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SUMMER STIPENDS
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Application Cover Sheet

PATSY RECORD
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Project title: Why are Management Scientists Unable to Forecast?

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Category *Please check all descriptions that apply, so as to ensure that your application is given full consideration in all competitions for which it may be eligible.*

1. Are you a member of the:
   - X School of Business
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Abstract Please limit your abstract to the space provided below. Do not photoreduce your material.

The ability of scientists to forecast accurately is directly affected by their choice of paradigm: probabilistic or deterministic. Accurate forecasting can only be done with deterministic models. Recent developments in physical chaotic dynamics have shown that some systems which appear random are in fact deterministic. The most famous of these systems is that of the Lorenz equations. If it can be demonstrated that the techniques most frequently used by management scientists to classify data as random inaccurately classify the Lorenz equations as random, then decision scientists may be encouraged to move past probabilistic modeling into chaotic determinism.

WHY ARE MANAGEMENT SCIENTISTS UNABLE TO FORECAST?

1. INTRODUCTION: TWO PARADIGMS

Exactly what will our freshman enrollment be next fall?

In spite of the remarkable developments in management science and related business subjects during the past 40 years, we are still unable to accurately predict numerous variables. Consider a service organization such as a bank, hospital or University which would like to know the future level of commercial loans, hospital patients or freshman students, or consider an industrial firm which wishes to know its demand next month in order to make plans for its work schedules, acquisition of supplies, production and inventory. Because individual agents value their freedom to make choices, it is not clear *a priori* what choices they will make. So management scientists, in order to describe such behavior use probabilistic models. Such models describe the values of a future variable, usually, as the sum of the currently known variable plus a random shock. In the simplest possible model, let

$$q(t+1) = q(t) + \varepsilon(t+1) \qquad (1)$$

express next period's demand, $q(t+1)$, as the sum of current demand , $q(t)$, plus a random influence, $\varepsilon(t+1)$. Most probabilistic models are much more sophisticated than this, but all have one thing in common, that is, the presence of the random influence $\varepsilon(t+1)$.

Models of this form and its various extensions seem to explain what management scientists observe, namely, the variability of the time series of production outputs, inventories, profits, prices, demands, wages, etc. But the best prediction we can make, using this probabilistic model, about the next period's value is that it is like today's value, plus or minus some random shock. This means that we have the ability to forecast well only when the future is very much like today.

Developments in operations research and management science since World War II have reflected the evolution of scientific methodology in the physical sciences. Measurement errors, unobservable variables, incomplete models and the introduction of expectations have swung the methodological pendulum towards probabilistic reasoning. Such reasoning has given rise to statistical techniques and the establishment of the field of decision sciences.

Although it is currently accepted by decision scientists that there is a clear dichotomy between deterministic and probabilistic modeling, relatively recent developments in physical chaotic dynamics have shown that certain processes, while they appear to be random, are in fact deterministic. Malliaris (1993) hypothesized that the S&P 500 Index, previously thought to be random, follows chaotic dynamics and used neural networks to confirm this hypothesis. Uses of chaotic dynamics in management science can be found in Sterman (1989a, 1989b), and Rasmussen and Mosekilde (1988). Malliaris and Salchenberger (1993a, 1993b) have shown that a deterministic model generated by neural networks outperforms the standard probabilistic option pricing models of finance.

The Lorenz (1963) equations are the most famous example of a system that generates chaotic dynamics. When both the step size and sampling jump in these equations are small, say .01 and 1 respectively, the data generated clearly demonstrates the deterministic nature of the system because such graphs are everywhere continuously differentiable. However, keeping a small step size but increasing the sampling jump transforms the data into a nondifferentiable function whose graph looks very much like a random walk. But to classify it as random would obviously be wrong since an exact relationship exists and has been generated directly by the Lorenz equations. The appendix provides a short technical discussion of deterministic, random and chaotic models for the interested reader.

2. RESEARCH PLANS AND CONTRIBUTIONS

The question I wish to address with a summer grant is: Would deterministic systems generated by the Lorenz equations be classified by decision scientists as random? If the most common tests of randomness, correlation dimension and the BDS technique, misclassify the data generated by the Lorenz equations as random, and I believe they will under certain circumstances, then management scientists may be believing the probabilistic model to be an acceptable choice when a deterministic model should be specified.

The very essence of this contribution is to demonstrate that it is possible for a decision scientist studying certain data to conclude that the model generating such data is random when actually it is not. A decision that randomness exists then supports a probabilistic model of the data and perpetuates the belief that non-deterministic models are plausible and accurate. The choice of a probabilistic model over a deterministic one means we are sacrificing our ability to forecast accurately.

To demonstrate this, I plan to generate several sets of data using the Lorenz equations. Because these equations are of the deterministic difference type, I need to use appropriate software that provides a computational algorithm. I then plan to use two statistical techniques, the correlation dimension technique and the BDS test, to check for the presence of randomness in the data, making use of software offered by Kocak (1989).

The bibliographic search for this paper has been completed and the necessary software has been ordered. Generation and testing of appropriate data sets using the Lorenz equations should take four or five weeks. To compare and analyze the results will take another four weeks. The results will then be prepared for publication and an article is expected by December, 1994.

