DESERT ISLAND DYNAMICS: AN ANNOTATED SURVEY OF THE ESSENTIAL SYSTEM DYNAMICS LITERATURE

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ABSTRACT

What should every professional system dynamicist know? What are the core works defining our field? This survey of the English-language system dynamics literature identifies and summarizes one view of the essential papers, books, games and software programs that have influenced the development of the field. Such a list serves as a means of reflecting on the foundations of current research and practice, thus providing a catalyst for a continuing discussion among system dynamicists on the major themes of the field and the contributions that define them. In presenting this bibliography, the authors encourage other researchers, practitioners and students to add their views to the present effort.

INTRODUCTION

What papers, books, games and software programs constitute the major works of system dynamics? Which contributions best define our paradigm, and which ones have pushed the boundaries of our field in new directions? In short, what system dynamics works would you take with you to a desert island?

We address these questions through an annotated bibliography of the important works in the field. Acknowledging that such a survey is bound to be subjective and limited (perhaps revealing our bias towards managerial applications and publications available in the US), we propose that it be viewed as a starting point for an on-going discussion among system dynamicists. We hope that the present list will catalyze an interchange of views on three questions. What contributions best define the field? What makes a given work significant to the field? What are the major themes and application areas in the field to date? Discussion of these questions can generate an improved version of the present bibliography. Proposals for including, excluding, or better classifying the works described here are welcomed from all.

In addition to serving as a tool for exploring the issues identified above, the bibliography could help to introduce the full range of system dynamics research to those outside the field, and be used as a pedagogical framework for advanced students. Recent efforts to develop a comprehensive bibliography of the field (Cooper and Steinhurst 1992) and to explore the evolution of feedback thought in social science (Richardson 1991) provide a context for the present effort and suggest ways in which users could further explore the themes that emerge from it.

HOW THE BIBLIOGRAPHY WAS SELECTED

While one version of this list would simply be the collected works of Jay Forrester (see the next section), in the present effort we attempt to complement the fundamentals that he and his colleagues first articulated in the 1960s with a sampling of the wide range of applications of system dynamics since then. Examples of these applications include the use of system dynamics for dispute resolution, comparative studies with fields as diverse as control theory and institutional economics, dynamic analysis of the effects of economic development, applications to ecology, psychology and physiology, and energy policy studies. Since a small number of works has been chosen to represent these areas, other equally important works have, by necessity, been omitted from our list. In addition, we focus on publications that have emerged from the system dynamics tradition, and thus do not include the vast literature on feedback, dynamics, and simulation in other disciplines; nor do we include the significant collection of criticisms of system dynamics that have appeared in other literatures. Obviously, these are important for one's training as well. Later bibliographies should address these areas.

INDUSTRIAL AND ECONOMIC DYNAMICS: THE FOUNDATIONS

Forrester, J. W. 1961. *Industrial Dynamics.* Cambridge MA: Productivity Press.

Presents dynamic analysis of a business problem through a model of a production-distribution system that shows oscillatory behavior. Policies to improve system performance are discussed, and numerous policy experiments are demonstrated. Includes full equation listing.

Forrester, J. W. 1968. *Principles of Systems.* Cambridge MA: Productivity Press.

System structure and behavior are differentiated, with examples showing how structure determines behavior. Rates and levels are described. Inventory model shows effects of delivery delay and resulting production cycles.

Forrester, J. W. 1975. *Collected Papers of Jay W. Forrester.* Cambridge MA: Productivity Press.

Includes many seminal papers, such as Industrial Dynamics: A Major Breakthrough for Decision Makers; Common Foundations Underlying Engineering and Management; A New Corporate Design; Market Growth as Influenced by Capital Investment; and Counterintuitive Behavior of Social Systems.

Meadows, D. L. 1970. *Dynamics of Commodity Production Cycles.* Cambridge MA: Productivity Press.

Develops a simple generic model of commodity supply and demand with explicit production capacity and delays, prices and markets. Applies the model to hogs, chicken and cattle.

Mass, N. J. 1975. *Economic Cycles: An Analysis of Underlying Causes.* Cambridge MA: Productivity Press.

Shows how production scheduling and work force management policies generate the 3-5 year business cycle. Economic cycles, in turn, are caused by capital investment policies that fail to account for delays in acquiring long-lead time plant and equipment.

