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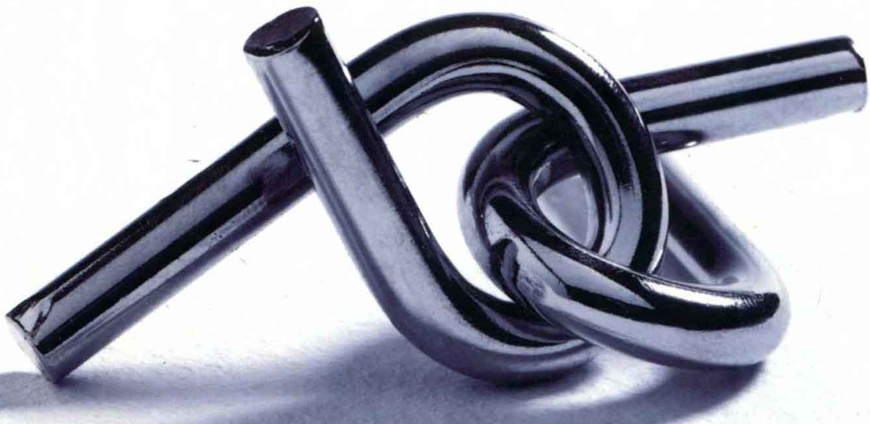
decision-making through systems thinking

second edition



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Management Science

Decision Making Through Systems Thinking

2nd Edition

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Preface

The subtitle '*Decision making through systems thinking*' indicates the focus of this text, namely to explore management science/operations research (MS/OR) within a broad systems thinking framework. It is this aspect that sets it apart from most other introductory MS/OR texts. Their emphasis is on mathematical tools and techniques of what has become known as **hard operations research**, and they offer little more than a few platitudes on the system context in which MS/OR work occurs.

The use of MS/OR is to provide insights for informed decision making. The vast majority of that decision making occurs within organizations or, in other words, within systems. Therefore, MS/OR can be viewed as a way of thinking with a system focus. This necessitates a good understanding of systems, system concepts, and system control. What is included in the system defined to analyse a particular problem and what is left out — the critical system boundary choices — may have important consequences for the people actively involved, as well as those passively affected.

Rather than assume that the usual starting point for an MS/OR project is a relatively well-structured problem, with clearly defined objectives and known alternative courses of action, the text steps back to the inception phase of most projects; namely, the presentation of a problematic situation, where the issues are still vague, fuzzy, and not yet seen in their proper systemic context. It demonstrates several aids to capture the problem situation in its full richness. This will facilitate gaining a more comprehensive understanding of the various issues involved, which in turn increases the likelihood that the problem formulation addresses the 'right' issues at an appropriate level of detail to provide insights and answers relevant for decision making.

Such an approach will also help the reader appreciate that for many decision situations there is no unique 'right' answer, but that the answer is affected by the world view accepted as relevant by the people involved, and by the boundary choices made for the system chosen. Much of Western Education encourages students to think in terms of a single right answer to problem solving. The MS/OR instructor thus faces a challenge to help students gain confidence in working within a mode of thinking which departs from such a narrow focus and which offers benefits that often go beyond the immediate concern. (See the special issue of *INFORMS Transactions on Education*, 12(1), September 2011, devoted to the challenge of teaching soft OR.)

These are the topics of Part I, together with graphical aids for depicting systems or views of important aspects of a particular system. Their aim is to make system modelling more accessible to the beginner.

Most hard operations research texts woefully neglect this essential foundation for effective MS/OR work. Their emphasis is on techniques and their mathematical development. However, applying techniques to 'problems', no matter how elegant the mathematics, without the underpinning of systems thinking needed to gain a sufficient grasp of the problem situations, will result in what Russel Ackoff [(1960) 'Case histories five years after,' *Operations Research*, March-April] coined as 'the surgery was successful, but the patient died.' He also adds that 'The surgeon (the operations researcher) cannot survive many such deaths.' Does not some of the disillusionment about operations research experienced in business and industry since the 1980s have its roots exactly in this emphasis on techniques, at the expense of systems thinking? A solid understanding of system concepts is as essential for hard OR that uses sophisticated mathematical modelling as it is for soft OR methodologies that seek culturally, politically, and socially acceptable compromises or accommodations in conflict situations.

