each one may be, all fall short of the need for a tool that will credibly model environments rife with multiple correlations and cascading risks.

Financial Risk Management (FRM) is both a generic term referring to the assessment and control of risk in financial markets and a very restricted professional designation. In recent years, casualty actuaries have become heavily involved in modeling phenomena on the asset side of an insurer's balance sheet as well. Financial risk management is becoming a major focus of the profession, as evidenced in contributions made in DFA and ERM modeling. The Capital Asset Pricing and Black Scholes models that are used in asset value determination use much of the same math as models used in various pure science investigations. The Brownian motion that characterizes stock price movement also arises in studies of atomic motion.

Enterprise Risk Management (ERM) uncovers the interconnectedness of operational risk, event risk, asset risk, liability risk, information risk and strategic risk. For insurance companies, it shows how the risks to the insurer itself are often correlated with the risks assumed under its coverage offerings. The major failing of ERM is that it assumes that each risk can be assessed individually and summed to all the others to reveal the enterprise total. ERM does not systematically incorporate a methodology to accurately value the effects of multiple correlations, non-linear correlations, cascading risks or positive feedback loops.

Dynamic Financial Analysis (DFA) is a tool that helps assess the uncertainty of financial results. It is a systematic approach to financial modeling that projects financial results under a variety of possible scenarios. By looking at key financial statement items as dynamic and probabilistic, it affords an opportunity to assess future financial results under a variety of scenarios. The most serious drawback to DFA models is that they are simply a compilation of traditional mathematically-calculated statistical analyses of aggregate data, iterated multiple times. Thus, not only are they linear, but they are also ponderous and require an inordinate amount of time to complete a single scenario.

The Need for a Different Approach

The inter-relationships between and among risk events and market participants have produced non-linear, cascading effects that do not follow traditional patterns or limits—and this has opened a new dimension for enterprise risk. The insurance process, with its multiple levels of interaction, demonstrates all the characteristics of a complex system. Traditional modeling techniques are inherently poor predictors of the behavior of complex systems, and so no refinement or expansion of traditional techniques will be able to meet the needs of a complex system.

Recognizing that the insurance market is a complex system, actuarial science must now seek out models specifically designed to give information about the behavior of a complex system. Complexity science uses the emerging power of computer technology and mathematics to allow scientists to take data from society and nature and let the data create its own categories. This allows scientists to approach reality before constraining it to the categories we have created for it.

Modeling Complex Systems

There is an elemental incompatibility between the underlying assumptions of traditional modeling techniques and the nature of complex systems. Luckily, there are new data extraction, analytical modeling, data visualization, and algorithmic and statistical methodologies evolving just as the need is becoming so great. Many of these are coming from the scientific communities in Santa Fe and Los Alamos, New Mexico, where scientists have been working for years to take the advanced models developed for applications of deep physics and apply them to the practical problems faced by organizations like insurance companies. These new tools are designed specifically to analyze non-linear complex systems. Their underlying assumptions include the certainty of multiple correlations and cascading events, features that are the hallmark of complex systems. They are, in fact, the tools of complexity science applied to actuarial science.

Applied Complexity Science

Complexity science, the study of complex systems, has been developing as a discipline for several decades. The mathematical origins of its primary analytical tool, simulation technology, go back at least half a century, to the work of John Louis von Neumann and Stanislaw Ulam in the 1940s and 1950s. Von Neumann was a brilliant mathematician who made seminal contributions to the field of computing, including applications of mathematics to computing, and the application of computing to such disciplines as mathematical physics and economics. Ulam is known as the mathematician who solved the problem of how to initiate fusion in the hydrogen bomb and devised the "Monte-Carlo method" widely used in solving mathematical problems using statistical sampling.

Complex Systems

The global insurance market is what scientists call a "complex system." Complex systems have been extensively studied and exhaustively defined over the past several decades. Complex systems-things like atoms, molecules, economies and insurance markets-consist of a large number of individual agents that behave in accordance with certain basic motivations, rendered as "rules." Agents change their behavior on the basis of information they receive about what the other agents in the system are doing in order to continue to adhere to their motivating rules and adapt to the changing environment.

Artificial Intelligence

The theoretical work of the 1950s mathematicians was picked up by others and spawned a broad spectrum of new analytical technology. A technology that showed brief promise early on was labeled "artificial intelligence." Researchers thought they could create artificial intelligence by capturing all of the rules for doing something. Although the promise of artificial intelligence as originally envisioned was never realized, the research led to two important and robust modern technologies: expert systems and machine learning.