Forrester, J. W. 1989. *The Beginnings of System Dynamics* (Working Paper No. D-4165). System Dynamics Group, Sloan School of Management, MIT, Cambridge MA.

A personal history beginning on the high plains of western Nebraska. Describes the early projects that shaped the field.

URBAN AND PUBLIC POLICY DYNAMICS

Forrester, J. W. 1969. *Urban Dynamics.* Cambridge MA: Productivity Press.

Seminal model of urban growth and decay, controversial then and vindicated now. Chapter 6 describes general characteristics of complex systems such as compensating feedback and shifting the burden to the intervener.

Mass, N. J., ed. 1974. *Readings in Urban Dynamics Vol. I.* Cambridge MA: Productivity Press.

Extensions, modification, and responses to criticisms of the *Urban Dynamics* model.

Schroeder, W. W., III, R. E. Sweeney, & L. E. Alfeld , eds. 1975. *Readings in Urban Dynamics Vol. II.* Cambridge MA: Productivity Press.

Further extends and explores the *Urban Dynamics* model.

Alfeld, L. E., & A. K. Graham. 1976. *Introduction to Urban Dynamics.* Cambridge MA: Productivity Press.

A very readable introductory text. Uses the urban system as an example to teach general points about modeling methods, formulation and analysis.

LIMITS TO GROWTH AND OTHER GLOBAL MODELS

Meadows, D. H., D. L. Meadows, J. Randers, & W. W. Behrens III. 1972. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind.* New York: Universe Books.

Classic controversial study of the human future. Nontechnical presentation of structure, assumptions, and results of the WORLD3 model. Concluded that present policies were unsustainable; shows how alternate policies could stabilize population at a high standard of living.

Forrester, J. W. 1973. *World Dynamics.* (2 ed.). Cambridge MA: Productivity Press.

The first global model, on which *Limits to Growth* was based. The extreme simplicity of the model allowed it to be presented to a wide audience.

Meadows, D. L., & D. H. Meadows, eds. 1974. *Toward Global Equilibrium: Collected Papers.* Cambridge MA: Productivity Press.

Describes and explores, through system dynamics models, policies for sustainability designed to avoid the collapse shown in the 'business as usual' WORLD3 scenarios.

Meadows, D. L., W. W. Behrens III, D. H. Meadows, R. F. Naill, J. Randers, E. K. O. Zahn. 1974. *Dynamics of Growth in a Finite World.* Cambridge MA: Productivity Press.

Full documentation and data for the WORLD3 model used in the *Limits to Growth.* Describes the structure and assumptions; includes all data needed for complete replication of all runs in the popular book. Formulations described here may be useful to all system dynamics modelers.

Meadows, D., J. Richardson & G. Bruckmann. 1982. *Groping in the Dark.* New York: Wiley and Sons.

Describes a range of global models built under different approaches and discusses the strengths, weaknesses, and implications of each. Presented in an engaging, personal style.

Meadows, D. H., D. L. Meadows & J. Randers. 1992. *Beyond the Limits: Confronting Global Collapse, Envisioning A Sustainable Future.* Post Mills VT: Chelsea Green.

Follows up on *Limits to Growth.* Shows that many problems described in 1972 have worsened, as predicted by the model. Argues for a shift in values necessary to create a sustainable and equitable future.

SD FOR MANAGEMENT: FIRM AND MARKET MODELS

Coyle, R. G. 1977. *Management System Dynamics.* New York: John Wiley & Sons.

Text emphasizing managerial modeling, with a focus on operations and examples including discrete elements.

Roberts, E. B., ed. 1978. *Managerial Applications of System Dynamics.* Cambridge MA: Productivity Press.

Extensive collection of early corporate models, including history and commentary by practitioners. Covers R&D management, production and operations, human resources, and other applications areas.

Lyneis, J. M., 1980. *Corporate Planning and Policy Design.* Cambridge MA: Productivity Press.

Begins with a simple model of inventory management in a manufacturing firm and gradually extends the model to one of the entire firm.

Hall, R. I. 1976. A System Pathology of an Organization: The Rise and Fall of the Old Saturday Evening Post. *Administrative Science Quarterly* 21 (2): 185-211.

A case-study using a system dynamics model to explain how failure to understand the feedbacks among policies governing ad rates, ad and editorial pages, marketing, and pricing lead to the failure of the Post just as circulation reached an all-time high.

