COMPLEX AND DISTRIBUTED SYSTEMS

Analysis, Simulation and Control

S. Tzafestas P. Borne Editors

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COMPLEX AND DISTRIBUTED SYSTEMS
Analysis, Simulation and Control

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1986

NORTH-HOLLAND
AMSTERDAM · NEW YORK · OXFORD · TOKYO

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ISBN: 0 444 70097 8
ISBN set: 0 444 70082 x

Published by:
ELSEVIER SCIENCE PUBLISHERS B.V.
P.O. Box 1991
1000 BZ Amsterdam
The Netherlands

Sole distributors for the U.S.A. and Canada:
ELSEVIER SCIENCE PUBLISHING COMPANY, INC.
52 Vanderbilt Avenue
New York, N.Y. 10017
U.S.A.

Library of Congress Cataloging-in-Publication Data

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Complex and distributed systems.

   (IMACS transactions on scientific computation ; v. 4)
   Includes bibliographies and index.
   1. Distributed parameter systems.  2. System
analysis.  3. Control theory.  I. Tzafestas, S. G.,
1939-     . II. Borne, Pierre.  III. Series: IMACS
World Congress on Systems Simulation and Scientific
Computation (11th : 1985 : Oslo, Norway).  IMACS
transactions on scientific computation ; v. 4.
QA402.C55  1986          003            86-16218
ISBN 0-444-70097-8 (U.S.)
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PRINTED IN THE NETHERLANDS

PREFACE

This fourth volume of the *1985 IMACS Transactions on Scientific Computation* contains selected papers on the analysis, simulation and control of complex and distributed systems, from those presented at the *11th IMACS Congress* (Oslo, Norway, August 1985). The authors were invited to provide extended and/or improved versions of their papers.

The volume is divided into the following five sections:

1. Complex system modelling, simulation and identification,
2. Bond graph analysis and modelling,
3. Nonlinear oscillators and chaotic systems,
4. Distributed parameter systems,
5. Control of complex systems,

which represent five major areas of system theory, and show the modern trend in the growing field of complex and distributed parameter systems theory.

In view of the extensive coverage of many timely and important aspects of complex and distributed systems theory and the rich set of new results derived by internationally known experts, it is hoped that this volume, together with the other volumes of the present IMACS Transactions, will be a useful addition to the technical literature used for research and teaching.

Athens, April 1986

Spyros G. Tzafestas

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CONTENTS

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Section III
NONLINEAR OSCILLATORS AND CHAOTIC SYSTEMS

Section IV
DISTRIBUTED PARAMETER SYSTEMS

Section V
CONTROL OF COMPLEX SYSTEMS

Section I

COMPLEX SYSTEM MODELLING, SIMULATION AND IDENTIFICATION

Complex and Distributed Systems: Analysis, Simulation and Control
S.G. Tzafestas and P. Borne (editors)
Elsevier Science Publishers B.V. (North-Holland)
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A CONCEPTUAL FRAMEWORK FOR MODELLING THE DYNAMICS OF ENVIRONMENTAL SYSTEMS

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A conceptual framework for modelling the dynamics of environmental systems is presented. It is argued that apparently stable systems can evolve via bifurcation when critical thresholds are exceeded. When a system is forced further away from equilibrium dissipative structures emerge. These dissipative structures are characterised by stochastic, non-linear feedback mechanisms which have the capacity to transform an apparently stable environmental system into a relatively more complex one which evolves. Some examples of these structures are simulated using system dynamics and the implications for further research are discussed.

INTRODUCTION

One of the major difficulties in building dynamic models of environmental systems resides in resolving the paradox that these systems are both stable yet evolve. Generally, model builders have concentrated their efforts on understanding the dynamics of stable systems. Whilst this research is well established it is clear that by focussing attention on stable systems model builders have, by and large, ignored the evolution of such apparently stable systems. This paper outlines a conceptual framework which can simultaneously accommodate both the dynamics of stable and developing environmental systems.

In the following section a brief definition and discussion of environmental systems is offered. It will be argued that the study of environmental systems transcends conventional disciplinary boundaries and, through necessity, has to embrace both hard and soft systems simultaneously. This discussion is then followed, in section three, by presenting a conceptual framework for modelling the dynamics of environmental systems. By drawing upon and extending the work of the Brussels school (1) it is argued that an apparently stable system can pass through a chaotic mode of behaviour which, if driven further from a previous position of equilibrium, can then undergo a radical transformation which has the potential for a new qualitatively different system to emerge. These dissipative structures are characterised by stochastic, non-linear feedback mechanisms and are present, but latent, in many environmental systems. The fourth section uses system dynamics and DYNAMO to simulate the various modes of behaviour described in the conceptual framework for modelling environmental systems. Finally, some of the implications of this conceptual framework for further research into the dynamics of environmental systems are discussed.

