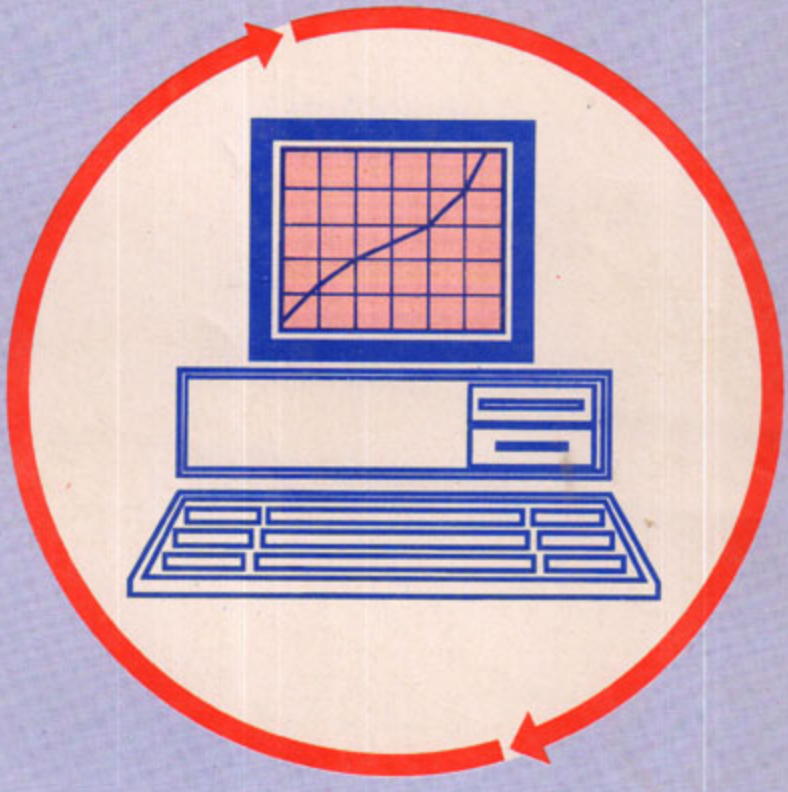
PRINCIPLES OF SYSTEM DYNAMICS



B.K. Bala

PRINCIPLES OF SYSTEM DYNAMICS:
WITH AGRICULTURAL, AQUACULTURAL, ENVIRONMENTAL AND SOCIO-ECONOMIC APPLICATIONS

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PREFACE

This book has been written primarily for undergraduate and postgraduate courses on system dynamics, systems engineering, system simulation, agricultural system and multidisciplinary courses on biological, agricultural, aquacultural, environmental and socio-economic systems. This book could be adopted for courses in electrical engineering and computer science. This would also serve as an excellent reference on modelling and simulation of agricultural, aquacultural, environmental and socio-economic systems. It is the outcome of several years of teaching and research in this areas by the author.

This book covers the wide spectrum of system dynamics methodology of modelling and simulation of complex systems, parameter estimation, tests for building confidence in system dynamics models and applications of system dynamics in the diverse fields of biological, agricultural, aquacultural, environmental and socio-economic systems. A good number of examples and listings of DYNAMO and STELLA programs followed by verbal description and flow diagrams are included for easy comprehension of the total procedures and rules of system dynamics modelling and simulation. Exercises have been included at end of each chapter for further practices.

I have great pleasure in expressing the acklowledgments which I owe to many persons in writing this book. I warmly recognise the continuing debt to my teacher, Dr. Donald R. Drew, W. Thomas Rice Professor of Systems Engineering, Virginia Polytechnic and State University, USA who introduced me System Dynamics at Asian Institute of Technology, Bangkok, Thailand. At Bangladesh Agricultural University I received encouragement and assistance from many of my colleagues specially Dr. A.T.M. Ziauddin and Dr. M.A. Satter, Department of Farm Power and Machinery who read the manuscript and made many helpful suggestions. I owe my thanks to Mr. B.K. Biswas for typing the manuscript and Mr. Anwar Ali for drawing the figures.

B.K. Bala

FOREWORD

Unfortunately, many past economic development efforts have not only been unsuccessful, but have led to a number of social problems such as the aggravation of poverty and hunger, and environmental problems such as the rapid depletion of natural resources and the generation of persistent pollution. This book describes a methodology called system dynamics that permits us to examine organizational arrangements underlying resource allocation and its consequences at social and ecological levels. It addresses the challenge inherent in the modelling and management of complex agricultural, aquacultural, environmental and socio-economic systems.