Morecroft, J. D. W. 1984. Strategy Support Models. *Strategic Management Journal* 5 (3): 215-229.

Describes the use of models as participants in the ongoing dialogue among managers regarding strategy formation and evaluation. Emphasizes the processes for model development and use that enhance the utility of modeling in design of high-level corporate strategy.

Morecroft, J. D. W., D. C. Lane, & P. S. Viita. 1991. Modelling Growth Strategy in a Biotechnology Startup Firm. *System Dynamics Review* 7 (2): 93-116.

Describes a case-study of a start-up in which system dynamics modeling helps to define a desirable growth strategy for the firm. The integrated model generated strategies that allowed different parts of the firm to choose consistent approaches.

Merten, P. P. 1991. Loop-Based Strategic Decision Support Systems. *Strategic Management Journal* 12: 371-382.

Describes a model of a multinational firm establishing new markets in less-developed countries. Captures qualitative shifts in firm structure and organization endogenously as the firm evolves.

ECONOMIC MODELS

Sterman, J. D. 1985. A Behavioral Model of the Economic Long Wave. *Journal of Economic Behavior and Organization* 6 (1): 17-53.

Proposes and tests a simple model of the long wave. The intended rationality of each decision rule is tested and the long wave is explained as the unintended result of the interaction of locally rational decision processes. The model is the basis for the STRATAGEM-2 game, and can exhibit chaos.

Saeed, K. 1986. The Dynamics of Economic Growth and Political Instability in the Developing Countries. *System Dynamics Review* 2 (1): 20-35.

Shows how rapid economic development can generate social and political instability through a model that links socio-political factors to economic development.

Sterman, J. D. 1986. The Economic Long Wave: Theory and Evidence. *System Dynamics Review* 2 (2): 87-125.

Comprehensive overview of the theory of long waves arising from the System Dynamics National Model. Reviews the feedback structures responsible for the long wave and empirical evidence supporting the dynamic hypotheses. Discusses the role of innovation and political value change.

Forrester, J. W. 1989. The System Dynamics National Model: Macrobehavior from Microstructure. In *Computer-Based Management of Complex Systems: International System Dynamics Conference*, ed. P. M. Milling & E. O. K. Zahn. Berlin: Springer-Verlag.

Provides an overview of the national modeling project in which both micro- and macro-economic factors are included. Model generates business cycles, inflation, stagflation, the economic long wave, and growth.

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

Sterman's 1985 model of the long wave is converted into a management flight simulator and used as an experiment in which subjects make the capital investment decision. Simple decision rules capturing subject's policies are estimated and explain their behavior well. Simulation of these rules yields deterministic chaos for about 25% of the subjects.

CONCEPTUALIZING, FORMULATING AND VALIDATING MODELS

Forrester, J. W. 1980. Information Sources for Modeling the National Economy. *Journal of the American Statistical Association* 75 (371): 555-574.

Argues that modeling the dynamics of firms, industries, or the economy requires use of multiple data sources, not just numerical data and statistical techniques. Stresses the role of the mental and descriptive data base; emphasizes the need for first-hand field study of decision making.

Legasto, A. A., Jr., J. W. Forrester & J. M. Lyneis, eds. 1980. *System Dynamics*. TIMS Studies in the Management Sciences. Vol. 14. Amsterdam: North-Holland.

Collection of papers focused on methodology. Includes Forrester and Senge on Tests for Building Confidence in System Dynamics Models and Gardiner & Ford's discussion on Which Policy Run is Best, and Who Says So?

Randers, J., ed. 1980. *Elements of the System Dynamics Method.* Cambridge MA: Productivity Press.

Includes Mass on Stock and Flow Variables and the Dynamics of Supply and Demand; Mass & Senge on Alternative Tests for Selecting Model Variables; and Randers' very useful Guidelines for Model Conceptualization.

Richardson, G. P., and A. L. Pugh, III. 1981. *Introduction to System Dynamics Modeling with DYNAMO*. Cambridge MA: Productivity Press.

Introductory text with excellent treatment of conceptualization, stocks and flows, formulation, and analysis. A good way to learn the DYNAMO simulation language as well.

Morecroft, J. D. W. 1982. A Critical Review of Diagramming Tools for Conceptualizing Feedback System Models. *Dynamica* 8 (part 1): 20-29.

