Applied Cybernetics

Its Relevance in Operations Research

A. GHOSAL

GORDON AND BREACH SCIENCE PUBLISHERS
New York London Paris

Gordon and Breach Science Publishers, Inc.
One Park Avenue
New York, NY10016

Gordon and Breach Science Publishers Ltd.
42 William IV Street
London WC2N 4DF

Gordon & Breach
7–9 rue Emile Dubois
Paris 75014

Library of Congress Cataloging in Publication Data

Ghosal, A
Applied cybernetics.

(Studies in operations research; 5)
Includes bibliographies.
1. Operations research. 2. Cybernetics.
I. Title. II. Series.
T57.6.G53 001.4'24 77-17045
ISBN 0-677-05410-6

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To my friend
N. PAUL LOOMBA
and my family
(Nomita, Raja, Somnath and Zinnia)

Acknowledgements

The author will be failing in his duty if he does not record his gratitude to Dr. Atma Ram, Chairman, National Committee of Science and Technology (India), Prof. Y. Nayudamma, past Director-General of CSIR, and Dr. A. Ramachandran, present Director-General of CSIR, for giving encouragement and providing facilities for research pursuits over a decade. Many of the case studies reported in this book were obtained from projects done by the author and his associates: thanks are due to the organizations which gave the author opportunity to work. The author is grateful to Prof. George Sphicas of Baruch College, Prof. Dan Shimshak and Mr. John Affisco of Rider College (his colleagues in New York) and his doctoral students at Delhi for collaborative work, comments and criticisms: to the author's secretary Ms. Kamlesh Punj for helping in the revision of the book, typing and preparation of indices, and to Messrs. J. C. Khanna and S. C. Vohra for preparing the figures. The author also thanks the International Association of Cybernetics, Namur, Belgium, for permission to reproduce his paper (first published in *Cybernetica*) in Chapter 6, and Prof. S. P. Ladany, Editor, Management Science Special Edition, for permission to use Example 5.8.2 in forecasting. All credit is due to Gordon and Breach editorial and production staff, both in New York and London, for getting the rather shabby manuscript into good shape. Finally should the author not be grateful to his wife Nomita and children for depriving them of many evenings, while preparing the manuscript?

Foreword

Professor Ghosal has written a book which considers problems in many diverse areas of operations research and treats them as cybernetic systems. He conveys the feeling that operations research is an exciting and expanding field and that cybernetics is a creative method of investigation. Using this approach, one can model, analyse, and gain insight into the complex systems that exist in real life. Although several books have been written in past years on cybernetic systems, this book, in our opinion, is notable because it achieves a balanced, high-level treatment of cybernetics, combining both theoretical and practical considerations. Professor Ghosal has produced a consistent and comprehensive presentation of cybernetics and its application to operations research which will not be found in any book to date.

The work for this book began at Baruch College of the City University of New York, where the author was a visiting professor from 1974–76. During that time Professor Ghosal delivered lectures to the doctoral faculty and students research seminar in management. These lectures were always informative and impressive. In addition, we were aware of the extensive research that Professor Ghosal had conducted in applied cybernetics. It was a great experience working with Professor Ghosal during those two years. His expertise extends into many different fields and this book draws from that knowledge. We are confident that this book will be recognized as a great contribution to the field of operations research and/or management science.

N. Paul Loomba

Chairman and Professor
Department of Management, Baruch College,
City University of New York

Daniel G. Shimshak

Assistant Professor
Department of Decision Sciences, Rider College

Preface

This monograph is the result of lectures given by the author at the doctoral programs in the Department of Management, Baruch College, and seminars given at various universities in the USA. The primary objective in these lectures and seminars has been to emphasize the applications of a cybernetic approach in problems of economics and industry. Though cybernetics had its birth in the USA through the work of Wiener, little has been done here on the cybernetics of economic planning, management systems, industrial problems, etc.: most of the work on cybernetics in this part of the world has been directed to the problems of theoretical development, biocybernetics, neurocybernetics, artificial intelligence, etc. An attempt has been made to develop the cybernetic approach in a few earthly problems of economics and industry.