ENVIRONMENTAL SYSTEMS ARE HARD AND SOFT

According to Bennett and Chorley an environmental system can be defined very broadly as an interdisciplinary study embracing 'physical, biological, man-made, social and economic reality' (2). Obviously, such a broad definition covers a whole host of disciplines and it is, perhaps, useful to consider environmental systems as the intersection of three sets namely the ecological; the economic and socio-political systems. The study of ecological systems is primarily concerned with the explicit elucidation of the structure and function of a plant or animal community and its natural habitat. The habitat can consist of both organic and inorganic material. Several texts have shown that the structure and functioning of ecological systems can be understood by use of computer simulation (3, 4). Whilst ecological studies are one important facet of environmental science it would be misleading to suggest that all environmental scientists are concerned solely with ecological problems. Increasingly, society's economic activities are having a major impact upon ecological systems. The misuse of ecological systems for short term economic gain can have a major, if not catastrophic, impact on the life support systems of this planet. If economic and ecological systems are not integrated in a holistic manner then serious repercussions may result from our short sighted negligence (5).

The study of the inter-relationships between economic and ecological systems do not, however, take place in a socio-political vacuum. Increasingly, decisions made by socio-political institutions can have a major impact on the environment. It is, therefore, essential that environmental scientists consider the way in

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which material aspects of our culture support a particular set of political ideas as opposed to more ecologically sensible political philosophies and practices. Pepper, for example, notes that 'the British Conservative Government in 1980-1 put so much research money into nuclear power rather than 'soft' energy sources perhaps because of the power of the pro-nuclear lobby and also because it wanted to break the political power of the coal-miners'(6). In an attempt to explain the way in which vested interests manipulate environmental decision making environmental scienticts need to consider critically the ethical principles and political practices of these groups.

Clearly, an environmental system is a complex phenomena and it cannot be studied in its entirety by adopting a purely ecological or economic or socio-political perspective. To try and explain the dynamics of environmental systems from any one or two perspectives is myopic. Yet, to try and develop a conceptual framework which can accommodate all three sets in an integrated, holistic dynamic framework is exceedingly difficult. One of the reasons for this difficulty resides in the fact that environmental systems are simultaneously hard and soft systems.

In a recent reappraisal of systems analysis Checkland has argued that hard systems are a special case of the so-called soft-systems methodology (7). A hard system can be characterised as the search for an efficient means of reaching a clearly defined objective or goal, once the goal or objective is clearly defined, then systematic appraisal of alternative solutions to the problem, helped by various techniques, enables the problem to be solved. A classic example of this approach was the successful attempt by the American nation to land a man on the moon. A soft systems approach provides a way of tackling ill-structured problems without imposing on them the means-end dichotomy which is characteristic of the hard systems approach. In many cases the use of verbal models helps to clarify the major interactions in a system without degenerating into arid polemic. Alternatively, some simulation modelling of soft systems can 'degenerate into science fiction, in which fragmentary data are pushed far beyond any limit of credibility (8).

The distinction between hard and soft systems is clearly illustrated below (see Figure 1). Despite the differences between these two approaches to using a systems approach to either optimize or to learn about a specific system of interest several researchers have failed to grasp the significance of the soft methodology (9). Often they have attempted to apply the hard systems approach to problems which are soft. One of the results of this major methodological mistake has been to ignore the interaction of clashing value systems found in soft systems by assuming that the system model builders implicit values are the only ones which are important. Witness, for example, the heated exchange over the value systems embedded in the World and Urban Dynamic models (10, 11, 12). If hard and soft systems are to be integrated in a coherent way then this problem of incorporating dialectical changes within our models must be tackled. Fortunately, the conceptual framework outlined in this paper is capable of achieving this synthesis of hard and soft systems.