Critiques causal-loop diagrams and proposes subsystem and policy structure diagrams as superior tools for representing the structure of decisions in feedback models.

Roberts, N., D. F. Andersen, R. M. Deal, M. S. Grant, & W. A. Shaffer. 1983. *Introduction to Computer Simulation: A System Dynamics Modeling Approach.* Reading MA: Addison-Wesley.

Easy-to-understand introductory text, complete with exercises.

Homer, J. B. 1983. Partial-Model Testing As A Validation Tool for System Dynamics. In *International System Dynamics Conference*: 920-932

How model validity can be improved through partial model testing when data for the full model are lacking.

Sterman, J. D. 1984. Appropriate Summary Statistics for Evaluating the Historical Fit of System Dynamics Models. *Dynamica* 10 (2): 51-66.

Describes the use of rigorous statistical tools for establishing model validity. Shows how Theil statistics can be used to assess goodness-of-fit in dynamic models.

Forrester, J. W. 1985. 'The' Model Versus a Modeling 'Process'. *System Dynamics Review* 1 (1): 133-134.

The value of a model lies not in its predictive ability alone but primarily in the learning generated during the modeling process.

Richardson, G. P. 1986. Problems with Causal-Loop Diagrams. *System Dynamics Review* 2 (2): 158-170.

Causal-loop diagrams cannot show stock-and-flow structure explicitly and can obscure important dynamics. Offers guidelines for proper use and interpretation of CLDs.

Forrester, J. W. 1987. Fourteen 'Obvious Truths'. *System Dynamics Review* 3 (2): 156-159.

The core of the system dynamics paradigm, as seen by the founder of the field.

Forrester, J. W. 1987. Nonlinearity in High-Order Models of Social Systems. *European Journal of Operational Research* 30 (2): 104-109.

Nonlinearity is pervasive, unavoidable, and essential to the functioning of natural and human systems. Modeling methods must embrace nonlinearity to yield realistic and useful models. Linear and nearly-linear methods are likely to obscure understanding or lead to erroneous conclusions.

Barlas, Y. 1989. Multiple Tests for Validation of System Dynamics Type of Simulation Models. *European Journal of Operational Research* 42 (1): 59-87.

Discusses a variety of tests to validate SD models, including structural and statistical tests.

Barlas, Y., & S. Carpenter. 1990. Philosophical Roots of Model Validation: Two Paradigms. *System Dynamics Review* 6 (2): 148-166.

Contrasts the system dynamics approach to validity with the traditional, logical empiricist view of science. Finds that the relativist philosophy is consistent with SD and discusses the practical implications for modelers and their critics.

Wolstenholme, E. F. 1990. *System Enquiry - A System Dynamics Approach.* Chichester: John Wiley.

Describes a research methodology for building a system dynamics analysis. Emphasizes causal-loop diagramming, mapping of mental models, and other tools for qualitative system dynamics.

Mass, N. 1991. Diagnosing Surprise Model Behavior: A Tool For Evolving Behavioral And Policy Insights (written in 1981). *System Dynamics Review* 7 (1): 68-86.

Provides guidelines for learning from surprise model behavior and describes tests to resolve discrepant behavior.

MODELING FOR LEARNING: SYSTEMS THINKING AND ORGANIZATIONAL LEARNING

Morecroft, J. D. W. 1988. System Dynamics and Microworlds for Policymakers. *European Journal of Operational Research* 35 (3): 301-320.

Describes the model-building tools available to managers and policymakers.

Kim, D. 1989. Learning Laboratories: Designing a Reflective Learning Environment. In *Computer-Based Management of Complex Systems: International System Dynamics Conference*, ed. P. M. Milling & E. O. K. Zahn. Berlin: Springer-Verlag.

A case-study of a process designed to convey dynamic insights to participants in a workshop setting designed around a management flight simulator game.

Senge, Peter M. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York: Doubleday Currency.

Introduces systems thinking as part of a wider approach to organizational learning. Conveys basic system structures to a non-technical business audience by means of anecdotes and archetypes.

Senge, P. M. 1990. Catalyzing Systems Thinking Within Organizations. In *Advances in Organization Development*, ed. F. Masarik. Norwood NJ: Ablex.

Presents a case study in which the use of system dynamics generated insights into a chronic business problem. Steps in generating, testing and disseminating a system dynamics model are described.