The central theme of cybernetics is the system through which a problem or a set of problems is identified and subsequently solved. Chapter 1 presents the basic cybernetic outlook, and illustrates through examples the art of looking at a problem through the mirror of a system. Commonality with the approach of a general systems theory has been explained. The forties saw the birth of two new fields – cybernetics and operations research (O.R.) – one after the war and the other before and during the Second World War through Blackett's Circus of O.R. Though Blackett's team stressed heavily the systems approach in solving problems of military strategy, present tendencies in O.R. concentrate subconsciously on treatment of problems within part of systems and sub-optimization. Only a few stalwarts like Ackoff and Stafford Beer have been trying to emphasize a systems or cybernetic approach to operational analysts. The author, in his dual capacity as a worker and the editor of the O.R. Series, has restressed the importance of such an approach in this monograph.

In Chapter 2 and subsequent chapters the treatment has a mathematical bias. Chapter 2 gives the mathematical preliminaries which an undergraduate with a knowledge of intermediate algebra and calculus can understand. Chapter 3 presents problems in macro-economics which have been done by pioneers like Keynes, Samuelson, Hicks, Leontief, etc.; cybernetic phenomena in their models have been briefly explained. It also presents a few problems in planning done by the author.

Chapter 4 gives a cybernetic view of stochastic systems, with special reference to problems in queueing and storage systems. The contribution of this chapter (which has been mainly the result of the author's work) has been to show that usefulness of developing a systems view in obtaining approximate solutions. The concept of isomorphic (or quasi-isomorphic) systems has been exploited in deriving solutions to complex network systems.

In Chapter 5 the problem of forecasting in real-life problems has been approached from a cybernetic angle. Basic concepts of a systems forecast have been presented, and a few practical examples of capacity forecasting, solved through non-linear differential equations, have been given.

Chapter 6 gives an exploratory treatment, from a theoretical point of view, of dynamic optimization problems. The concept of an acceptable optimum solution given here is akin to the famous "satisfycing" concept of Simon.

There are hosts of real-life problems in industrial economics and national or corporate planning which are amenable to applied cybernetics but have not been dealt with here. The author hopes to write a more detailed treatise on the subject in future. Meanwhile, however, the present monograph can be hopefully used, with explanations and modifications by the instructor, for a one-semester course in applied cybernetics to graduate students in management science, operations research, economics, mathematics or engineering.

It is possible that there have been errors in such an informally written monograph; the author will be grateful if these are brought to his notice. No attempt at bibliographic excellence has been made. The bulk of Chapters 4–6 is based on the research done by the author and his associates.

The author is grateful to Professor Stafford Beer, who baptized him through a short conversation in a conference on O.R. in England in 1964, and for his encouragement. Beer's monumental work on Chilean national planning (*Platform for Change*, John Wiley, New York, 1975) bears ample evidence to the scope of a cybernetic approach in diagnosing, formulating planning problems and in offering updated solutions through a dynamic information flow. The author acknowledges his gratitude to Prof. N. Paul Loomba, Chairman, Department of Management, Baruch College, New York, for supplying working facilities; to the secretaries in this department and to Mrs Judith Moden Stewart of Monash University, Australia, for typing the manuscript.

Amitava Ghosal

Department of Management, Baruch College,
The City University of New York.

Contents

Chapter 1

Introduction

1.1 Cybernetic approach

The central theme of cybernetics is the system which it proposes to study. The way a system is defined is the basis of a cybernetic approach to a problem. It is the transfer of information from and to the system which determines the working of a cybernetic system – in a physical system, on the contrary, we are principally concerned with the manner in which energy is transferred.

Cybernetics has been defined in a number of ways by various workers over the last 25 years. Wiener (1948) defines it as the "Science of control and communication in the animal and man", and thereby restricted its scope to the physical world. Stafford Beer (1966) put it more broadly:

> The new science of cybernetics is the science of control and communication – whenever these occur in whatever kinds of systems. The core of cybernetic research is the discovery that there is unit of natural law in the way control must operate, whether the system controlled is animate or inanimate, physical or biological, social or economic.