Expert Systems

Expert systems are the rules-driven technological descendants of artificial intelligence. In the 1960s, linguistics contributed the concept of fuzzy logic, a superset of Boolean logic designed to handle values that are neither completely true nor completely false. This led to the development of fuzzy expert systems, which came into widespread use in the early 1990s primarily as control and data analysis systems using a collection of fuzzy membership functions and rules. Today, these survive as knowledge-based expert systems, application programs that make decisions or solve problems in a particular field by using stored knowledge and analytical rules defined by experts in the field. Although such systems can become extremely complex and encyclopedic in the scope of the information to which they provide access, they do not help us to analyze complex systems because they do not address the inter-relationships between the various pieces of information.

Machine Learning

Machine learning—the ability of a computer system to autonomously acquire and integrate knowledge—is fundamental to the study and analysis of complex systems. Machine learning is the capacity to learn from experience, analytical observation and other means, and therefore to continuously self-improve. It makes possible adaptive agent-based simulation technology, which is the best tool available today for the study of complex systems. Simulation technology is not new: for decades, scientists have used it to study many aspects of the natural world that seemed closed to traditional scientific methods.

Particle Mathematics

Insights coming from discoveries in modern physics are breathtaking, and they are beginning to influence actuarial science. The mathematics physicists have used to penetrate the dual (wave-particle) nature of subatomic physical reality is now proving to be applicable to practical problems of modern finance. Mathematical tools used by physicists to probe the equivalence of matter and energy, the merging of space and time, the interconnectedness of disparate parts of the cosmos, are the same ones used by actuaries to trace the connections between contingencies in the world and financial consequences in society.

In particular, scientists who have become interested in complex adaptive systems have begun to uncover patterns from nature which are duplicated in the world of finance. From data mining and visualization through neural networks and genetic algorithms, patterns of self-organization, emergence, fractal structures and dynamic landscapes have proven to be vital in interpreting patterns that influence the outcome of risk management activities.

Chaos Theory

Chaos theory had discovered that simple natural phenomena like clouds, coastlines and flowers did not conform to the mathematical structures scientists had created by which to analyze them.

By allowing natural phenomena to define themselves using advanced computer technology, scientists were able to create new models of nature which conformed more closely to actual nature than the nature we imposed on nature.

From Laboratory Development to Desktop Application

Until recently, simulation technology was largely confined to the supercomputing facilities of facilities like the Los Alamos National Laboratory because the huge amounts of data required to build a useful simulation could only be processed on large supercomputing platforms. Today, the processing power to create a realistic simulation of a restricted environment can be packaged in a personal computer or even a laptop. This revolution in the availability of computing power has spurred the growth of a burgeoning industry in applied complexity science.

Complexity scientists in Los Alamos and Santa Fe have harnessed the power of computer and analytical methodologies used by leading physicists to apply to practical problems of business. One area of recent business stress which is especially amenable to these technologies is risk analysis. The dynamic, nonlinear, agent based methodologies used by these scientists in finding patterns in complex adaptive systems are ideally suited to a world of extreme events and high correlation.

Complexity science and its sister area of chaos theory have brought the power of the computer and advanced mathematics to the world of risk. Because they allow data to form its own categories (using mechanisms like neural networks) and because they allow analytics to form around the emerging data structures, they avoid the rigidity of traditional linear models. In the case of extreme events and unusual correlations, this is a way to better address the real world of risk rather than the one which we assume exists.

Analytical Tools for Complex Systems

Complex systems are best studied through the technology of adaptive agent-based simulation, a technology expressly designed to analyze and model them. Adaptive agent-based simulation technology depends on a new breed of risk assessment and management tools developed from the practical application of complex systems simulation technology. Originally designed to detect patterns that exist within complex adaptive systems like the human body or the atom, these deep methodologies were found to apply to the very practical problems with which businesses and other institutions were struggling.

Adaptive Agent-Based Simulation

Adaptive agent-based simulation builds a modeling system that permits the modeler to keep track of and modify the behavior of each individual in a synthetic population. It uses all of the modern mathematical techniques described above, but depends especially on machine learning to develop reliable simulations. Simulators permit modeling in real time and demonstrate interactions and correlations between multiple events in real time.