Richmond, B. 1990. Systems Thinking: A Critical Set of Critical Thinking Skills for the 90's and Beyond. In *International System Dynamics Conference*, ed. D. F. Andersen, G. P. Richardson & J. D. Sterman.

Proposes a process and skill set to teach systems thinking. The process relies on learner-directed learning. The skill set includes general scientific reasoning and SD, supported by simulation.

Morecroft, J. D. W., & J. D. Sterman, eds. 1992. *European Journal of Operational Research:* Special Issue: Modelling for Learning, 59 (1).

17 papers describing models and methods to enhance learning, both for individuals and organizations. Covers elicitation and group process techniques, management flight simulators, and tools for capturing, representing, and simulating mental and formal models.

DECISION MAKING

Morecroft, J. D. W. 1983. System Dynamics: Portraying Bounded Rationality. *Omega* 11 (2): 131-142.

SD models represent decision making as boundedly rational. Reviews and contrasts the concept of bounded rationality as developed by Herbert Simon. Uses Forrester's Market Growth model to show how locally rational decision rules can interact to yield globally dysfunctional outcomes.

Morecroft, J. D. W. 1985. Rationality in the Analysis of Behavioral Simulation Models. *Management Science* 31 (7): 900-916.

Shows how the intended rationality of decision rules in SD models can be assessed, and how one analyzes a simulation model and output to understand the assumed bounds on rationality in dynamic models. A model of salesforce effort allocation is used to illustrate.

Sterman, J. D. 1987. Expectation Formation in Behavioral Simulation Models. *Behavioral Science* 32: 190-211.

Proposes and tests a simple dynamic model of expectation formation in dynamic models (the TREND function). Shows how the TREND function explains a forty year history of inflation forecasts and several different types of long-term energy demand forecasts.

Sterman, J. D. 1989. Misperceptions of Feedback in Dynamic Decision Making. *Organizational Behavior and Human Decision Processes* 43 (3): 301-335.

Describes an experiment with a simple economic system in which subjects systematically generate costly oscillations. Estimates decision rules to characterize subject behavior. Finds that people systematically ignore feedbacks, time delays, accumulations, and nonlinearities. These misperceptions of feedback lead to poor quality decisions when dynamic complexity is high.

Sterman, J. D. 1989. Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment. *Management Science* 35 (3): 321-339.

Analyzes the results of the Beer Distribution Game. Misperceptions of feedback are found to cause poor performance in the beer game, as in other experiments. Estimates of the subjects' decision rules show they ignore time delays, accumulations, feedbacks, and nonlinearities.

SELECTED APPLICATIONS OF SD

Levin, G., G. B. Hirsch, & E. B. Roberts. 1975. *The Persistent Poppy: A Computer-Aided Search for Heroin Policy*. Cambridge MA: Ballinger.

Examines the interactions within a community among drug users, the police and justice system, treatment agencies, and the citizens. Analyzes policies designed to restore the community's health.

Levin, G., E. B. Roberts, G. B. Hirsch, D. S. Kligler, N. Roberts, & J. F. Wilder. 1976. *The Dynamics of Human Service Delivery*. Cambridge MA: Ballinger.

Presents a generic theory of human service delivery, with case studies and examples drawn from mental health care, dental planning, elementary education, and outpatient care.

Cooper, K. G. 1980. Naval Ship Production: A Claim Settled and a Framework Built. *Interfaces* 10 (6): December.

An SD model was used to quantify the causes of cost overruns in a large military shipbuilding project. One of the first and most successful applications of system dynamics to large-scale project management; initiated a long line of related project modeling work.

Jensen, K. S., E. Mosekilde, & N. Holstein-Rathlou. 1985. Self-Sustained Oscillations and Chaotic Behaviour in Kidney Pressure Regulation. In *Laws of Nature and Human Conduct*, ed. I. Prigogine & M. Sanglier. Brussels: Taskforce of Research Infromation and Study on Science.

Presents a system dynamics model of the dynamics of rat kidneys. Experimental data show previously unexplained oscillations, sometimes chaotic. The model explains how these fluctuations arise. Excellent example of SD applied to physiology.

Homer, J. B. 1985. Worker Burnout: A Dynamic Model with Implications for Prevention and Control. *System Dynamics Review* 1 (1): 42-62.