Part II gives an overview of, and contrasts the two major strands of management science, i.e., hard OR and soft OR, and their overall methodologies. While most analysts who use hard OR agree on the general form of the hard OR paradigm, soft OR covers such a wide range of approaches that no single methodological framework can capture them all. Not only do they differ in terms of their specific aims — problem structuring, learning, conflict resolution, contingency planning, as well as problem solving — but also in terms of their suitability for specific problem situations. Of necessity, the chapter devoted to soft OR can only scratch the surface of this vast area. It is restricted to an introductory survey, exploring and contrasting the same case under three of the best known approaches.

Part III looks at two topics that unfortunately are again neglected by most MS/OR texts, but that any successful modeller needs to be thoroughly familiar with. First, most projects involve costs and benefits. These may be of a monetary or intangible nature. Which cost and benefits are relevant for a particular problem? Some of these costs and benefits occur in future periods. How do we deal with that?

Second, much decision making involves planning over time in response to future events. The sequencing of decisions becomes an integral aspect of the problem. How can this be captured by the models?

Part IV is largely devoted to hard OR. A number of MS/OR techniques borrow a leaf or two from managerial economics, in particular the principle of marginal analysis.

A variety of restrictions may be imposed on the decision process, relating to limited resources or qualitative properties the solution has to satisfy. What effects does this have on the solution and the process of obtaining it? What kind of insights can we derive from analysing these effects? The concept of shadow prices is introduced here in general terms and then in the context of linear programming.

Most decisions are made under various degrees of uncertainty about the outcomes. What is uncertainty? How do we react when faced with uncertainty? How can we

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model uncertainty? We make an excursion into waiting lines, simulation, and decision and risk analysis.

We return to the topic of decision making over time by exploring, albeit all too briefly, how to capture the dynamics of system behaviour through simulation.

Finally, there is a brief discussion on how the decision process needs to be adapted if we explicitly acknowledge the fact that the decision maker may be faced with conflicting goals.

Part IV thus gives an introduction into several well-known OR techniques. However, the emphasis is not on the tools themselves, but on how these tools should be used within a systems thinking framework, and what insights we can get from their use. The text is not an elementary introduction to MS/OR techniques. At an introductory level, although interesting and fun, these techniques are often reduced to the triviality of cranking a computational handle for a drastically simplified toy problem, devoid of most real-life semblance. Why not let software crank that handle?

Furthermore, the astronomical computational speed of even the modest laptop and the easy availability of MS/OR software have practically eliminated the need to know the inner workings of advanced hard OR algorithms, such as the simplex method, the various integer and non-linear programming techniques, and the intricacies of the plethora of search algorithms. Such details are needed for software developers, but not for the practising MS/OR analyst.

Rather than discuss concepts in the abstract, they are demonstrated using practical case studies derived from projects that the authors have been involved in or that have been reported in the literature. Some of them had to be trimmed to reduce their complexity and render them amenable for inclusion in the limited space of a textbook, but they have retained the essentials of their original flavour. Most chapters also have one or more case scenarios for the reader to test his or her understanding of the material. Although much simplified, they are again derived from actual projects, some of them undertaken by our honours students.

In Parts III and IV, whenever possible, the quantitative analysis is demonstrated using the power and flexibility of spreadsheets. The text uses Microsoft Excel©, but this choice is more one of convenience, rather than preference. Any other spreadsheet software with optimizer or solver capability and the facility for generating random variates will do.