Inside the Black Box

One of the barriers to widespread promulgation of adaptive agent-based simulation technology is the "black box" mystique that sometimes surrounds it. While it is true that the science and mathematics behind it is very complex, some of the families of algorithms and analytical techniques that were developed to implement machine learning are familiar to many, if not all, actuaries, though they may be applied in very different ways. In this section of the paper, we examine some of the nuts and bolts that go into building the black box.

Data Mining

The proliferation of data has led to the rapid emergence of new technologies and disciplines focused on how to store, retrieve and use it. While data has been accumulating in mainframe systems for 50 years, it was barely a decade ago that the first client-server terabyte data storage banks were deployed. Moving these data storage banks, now commonly called data warehouses, to the client-server environment greatly increased flexibility in querying the data. Data warehouses were the strategic prerequisites to data marts, tactical data repositories designed for ease of access and usability for a particular purpose and to meet an immediate need.

The discipline of knowledge management emerged as businesses struggled to organize these huge volumes of data into information and hence, it was hoped, into knowledge. This led to the technology of data mining, the process of extracting valid, useful, previously unknown and ultimately comprehensible information from data warehouses. Data mining includes the classification, clustering and segmenting of the data, as well as the detection of rules of association, sequential patterns and deviations.

Data Fusion

Until recently, a prerequisite to successful data mining was data normalization: that is, the data to be mined would have to be housed in a single database, or, if distributed, in databases of parallel structure. One of the advances that has made adaptive agent-based simulations easily accessible for business applications is the evolution of software agents that are able to mine disparate databases for patterns and correlate those patterns outside the structure of an individual database.

This technique, called data fusion, means that companies can correlate information from legacy mainframe databases, client-server CRM systems and purchased census or marketing data without porting any of it to a different system or structure. The mathematical techniques used by individual agents to mine the data are not unfamiliar—they include, for example, cluster correlations, logistic regression and partial least squares. The ability to correlate non-normalized data, however, is revolutionary.

Building Non-linear Models

Though data mining is an advanced technology, by and large it remains mired in the linear mind-set. Non-linear correlations defy traditional linear actuarial mathematics. Since complex systems are, as we have said, non-linear in nature, data mining can only provide limited insight into such systems. More often than not, in non-linear systems causes lead to effects that appear entirely counterintuitive. For example, a group of researchers at Los Alamos built a transportation system simulation that would display both the traffic congestion and the air pollution effects of creating incentives for people to use public transportation. The simulation revealed that air pollution will increase when car traffic decreases in certain situations. The finding was validated—it derived from the traffic pattern shifting to many shorter trips, so that the pollution-controlling catalytic converters in most cars never warmed up enough to affect emissions—but it was certainly a surprise to traffic planners!

The adaptive agent-based simulation technology was developed specifically to analyze non-linear systems. It incorporates a number of new mathematical tools expressly created for dealing with complex systems. It also incorporates what researchers have learned about human perception in the past half-century to order the information in ways that are more accessible to human perception. Both the analysis and the visualization tools are necessary to reduce these unimaginable volumes of data to information that is meaningful in human terms and, ultimately, to knowledge. We will briefly touch on some of the more well-known or significant of these tools.

Cellular Automata

Cellular automata are commonly mentioned in connection with complexity science and have come to represent complexity in the popular culture. The most basic cellular automata play a simple "game" in which you have a row of agents, and each agent can be black or white. Agents determine whether they will be black or white by looking at what their neighbors are doing. So if an agent has a black neighbor both to the right to the left, there might be a rule that says: "If my neighbors are both black, I'm going to be white." Of course, neighboring agents also have rules and are following them, so that the environment continues to evolve.

Cellular automata are fascinating because very complicated behaviors, a kaleidoscope of patterns, can form from very few, very simple rules. Mathematically, cellular automata illustrate the ability of local parallel update rules to generate spatial structure from disordered initial states. The mathematics of cellular automata can also be traced back to the work of von Neumann and Ulam in the 1940s. Today, the game LIFE, invented by Cambridge mathematician John Conway, is the most popular illustration of cellular automata. It presents a simple two-dimensional analog of basic processes in living systems. The game traces changes through time in the patterns formed by sets of adaptive cells arranged in a two-dimensional grid. Any cell in the grid may be either "alive" or "dead." The state of each cell changes from one generation to the next depending on the state of its immediate neighbors, according to a simple set of four rules.