Coiffignul (1958) defined the functions of a cybernetic approach as that of providing the art of approaching the solution of various problems through study of respective systems and prescribing how to act under various possible circumstances. A knowledge of problems concerning a given system and ways of acting under different circumstances provides the basis of regulation and control of the system. Optimization of an activity is not the principal aim of a cybernetic approach, but it is possible that knowledge regarding optimal solutions under various conditions may be obtained from the study of the system.

While tackling a problem in the sphere of economic, industrial, social or biological world, a cybernetic approach comprises the following steps: (i) the overall system relevant to the problem is defined in terms of elements, their interrelations; (ii) the problem is defined in quantitative terms (as far as possible) in terms of elements of the system; (iii) the communication and control mechanism of the system is studied by taking into effect the deterministic and stochastic elements; (iv) finally a decision mechanism of how to act under various situations is prescribed. Studying the changes in the system and adapting decisions accordingly forms an essential feature of a cybernetic system. Thus we are not only trying to estimate the output of system for different values of the system, but also gauging the effect of the output on the inputs – in other words, on the behaviour of the elements within the system. This is characterized as the feedback effect, which is explained from a control theoretic viewpoint in Chapter 2. The steps (iii) and (iv), referred to above, are possible through the knowledge of (a) the mechanism of determining the output from knowledge of input elements and their behaviour and (b) an appraisal of feedback effects of the system.

1.2 Applied cybernetics

Applied cybernetics is the branch of study which enables us to identify a system and its behavioural features, viz. input–output mechanism, feedback effects; and take decisions accordingly through a cybernetic approach. Thus we define the problem in view of terms of a cybernetic model and study the input–output mechanism with a view to developing a decision-mechanism under various possible situations. This book is concerned with developing cybernetic approach to problems in economic, industrial and a few social spheres; it does not deal with problems in biocybernetics (which deals with applications of cybernetic approach in biological, biomedical and physiological problems the literature on which itself is extensive (Klir and Valach, 1965)). Most of the problems in management science lend to deeper understanding through a cybernetic outlook; Stafford Beer (1966) puts it aptly:

> If cybernetics is the science of control, management is the profession of control. Hence we may recognize the subject of management cybernetics as a rich provider of models.

The art of looking at a problem through a relevant system is an important feature of applied cybernetics. Examples given in this chapter (Section 1.5) indicate that a problem viewed through a system is sometimes different from the apparent problem; and an appropriate reformulation of the problem is the first requisite to the determination of a reasonable solution.

1.3 Examples

Formulation of problems through a cybernetic approach can be appreciated through the following examples. The first step, as explained in Section 1.1, is to define the system and then to understand the mechanisms of self-regulation through an overview of the system. All the examples are taken from economic and industrial fields.

1.3.1 An inventory problem

A manufacturing plant keeps an inventory system of its finished products which comprise mostly machine parts. During recent months the inventory is building up beyond expectation, in spite of the fact that wholesale prices have not been increased and the level of production has not been increased. While studying the problem, the system was defined in terms of production unit (number of various components being manufactured), consumers' demand, advertisement mechanism, price structure, and sales behaviour. A technical appraisal of the demand showed that there was a drop of demand in 80 per cent of products due to technological change, that is, consuming industry shifting to a different style of production; on the other hand there was a substantial increase in demand in 20 per cent of products – these had no inventory at all. The marketing department was not aware of this change, and had advertised on 80 per cent of the products which had dropped in sales and increased in inventory. The reformulated problem was whether the production unit could adapt to a change in production structure by manufacturing more of the items which were showing better sales potential arising out of a small technological change. In other words, it was a problem of implementation of a feedback of changing demand structure on the production system.