Explains how knowledge workers can experience cycles of burnout through a simple system dynamics model. Avoiding burnout requires that one work at less than maximum capacity.

Homer, J. B. 1987. A Diffusion Model with Application to Evolving Medical Technologies. *Technological Forecasting and Social Change* 31 (3): 197-218.

Presents a generic model of the diffusion of new medical technologies. Case studies of the cardiac pacemaker and an antibiotic illustrate how the same model can explain the different diffusion dynamics of successful and unsuccessful technologies.

Gardiner, L. K. and R. C. Shreckengost. 1987. A System Dynamics Model for Estimating Heroin Imports into the United States. *System Dynamics Review* 3 (1): 8-27.

Describes how the CIA used SD to estimate the illegal importation of drugs to the US.

Ford, A. & M. Bull. 1989. Using System Dynamics For Conservation Policy Analysis In The Pacific Northwest. *System Dynamics Review* 5 (1): 1-15.

Describes the use of an extensive SD model of electric power generation with endogenous demand. The model is used to evaluate strategies for conservation and new generation capacity. Includes discussion of implementation and integration of the SD model with other existing planning tools.

Sklar Reichelt, K. 1990. *Halter Marine: A Case Study of the Dangers of Litigation.* (Working Paper No. D-4179). System Dynamics Group, Sloan School of Management, MIT, Cambridge MA.

A case-study illustrating the use of system dynamics in litigation. Suitable for classroom teaching.

Abdel-Hamid, T. K. and S. E. Madnick. 1991. *Software Project Dynamics: An Integrated Approach.* Englewood Cliffs NJ: Prentice Hall.

Integrated SD model of the software development process. The model covers design, coding, reviewing, and quality assurance; these are integrated with resource planning, scheduling, and management of software projects. Includes full documentation, validation, and policy tests.

Sturis, J., K. S. Polonsky, E. Mosekilde and E. Van Cauter. 1991. Computer Model for Mechanisms Underlying Ultradian Oscillations of Insulin and Glucose. *American Journal of Physiology* 260 (Endocrinol. Metab. 23): E801-E809.

New experimental data show that the human glucose/insulin system is inherently oscillatory. An SD model explains these dynamics. The model is validated against detailed physiological data.

Naill, R. F. 1992 A System Dynamics Model for National Energy Policy Planning. *System Dynamics Review* 8 (1): 1-19.

Naill, R. F., S. Belanger, A. Klinger, & E. Peterson. 1992 An Analysis of the Cost Effectiveness of U.S. Energy Policies to Mitigate Global Warming. *System Dynamics Review* 8 (2): 111-128.

Reviews the 20 year history of the SD energy models used by the US Dept. of Energy to forecast and analyze policy options for national energy security, including the impact of US policies on global climate change.

Homer, J. B. 1993. A System Dynamics Model of National Cocaine Prevalence. *System Dynamics Review* 9 (1): 49-78

An excellent model of the interacting dynamics of addiction, policy-setting, and enforcement.

CROSS-FERTILIZATION AND COMPARATIVE METHODOLOGY

Meadows, D. H., & J. M. & Robinson. 1985. *The Electronic Oracle: Computer Models and Social Decisions*. Wiley and Sons.

Comparative assessment of the underlying assumptions, boundary, limitations, and uses of different models, including optimization, simulation, and econometrics. Offers guidelines for assessing model assumptions, including ways to recognize the implicit biases of each modeling paradigm.

Sterman, J. D. 1985. The Growth of Knowledge: Testing a Theory of Scientific Revolutions with a Formal Model. *Technological Forecasting and Social Change* 28 (2): 93-122.

Presents a formal dynamic model of TS Kuhn's theory of scientific revolutions.

Sterman, J. D. 1988. A Skeptic's Guide to Computer Models. In *Foresight and National Decisions*, ed. L. Grant: 133-169. Lanham MD: University Press of America.

Reviews different modeling methods and their underlying assumptions in nontechnical language. Provides a list of questions model users should ask to assess whether a model or method are appropriate to the problem.

Allen, P. M. 1988. Dynamic Models of Evolving Systems. *System Dynamics Review* 4 (1-2): 109-130.

Reviews approaches to nonlinear dynamics, self-organization, and evolution developed in the Brussels school by Prigogine, Allen, and others. Provides illustrations and examples.