The behavior of LIFE illustrates how cellular automata reproduce the tendency toward order of living systems. Starting from an arbitrary initial configuration, order (pattern) usually emerges fairly quickly. Ultimately, most configurations either disappear entirely or break up into isolated static or cyclical patterns. This and other games that illustrate different mathematical concepts in cellular automata can be found at: http://psoup.math.wisc.edu/sink.html. These concepts are mathematically fascinating, but so far have given rise to very few practical applications, and these mostly in the area of modeling natural systems. Complexity scientists who deal with business simulations do not generally consider cellular automata particularly useful.

Neural Networks and Genetic Algorithms

Neural networks and genetic algorithms are critical building blocks for non-linear models. Loosely based on the human brain's physical pattern of learning, neural networks receive data as input and produce output in the form of behavior. Genetic algorithms are a class of heuristic optimization methods and computational models of adaptation and evolution based on Darwinian natural selection. Just as neural networks mimic the activity of the brain, genetic algorithms are based on DNA and genetics. The agents of a simulation behave in reaction to the inputs. Driven by their genetic algorithms, they survive, die or dominate. Those who die are eliminated from the simulation, those who survive are retained and mated, and those who dominate – the superheroes – are emulated.

Data Visualization

Data visualization is critical to building useful simulations. It allows scientists and non-scientists alike to explore trends within a body of data by visually orienting themselves to the patterns in the data. Because it can help translate data patterns into insights, data visualization is a highly effective decision-making tool. It can represent scenario results in graphic format or in the form of pro-forma financial statements or in any other format that makes sense in the context of the industry being modeled. A common use is to aggregate inconceivable amounts of data into patterns that make sense to the eye.

Simulation for Insurance Companies

Complexity science uses the emerging power of computer technology and mathematics to allow scientists to take data from society and nature and let the data create its own categories. This allows scientists to approach reality before constraining it to the categories we have created for it. Data mining techniques of high sensitivity, algorithms incorporating elements of neural networks, genetic algorithms, cellular automata, partial least squares, logistic regression and advanced data visualization processes are all ready for deployment in the insurance industry. They have been tested and found to be robust and efficient in the most trying of circumstances.

The adaptive agent-based simulation tools developed for actuaries by complexity scientists complement traditional DFA and ERM modeling approaches. They help provide a global, integrated look at a company's risk profile. They can be used strategically to test different growth and hedge strategies over a long time horizon given various scenarios about extreme events and cross correlations.

They can be used to support pricing and capital allocation decisions as well as reinsurance and diversification programs. Risk-Return analysis, line of business allocations, demographic structure and product design can all benefit from such powerful perspective. The power of decades of effort in the most powerful research institutions in the world is brought to the desktop of the contemporary insurance executive.

Insurance Applications of Simulation Technology

Every type of insurance coverage has unique issues that have arisen in recent years. Adaptive agent-based simulations have been developed to meet insurers' need for models that incorporate the dynamics of insurance instead of trying to fit data into historic, static techniques. Operating without the limitations of linear thinking, adaptive agent-based simulation can model correlative and cascading effects on unprecedented scales. Rather than presume outcomes or statistical limits, adaptive agent-based simulations enable the key influencing factors (agents) to shape the outcome. The subsequent model is a more responsive, more accurate reflection of today's complex risk dynamics.

Simulation for Property and Casualty Insurers

A simulation of the impact of catastrophic events on the insurance industry has been developed using the most advanced tools available to complexity scientists. Assuratech's *InsuranceWorld©* simulates how various insurers, reinsurers and capital markets in general will fare under different catastrophic scenarios. It can be used by an individual company to strategize how to position itself relative to competition, or by regulators or others interested in some of the larger issues involved in extreme event coverage.

The *InsuranceWorld©* simulation is populated by five primary insurers and five reinsurers who operate in four or more markets within a described economy and are impacted by three or more extreme events (natural or man-made catastrophes). Using selected parameters and strategies for the companies and certain scenarios for the economy and nature, it produces financial statements for companies and global outputs. For example, a company might use the model to develop hedging strategies by comparing projected financials with and without the strategies.

A specific terrorist component can be added to the simulation to show various worldwide assets vulnerable to attack, various scenarios for insurance coverage, various events which could affect those assets and coverages and various ways of adjusting. In the area of policy and planning, such a module could help model how government and industry can share layers and slices of terrorism risk. It could also provide advanced maximum insured loss scenarios.