A CONCEPTUAL FRAMEWORK

In order to make progress in the dynamic modelling of environmental systems it is essential that a framework is developed which can incorporate both the hard and soft elements of these complex systems. Furthermore, it is fundamentally important that the conceptual framework can resolve the paradox that environmental systems are both stable yet evolve. Generally, model builders have concentrated their efforts on understanding the dynamics of stable systems. Whilst this research is well established it is clear that by focussing attention on stable systems model builders have, by and large, ignored the evolution of such apparently stable systems. This section outlines a conceptual framework which can simultaneously accommodate both the dynamics of stable and developing hard and soft environmental systems.

Any dynamic model may be defined as a simplification of a real world system which changes through time. This apparently straightforward definition of dynamic models hides a bewildering richness of dynamic behaviour (13). This dynamic behaviour can be described as synchronic or diachronic change (14). Synchronic change

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	Paradigm 1 Hard systems thinking	Paradigm 2 Soft systems thinking
C: Customers	Decision-makers who command real world systems	Participants who debate the differences between the models and the expression of the problem situation
A: Actors	External analysts and engineers	Those who choose to take part: analaysts and/or problem owners
T: Transformation	Information into advice to decision-makers	Information into specific learning for the "actors"
W: Worldview	Real world problem is systemic. Methodology is systematic Optimization is possible	Real world problem is problematical. Methodology is systemic Learning is possible
O: Owners	Decision-makers/ clients	"Actors" as defined above, or the analyst
E: Ethics	Power structures and value systems of the decision-maker clients	As little as possible compatible with achieving change in the problem situation

Figure 1 Hard and Soft Systems (After Checkland 1984)

describes the way in which the elements of a system alter through space-time within a fixed structure. Diachronic change, however, describes the processes whereby the structure of a system is transformed into another form. Most dynamic models of environmental systems have examined synchronic structures but it is becoming increasingly obvious that diachronic change must be examined if we are to understand the complexities of the dynamics of environmental systems.

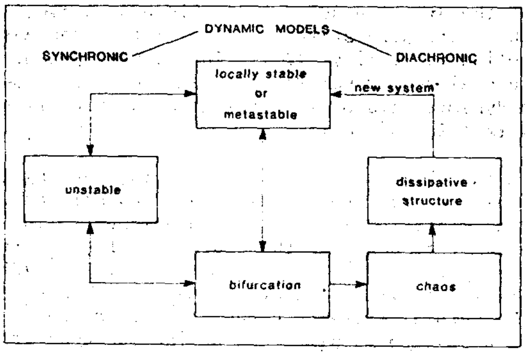

Fig. 2 Various modes of behaviour in dynamic models

In figure 2 a conceptual framework which attempts to integrate both synchronic and diachronic structures is illustrated. Beginning with systems which are locally stable, emphasis is placed on those systems which are in dynamic equilibrium (i.e. whose macroscopic state variables do not fluctuate through time although the microscopic elements may, in fact, change). Included in this class of local stability is the concept of stable cyclical oscillations in the behaviour of a system. As an open environmental system is driven further away from locally stable locations by either exogenous or endogenous change then unstable behaviour is exhibited. An obvious manifestation of such change is a demographic system collapsing to extinction or increasing exponentially.

Apart from the obvious forms of instability a more interesting case is that of bifurcation. Several workers have noted that primary bifurcation or the hysteresis phenomenon can be exhibited in a variety of environmental, biological and chemical systems (15). By forcing a system beyond a threshold of stability the system can achieve a new locally stable state. Alternatively, these primary bifurcations can be developed so that the trajectory of the system changes in a more complex manner. As the system moves away from one position of dynamic equilibrium further bifurcations are possible until chaotic behaviour is observed even in systems with deterministic equations (16).

Chaotic behaviour is observed in many dynamic system models which have one, or more, feedback loops. These non-equilibrium systems, especially when interacting with the outside world may also form the genetic phase for the formation of new structures. These new structures are termed self-organising or dissipative structures. They may appear locally stable but are, as Prigogine and Stengers write 'essentially a reflection of the global situation of non-equilibrium (processes) producing them' (17). Unlike bifurcation and chaotic behaviour in dynamic models of environmental systems these dissipative structures are generated by a mix of deterministic and stochastic elements. It is important to realise that such stochastic perturbations may be very small in any environmental system but can alter fundamentally the entire system of interest. Furthermore, these structures are created and maintained in open systems by a continuous influx of energy or matter (18). In this way the dynamics of environmental systems can exhibit diachronic as well as synchronic change.

SOME EXAMPLES

Numerous examples could be given to illustrate the use of this new conceptual approach to modelling the dynamics of environmental systems. Three examples (population growth using a logistic equation; a dynamic version of Christaller's theory of central places; and the environmental management implications of dynamic models) are described briefly below. In each example, there is a wide range of dynamic behaviour implicit in these relatively simple models.