1.3.2 Educational planning

In the fifties a planning study in a developing country indicated that industrial production there for the next decennium would suffer if the education system did not increase the number of engineering graduates by at least four times. The policy was implemented by starting a number of high-level engineering schools. During the first 10 years industry benefited substantially through availability of qualified engineering personnel within the country. However, the increasing trend in production of engineering graduates continued; and in the early seventies it appeared that there was over-production of engineers. The increase in industrial development was not commensurate with that of production of engineers with the result that many fresh engineering graduates had to be without jobs. A plan for industrial development had called for the starting of new engineering schools; the effect of new schools on the industry at large was significant because the industry had the benefit of qualified personnel who would otherwise have had to have been hired from foreign countries at a higher cost; the later effect was, however, unemployment among engineers. A mechanism for monitoring the requirement of engineering personnel in industries and transmitting in the educational system which could increase or decrease admission programmes could be worked out on the basis of a cybernetic system, but the solution might be difficult to implement.

1.3.3 A social problem

A region in a developing country showed severe food crisis. To combat it, the authorities rushed food supplies (comprising primarily of grains from neighbouring regions). A statistical survey made a few months later showed that about 25 per cent of the population were starving, even though there was no shortage of food in the market. These people could not afford to purchase grains, not to speak of high-cost protein items, due to their low income. A quick improvement of real income is a far more serious problem than that of rushing food to a region.

1.3.4 Forecasting problems

Forecasting in economic problems also presents a good deal of complexity which can be better understood through an appraisal of the underlying cybernetic system. While forecasting on the basis of past trend, we assume that the trend would continue in the future. Growth in economics is not akin to growth in biological systems – sustenance of growth depends on the efforts made in producing capacities, procuring resources etc. In a problem of predicting airtraffic in a developing country, it was found that traffic depended more on the airline capacity (number of aircrafts put in to service) than other factors. Economic factors like indices of national income, regional economic development would give an indication of potential demand which was substantially greater than capacity available. The problem of forecasting air traffic can also be made from the appraisal of the economic system from which we can obtain the forecast as an output, and various economic indices serve as inputs. These problems will be gone into detail in the chapter on forecasting (Chapter 5).

Examples given above help us in realizing the control mechanism of systems relevant to respective problems. Most of the real-life problems are dynamic in character, and the realization of the system behaviour helps us working out a control mechanism.

1.4 Cybernetic system

A system is an ensemble of elements, some or all of which are interrelated. For identifying a system, we have to know its behavioural characteristic which is represented by (i) the manner in which various elements within the system are related within the system, and (ii) the manner in which the elements react to any external influence. The external influence, in cybernetic language, is called *environment*. The effects of the environment on the system are called *stimuli*, while the effects of the system on the environment are called *responses*. The response of a system to any stimulus is dictated to a great extent upon the way the elements are organized within the system.

A system may be classed under any of the following three categories:

i) It may be a *closed system*, implying that there is no effect of the environment on the system.

ii) It may be an *open system*, implying that there is always an effect of the environment on the system.

iii) It may be a *partially closed system*, in which case the environment has effect only on a subset or a few subsets within the system.

We may also conceive of a subset of the system being closed to another subset of the system. One system may comprise a number of subsets or subsystems, while the entire system may be a subset of a larger system. A very large system like say the economy of a country, or even the plan structure of a big firm may be called a *mega system*. An algebraic description of a system is given in the next section. A non-mathematical reader may refer to Klir and Valch (1965) for an excellent exposition of the concept of a system.

1.5 Systems view vis-à-vis cybernetics

From the discussion of foregoing sections we find that there is a great similarity between systems view, as we understand in the sense of systems theory (see Churchman, 1968, for an excellent overview of systems approach), and the cybernetic approach. In fact, it should be so, because cybernetics is nothing but the science of systems. The key to the solution of a problem is to look at it through a relevant system, and follow the steps referred to in Section 1.1. A flow-chart of the cybernetic or systems approach to problem-solving is given in Figure 1.

A problem, posed by management (or, say, the country at large), is taken as the *apparent problem*, to start with. It is examined through a relevant system, by considering elements, their mutual interactions and relations with the outer world, etc.; and only through such a process of initial analysis, is the *real problem* diagnosed and formulated. A formulation of the problem will depend upon the *model structure* conceived for the system; and whenever it is possible to formulate a problem in quantitative terms, it has to be done so in terms of a mathematical model. The mathematical model will take into consideration communication and control mechanism in the system, impulse–response or input–output mechanism which gives a basis for roughly predicting the output of the