By implementing Assuratech's agent-based, nonlinear modeling, insurers can test for the impact of extreme events and high correlations in ways never before possible. As a result, senior executives can protect their companies and earnings flow from disruptions that have never before been hedgeable—a significant market advantage for the first user of this technology.

Simulation for Workers' Compensation Insurers

Following the pattern of the *InsuranceWorld©* simulator, similar simulators are being developed to model other insurance markets. A market in dire need of this technology is the workers' compensation market. A convergence of events, some natural, some human-generated, has brought the workers' compensation system to a crisis. Workers' compensation rates determine a major cost of doing business in a state, and as a result are always under scrutiny by State Insurance Departments and other government agencies. Self-insurance is an option often chosen by businesses, which further complicates the environment in which workers' compensation operates.

Fraud has always been a problem, as worker injuries are not always easy to determine objectively. Because of the time lag between insurance coverage and the payout of associated claims, there is uncertainty about the true liabilities at any point in time. As if these traditional issues related to workers compensation were not enough, we now impose the complexity of terrorism, globalism, and the information revolution. Workers' compensation professionals are looking for new perspectives and tools by which to help manage the dynamic risk landscape that they now face.

A market simulator for the workers' compensation industry would provide senior management strategic decision-support information to enable them to anticipate the repositioning of the company forward of major swings in the market. The tool can examine external market influences in a comprehensive manner and reliably estimate their effect on an insurer's market share. It demonstrates in the familiar terms of a financial statement the cascading effect of dramatic swings in market share on such factors as pricing, investment performance, solvency and overall company fiscal health. It can also demonstrate the effects of extreme events such as natural disasters and terrorism. This tool can easily accommodate the additional uncertainty that stems from longer-tailed liabilities and the impact of immature loss ratios on company financials.

The Emerging Paradigm

In recent years, actuarial periodicals have seen an explosion of articles incorporating elements of the new math. From multifractal modeling and non-linear perspective through neural networks and dynamic pricing, actuaries are beginning to utilize new areas of modern mathematics.

Given the underlying nature of actuarial phenomena, this is unavoidable. Differential equations that portray physical phenomena of the type modeled in actuarial applications are as complex as any faced by modern physicists. The uncertainty behind actuarial calculations trumps even that articulated by Heisenberg. The probabilities behind the financial impacts of actuarial events make those of particles hidden in Schrodinger's wave equation seem manageable.

By bringing the force of the advanced technology and mathematics of recent years into the actuarial paradigm, actuaries will see significant improvements in modeling capabilities. Problems felt to be intractable will open up to the new perspective. The challenges of the new global economy will again be matched against analytical tools capable of meeting them.

Conclusion

Adaptive agent-based simulation technology rests on the simple premise that the aggregate statistical behavior of market or population segments (the top-down view) is the result of the behavior of the individual agents that comprise that segment ***and their interactions.*** The tools developed by complexity scientists to model agent behavior in the insurance market represent a new paradigm in risk modeling. They address emerging issues and encompass extreme events, multiple correlations and other revolutionary changes in market environment that have recently plagued the financial community.

The mathematics behind the new tools is the same as that at the foundation of actuarial mathematics. Most applied mathematics involves finding functions which fit phenomena of interest, and making adjustments thereto as needed. Actuarial phenomena, like physical phenomena, are not well-behaved, and techniques which can allow data to form its own categories, and which can account for the underlying complexity of interrelationships, will ultimately carry the day.

The Authors

Lee Smith, BS, MA, FCAS, MAAA

Mr. Smith has over thirty years' experience in consulting, industry, and academia. The majority of his experience involves areas of financial services and insurance. He has served as Director of Planning at Aetna Insurance Company, Chief Actuary and Policy Director for the Michigan Insurance Bureau, Adjunct Professor of Actuarial Science at the University of Michigan, President of Midwest Casualty Actuaries, and National Director of Ernst & Young's Actuarial and Risk Management Practice. He can be reached at LeeSmithM@aol.com.

Lilli Segre Tossani, BA, MA

Lilli Segre-Tossani is a technical writer who has worked for fifteen years in the fields of information technology, financial and legal services, and organizational consulting. She can be reached at tossani@attglobal.net.