When a population is composed of single generations with no overlap between successive generations then the population growth occurs in discrete steps. In such circumstances it is convenient to model these systems of interest as difference equations (19). The logistic equation (S-shaped curve) is probably the simplest form of non-linear equation used in ecological studies. There are various ways of writing the logistic equations but a discrete version could be written as follows

$$\Delta p_t = rp_t \left(1 - \frac{p_t}{L}\right) \qquad \text{(equation 1)}$$

where p is the number of people, L is the upper limit of carrying capacity on this number and r(1-P/L) is the rate at which new people are recruited into the system. This difference equation can be modelled using system dynamics to produce a variety of dynamic behaviour. When $0 < r < 1$ then the system converges monotonically towards L. Oscillating convergence towards L is observed when $1 < r < 2$. If, however, the condition $2 < r < 2.57$ a series of stable limit cycles of period 2^n can develop. When $r > 2.57$ then the logistic equation model enters into chaotic behaviour. As the name implies, chaotic behaviour is unpredictable. Any value of r which falls into this regime can generate trajectories that may settle into a stable limit cycle of any integral period or may never settle into a finite cycle (20) in Figure 3.

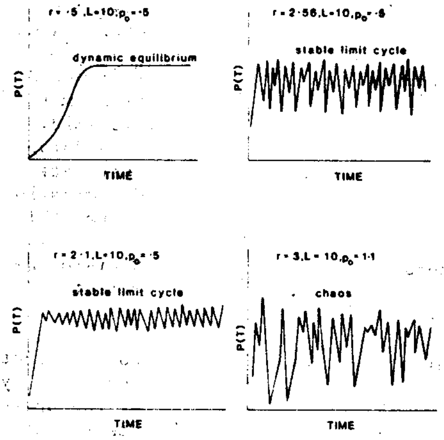

Fig. 3.
Various modes of behaviour in a simple difference equation
see text for explanation

As is well known, Christaller's (1933) theory of central places showed three different hexagonal lattices depending on the marketing, transport or administrative principles ($k = 3$, 4 and 7 respectively). Each of these sets of hexagonal patterns appear to be timeless, optimised spatial configurations. It was, however, clear to Christaller that these static patterns represented 'only a snapshot of the existing world in continuous change; the stationary state is only fiction whereas motion is reality' (21). In the past decade several researchers have attempted to provide a dynamic version of Christaller's pioneering work (22, 23, 24).

In the 1970s a dynamic model of interacting urban centres, combining both stochastic and deterministic elements, was developed in an attempt to describe the evolution of a central place system (25-28) 1978, 1979a, 1979b, 1981). Using a modified logistic equation in which the natural carrying capacity L (equation 1) of a particular place can be increased by its potential employment capacity as used in the familiar Lowry model (29). Unlike the previous example, however, each population centre is in competition with other centres of activity located elsewhere. Furthermore, each central location is able to act as a focus of production and consumption for the inhabitants of the central place and those in the immediate hinterland. By incorporating non-linearities and stochastic processes into this dynamic model a qualitatively more realistic evolution of central place patterns has been produced. Preliminary empirical work indicates that this model is sufficient to describe correctly the evolution of tertiary employment and residential structure in the Bastogne region of Belgium, 1947-70 (30).

In the previous two examples it is clear that even in the case of some simple, non-linear dynamic models there is a very sharp transition from stable to unstable or chaotic behaviour as a parameter exceeds a critical threshold value. Within the range of a critical threshold value it is possible to optimise some aspect of the behaviour of the modelled system. In this way it may be possible to develop simple models which may be used for environmental management and planning (31). It is, however, very clear that if simple dynamic models are to be used in environmental management and planning then there is an urgent need to develop rigorous methods to determine sensitive parameters before policies emanating from these models are put into practice.

Apart from the technical problems involved in using dynamic models of environmental systems for management or planning purposes there are also deeper ethical considerations to be taken into account. O'Riordan (32) notes that the environmental ethic exists to change people's outlook on the world, their values and behaviour and not just to shift public policies and redirect particular decisions. One way of addressing ethical issues involved in environmental management and planning is to use a simple dynamic model of structural conflict in the environment. In the case of advanced industrial societies three different attitudes towards the environment can be discerned. The conservative approach suggests that the market mechanism will solve environmental problems when they arise. The liberals, however, suggest that such problems can be eradicated only if further funding is given to environmental management. Finally, the radicals argue that a fundamental shift in attitudes to the environment is required to resolve the problems. These three different attitudes have been built into a dynamic model which incorporates a dissipative structure. This dissipative structure is triggered by stochastic perturbations in a non-linear feedback loop. The result of triggering this dissipative structure can reveal the ways in which conflicting values can lead to different forms of social evolution which are either antagonistic to, or in harmony with, the environment (33).