Powers, W. T. 1990. Control Theory: A Model of Organisms. *System Dynamics Review* 6 (1): 1-20.

An explicit feedback control perspective on perception and decision making in living organisms. Argues the behaviorist and cognitive paradigms have fundamentally misunderstood the concept of feedback. For Powers, feedback allows organisms to control perceptions by altering behavior.

Radzicki, M. J. 1990. Methodologia Oeconomiae et Systematis Dynamis. *System Dynamics Review* 6 (2): 123-147.

Surveys the institutionalist paradigm in economics and argues that system dynamics is compatible with the institutionalist perspective. The SD approach offers a means by which institutional theories can be formalized and tested.

Kim, D. H. 1990. *Toward Learning Organizations: Integrating Total Quality Control and Systems Thinking*. (Working Paper No. D-4036). System Dynamics Group, Sloan School of Management, MIT, Cambridge MA.

Argues that SD and Total Quality Management are complementary approaches to improvement and organizational learning. Systems thinking and modeling are needed to speed the improvement cycle for processes with long time delays.

OTHER THEMES: PULLING THE THREADS TOGETHER

Meadows, D. H. 1989. System Dynamics Meets the Press. *System Dynamics Review* 5 (1): 68-80.

Reviews the history of encounters between SD and the media. Offers guidelines for effective communication to the public at large. Stresses the importance of communicating even the simplest system concepts.

Richardson, G. P. 1991. *Feedback Thought in Social Science*. University of Pennsylvania Press.

Traces the history of the concept of feedback in the social sciences through two threads of thought – the cybernetic and feedback threads. System dynamics is placed in context in a readable and scholarly manner.

Meadows, D. H. 1991. *The Global Citizen*. Washington DC: Island Press.

A collection of Dana's syndicated newspaper columns applying system dynamics principles to problems of everyday life, from organic farming to the fall of the Soviet Union. Emphasizes environmental issues.

Cooper, K. and W. Steinhurst, eds. 1992. *The System Dynamics Society Bibliography*. System Dynamics Society. Available from Julie Pugh, 49 Bedford Rd., Lincoln MA, USA 01773.

Lists over 3,000 system dynamics journal articles, books, conference proceedings and working papers. Available in computer-readable format and compatible with bibliographic software.

GAMES

The Beer Distribution Game

This simple four-stage production-distribution board game provides many students with their first exposure to system dynamics. Illustrates how structure determines behavior. Instructions, videos, analyses, and interpretive papers are available from John Sterman at MIT.

STRATAGEM. D. L. Meadows, UNH, Durham NH.

Interactive computer-supported board game. Each team manages the development of a nation over a century, including population and agriculture, energy, industry, pollution, and foreign trade. Widely used around the world as an introduction to issues of sustainable development.

Fishbanks Game. D. L. Meadows, UNH, Durham NH.

Computer supported board game in which players manage a fishery. Illustrates principles for management of renewable resources. Widely used in education; certified by the US Dept. of Education. Easy to play by everyone from high schools students to government officials.

People Express Management Flight Simulator. J. D. Sterman, MIT Sloan School of Management, Cambridge, MA.

An interactive simulation exercise that gives users first-hand experience at the controls of the airline company. It illustrates feedback effects and non-linearities at work, providing participants with an experiential learning opportunity.

SOFTWARE

DYNAMO. Pugh-Roberts Associates, Cambridge MA.

The first widely-used computer language developed to simulate system dynamics models, *DYNAMO* is still in use, available for mainframes and PCs. Many of the models in the system dynamics literature were simulated in *DYNAMO*.

STELLA and *ithink*. High Performance Systems, Hanover NH.

User-friendly modeling software with full graphical interface. Models are entered graphically, at the level of the stock and flow diagram. Widely used in education from elementary school up; also used in research and practice.

Vensim. Ventana Systems, Harvard MA.

Powerful simulation environment for SD models. Runs on workstations and PCs. Includes array capability and a wide range of features for analyzing model behavior.

Microworld Creator and *S^4*. Microworlds Inc., Cambridge MA

Easy to use environment for simulation and gaming. *S^4*, the 'industrial strength' version, supports arrays and includes diagnostics for analyzing behavior. Both *Creator* and *S^4* support user-defined information displays and facilitate rapid development of management flight simulators.