In this important and provocative book, Professor Bala elucidates some of the basic methods of system dynamics in a agricultural context, and illustrates the value of the approach through a large number of examples and case studies. The book is essentially about man's search for efficiency in agricultural production achieved within the ecological framework in which farming is conducted so as not to exploit the natural environment. It provides a foundation for integrating agricultural and environmental policies for achieving sustainable development.

In the management of farming system it can be expected that an understanding of the links between the various components in the production process will be at least as important as a knowledge of the separate components themselves. This being so, the all-embracing approach offered by the systems concept is likely to prove almost essential to good management in agricultural production. Traditional methods used to deal with the biological and economic aspects of agricultural production have not been entirely successful in handling the inherent complexities. Some of deficiencies of such methods are briefly discussed, before examining the possibilities for and problems of applying system dynamics to agricultural problems.

September 1994

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CONTENTS

1

Systems

1.1 Introduction

We live within a highly complex socio-technical-natural environment. In the past people were not much conscious about the environmental pollution and degradation. But they are now becoming increasingly conscious of the environmental hazards. Hence, our objective is to design and manage all the development programs such as agricultural, aquacultural and industrial development programs for improved quality of life with minimum distortion of the environment.

The system dynamist is concerned with understanding and managing the complex system in order to provide the desired performance. The twin goals of understanding and management are complementary. Since, in order to manage the system more effectively, the system under consideration must be modelled and well understood. The present challenge to the system dynamist is the modelling and management of complex agricultural, aquacultural, environmental and socio-economic systems.

System dynamics is a methodology of constructing computer models based on feedback concept borrowed from the wealth of control theory. System dynamics was developed at MIT by J.W. Forrester during the 1950's and it was originally applied to the industrial firms. The methods worked out by Forrester and his group have since been applied to a variety of fields. Forrester essentially developed a guiding philosophy and a set of representational techniques for complex, nonlinear, multiloop systems. Therefore, it is well suited to physical, agricultural, aquacultural, environmental and socio-economic systems. It is notoriously difficult to handle

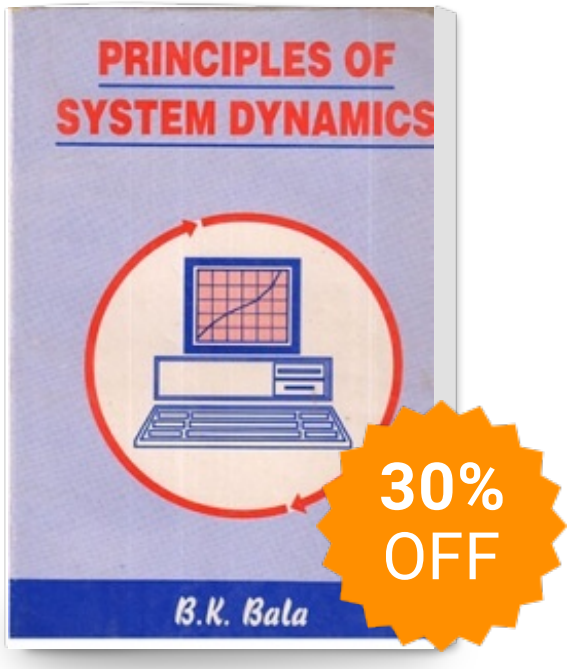
nonlinear, time lagged feedback systems mathematically. Forrester and his associates developed a computer language DYNAMO to handle such complex system with limited training in mathematics and computing. DYNAMO is a very specialized language designed to simulate system dynamics models. Some new packages are now available and one such package is the DYMOSIM developed by Mohapatra and his group at IIT, Kharagpur. But any system dynamics model can be written in a general purpose language such as FORTRAN.

Again, some software programs and packages have now become available that offer dynamic modelling capabilities and sophisticated graphics interfaces. STELLA an icon oriented software developed by High Performance Systems has revolutionized the system dynamics modelling process and allows you to model virtually any process. Thus, STELLA enhances your understanding of biological, social and physical systems. STELLA software also automatically creates the framework of equations needed to bring the model to life - high level mathematics is not required. Essentially STELLA has opened up the modelling process to a much wider audience to inetract intensively with model development.

1.2 Open and Feedback Systems

According to Forrester system means a grouping of parts that operate together for a common purpose. For example, a tractor is a system of components that work together for providing cultivation. A system may include people as well as physical parts. A family is a system for living and raising children. Systems may include biological as well as economic components and such systems are known as bio-economic systems. Agricultural and aquacultural systems are examples of bio-economic systems. Crop- irrigation system is an example of an agricultural system while prawn production system is an example of aquacultural system. In aquacultural system aquatic animals are raised to maturity in an economic manner. A system may include physical, economic, social, biological, technological and political components and such a system is highly complex. For example, an environmental system consists of physical, biological, social, technological, economic and political components and their interactions.

Principles of System Dynamics



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