CONCLUSION

This paper has described the nature of environmental systems as the interaction of ecological, economic and socio-political sets. One of the problems in studying environmental systems resides in the fact that they are both hard and soft. Furthermore, in attempting to model the dynamics of these systems it is clear that both synchronic and diachronic change must be considered. The conceptual framework outlined in the paper incorporates hard and soft systems as well as synchronic and diachronic change.

By drawing upon the notion of dissipative structures it is possible to portray the dynamics of environmental systems as cyclic phenomena moving from stability, into instability, bifurcations, chaos and into dissipative structures. These latter structures can radically transform the behaviour and structure of the entire system of interest. These revolutionary changes are embedded in complex systems and are triggered by low probability stochastic changes which cause fundamental shifts in the structure and function of hitherto apparently stable systems.

Whilst this conceptual framework for modelling the dynamics of environmental systems is tentative it is clear that several environmental systems do in fact exhibit these modes of behaviour. Several examples of the dynamics of environmental systems have been discussed using the method of system dynamics simulation. These examples include stable but oscillating predator-prey relationships; the chaotic behaviour of urban dynamics and dissipative structures illustrating the emergence of a more ecologically sane society as a result of dialectical conflict in a model of an environmental system. Obviously, much more detailed empirical and theoretical research needs to be undertaken in order to comprehend the dynamics of environmental systems. Nevertheless, the conceptual framework described above offers environmental scientists a new and useful way of understanding and changing environmental systems as they unfold around us.

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Elsevier Science Publishers B.V. (North-Holland)
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ON THE STOCHASTIC SIMULATION AND OPTIMIZATION IN PRODUCTION ENGINEERING

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ABSTRACT - The problem of the stochastic simulation and optimization of machining processes in production engineering is here considered with particular attention to optimization analysis. An application to grinding processes is also developed.

1. INTRODUCTION

The construction of reliable and rapid simulation models holds basic importance in the design and inspection of the production systems. Moreover it is well understood, see for instance refs. /1÷3/, that the simulation of a machining operation in production engineering can be defined by input-output models with random parameters or noise. The stochasticity of such simulation models links up, in general, with the uncertainly in which works the whole production system (for the continual changes of the various costs, for the increasing bonds in environment, for the tumultuous technological development, etc.) and, in particular, with the fact that each machining operation is not deterministically repeated (e.g., when the production is realized by several operating machines working in different operation conditions).

More in details on the content of this paper, the second section contains the description of two classes of input-output models which can define a general framework suitable to include consistent simulations of several machining processes, such as the ones considered in refs. /4÷7/, and which will be afterwords analysed in the application. The third section defines the structure and the formulation of the optimization process; in this section the main lines to be followed in the computer aided optimization are also indicated. The final section contains an application to the analysis of grinding process, a problem which has been already considered by the Authors in the paper /4/, where a stochastic formulation of the Mayne and Malkin model /5/ was proposed.

2. A FRAMEWORK FOR MODELLING AND SIMULATION

A framework for two simple models towards the simulation of machining processes is here considered in a general form, namely without any particularization. The application realized in the last section will then show how the simulation of the grinding process can be cast into the above announced framework.

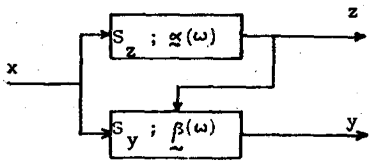

Fig. 1 - Input-output scheme (model 1)

With reference to the input-output scheme sketched in fig.1, the first simulation model (model 1) is characterized by the following items:

a) x is the input, variable technological parameters characterizing the machining process (cutting velocity, machining dept, etc);

b) z is the output, quantitative production obtained as a stochastic algebric map from x into z:

$$z = S_z(x;\ \underset{\sim}{\alpha}(\omega)) \qquad (1)$$

where $\underset{\sim}{\alpha}$ is a set of random parameters characterizing the simulation model;

c) y is the energy spent to obtain z and

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