The outcome of this research could contribute to the existing literature of management science in several ways. First, if it can be demonstrated that the two most frequently used techniques of correlation dimension and the BDS test fail to detect the chaotic structure and thus the deterministic relationships of the Lorenz equations, this result would encourage decision scientists who support the plausibility of probabilistic modeling to search for more powerful tests. Other decision scientists would be encouraged to change the focus of their modeling to those models which have the ability to forecast, i.e., deterministic models. As decision scientists have followed the lead of the physical sciences in the past, so do they now need the motivation to follow the current lead into chaotic determinism. The results from this study should provide encouragement in that direction.

3. APPENDIX --- Technical discussion of deterministic, random and chaotic models.

DETERMINISTIC VS RANDOM MODELS

Deterministic models consist of exact relationships. Abstracting from specific modeling considerations, the notion of determinism is clearly demonstrated in the relationship of a function

$$y = f(x) \qquad (2)$$

where f denotes the set of ordered pairs (x,y). In other words, each x is unambiguously associated with a specific y, with such a y being equal to f(x). From the simple calculus where $f(x):\mathbf{R} \rightarrow \mathbf{R}$, **R** denoting the real numbers, to multivariate calculus, differential equations, real analysis and functional analysis, the subject matter remains exact relationships between or among certain variables. These exact relationships can become quite complicated, particularly when such a relationship is between derivatives (i.e. differential equations) or even among functions themselves (i.e. functional analysis).

Mathematics demonstrates that, independent of its intrinsic interest, randomness is not an alternative of equal standing but a temporary substitute to determinism. From the elementary probability, where one flips a coin, to measure-theoretic probability, the notion of a function prevails. What changes is the domain of the function. In probability, the domain is a random set and a function that takes its values from a random set is called a random variable.

In searching for causal relationships, a scientist may choose an exact or a random model. Priority in the applied sciences and in pure mathematics has been given to deterministic models while randomness is viewed as a temporary methodological substitute. While deterministic analysis is founded on functions relating measurable spaces, probability specializes this relationship between a probability space and a measurable space. Thus, randomness can be mathematically axiomatized as a special case of determinism with the obvious implication that determinism remains the central goal of scientific endeavor.

THE LORENZ EQUATIONS AND CHAOTIC DYNAMICS

Chaotic dynamics was developed precisely for the purpose of demonstrating that there exist exact functions which generate very complicated trajectories that appear like random.

From the seminal work of Eckman and Ruelle (1985) to the numerous texts about dynamics such as Devaney(1986) or Guckenheimer and Holmes (1983), scientists have exposited an exciting new branch of mathematics which reinforces determinism.

Devaney (1986) presents the essential elements of chaotic dynamics, while Guckenheimer and Holmes (1983) treat the subject at a more advanced level. We say that a function **f: R → R** is chaotic if is satisfies three conditions:

1. f is topologically transitive.
2. f has sensitive dependence on initial conditions.
3. f has periodic points that are dense in the real numbers.

The Lorenz equations which generate a chaotic dynamic system are:

$$x_t = s(-x_{t-1} + y_{t-1})$$

$$y_t = rx_{t-1} - y_{t-1} - x_{t-1}z_{t-1}$$

$$z_t = -bz_{t-1} + x_{t-1}y_{t-1}$$

Depending on the step size and sampling jump chosen, the graphs of these equations can appear to be either continuously differentiable, or random. An exhaustive analysis of the numerous properties of these equations may be found in Sparrow (1982).

Bibliography:

Devaney, R. An Introduction to Chaotic Dynamical Systems, Benjamin/Cummings Publishing, Menlo Park. Calif., 1986.

Eckman, J. and D. Ruelle, "Ergodic Theory of Chaos and Strange Attractors", *Review of Modern Physics*, Vol. 57, 1985, pp. 617-656.

Guckenheimer, J. and P. Holmes, Nonlinear Oscillations, Dynamical systems and Bifurcations of Vector Fields, Springer-Verlag, New York, 1983.

Kocak, H., Differential and Difference Equations through Computer Experiments with PHASER: An Animator/Simulator for Dynamical Systems for IBM Personal Computers, Springer-Verlag, New York, 1989.

Malliaris, M. "Modeling the Behavior of the S&P 500 Index: A Neural Network Approach", currently being reviewed by *Neurocomputing.*

Malliaris, M. and L. Salchenberger, "A Neural Network Model for Estimating Option Prices", *Applied Intelligence*, 3, 1993a.

Malliaris, M. and L. Salchenberger, "Beating the Best: A Neural Network Challenges the Black-Scholes Formula", *Proceedings of the Ninth IEEE Conference on Artificial Intelligence for Applications,* March, 1993b, pp. 445-449.

Rasmussen, D.R. and E. Mosekilde, "Bifurcations and Chaos in a Generic Management Model", *European Journal of Operational Research,* 35, 1988, pp. 80-88.

Sparrow, C., The Lorenz Equations: Bifurcations, Chaos and Strange Attractors, Springer-Verlag, New York, 1982.

Sterman, J.D., "Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment", *Management Science*, vol. 35, No. 3, 1989a, pp. 321-339.

Sterman, J.D., "Deterministic Chaos in an Experimental Economic System", *Journal of Economic Behavior and Organization,* 12, 1989b, pp. 1-28.