The use of spreadsheets implies that the level of mathematics involved remains at a fairly elementary level and does not go beyond high school mathematics and statistics. In Parts III and IV, the emphasis is not on the mathematics, but on the concepts and the process of quantitative decision making. The book lives on the principle of 'never let the mathematics get in the way of common sense!' Any instructor who deplores the apparent lack of mathematical rigour may do well to weigh the points raised in Chapter 20 before dismissing this text.

By the time the reader has digested the wealth of learning opportunities offered by this text, he or she will approach all types of problem solving — not just those suitable for quantitative modelling — from a more comprehensive, more enlightened, and insightful perspective. Hopefully, the reader will also have been encouraged to reflect on and become more critical of his or her own way of looking at the world.

The main audience of the text is at an introductory undergraduate or MBA level for a 50- to 80-hour course on analytical decision making, where the emphasis is on methodology and concepts, rather than mathematical techniques. This is the use we have put it to at the University of Canterbury. It is sufficiently challenging for the MBA level, where the focus should be on insights rather than techniques. The real-life case studies used in many chapters make the text particularly relevant and attractive to mature MBA students. However, it is also suitable for self-study and as recommended background reading to set the stage for an introductory course in MS/OR, systems thinking, and computer science.

The text puts the techniques into their proper perspective in the decision making process. Rather than see them as the central and most important part of the analysis, it recognizes that they are powerful analytical and computational aids, but that they usually constitute only a small portion of the total effort that goes into any project. It is not the tools that 'solve a problem', but the process in which they are used.

Thanks go to several people who have contributed in various ways to this text and its precursors, but in particular to Ross James and Nicola Petty who have used its precursors and made numerous valuable suggestions for improvements. And then there are the thousands of students who read the text and whose questions and queries for explanations have led to saying some things more simply and clearly.

The scholar and teacher who has undoubtedly shaped the whole approach to systems thinking and MS/OR more than anybody else is the late C. West Churchman. This text is dedicated to him.

Contents

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1

Management science/ operations research and systems thinking

Learning objectives

- Appreciate/recognize that most human activity occurs within systems.
- Appreciate that decision situations within systems are often complex and need a new way of thinking.

Introduction

This chapter aims to whet your appetite to learn more about the complexity and challenge of effective problem solving. We will briefly describe five real-life situations that each involved making recommendations as to the best course of action to take. Three look at commercial situations, while the other two deal with issues of public decision making and policy. They are intended to give you a feel for the great variety of decision making problems, in terms of the areas of application, the types of organizations involved, the degree of complexity, the types of costs and benefits, as well as their importance. In each instance a systems approach, based on systems thinking, will lead to more insightful decision making.

1.1 Real-life complex decision situations

Call centres

Since the early 1990s, call centres have become an ever more predominant interface between all types of organizations and individuals wanting information, service or assistance, such as requests for emergency services, reporting of crimes to the police, requests for information from the Inland Revenue Service, help from software providers, inquiries about policies and filing of claims to insurance companies, inquiries about products and services to retailers, and not to forget the oldest of such services, telephone directory assistance.

Callers to a call centre, who are more likely than not put on hold, would obviously like to speak to a real person as quickly as possible. Some callers may become impatient and renege if they deem that the time on hold is too long. On the other hand, the call centre does not want to have staff sitting around idle, waiting for calls. Idle operators are costly. Effective operation of a call centre requires a judicious balancing of these opposing aims. Determining 'best' staffing levels is one of the main concerns for call centre management.

The problem is made more difficult by the fact that some aspects, such as salaries and equipment, can be expressed in monetary terms, while others, particularly for emergency service call centres, largely defy any attempt to express them in this way. How do you evaluate a 10% increase in the waiting time which may result in a 40% increase in the likelihood of a loss of life or of serious injury?

Example 1-1: Financial services call centre

The financial services industry is a major user of call centres for generating new business where the products offered may be insurance, loans, savings, credit card and other banking services. The case in question concerns a call centre of a regional company specializing in personal loans of up to £15,000 for periods between 1 and 5 years. This market is particularly competitive with several nationally known companies offering similar borrowing terms. The company stimulates new business by advertising on television, in newspapers, and by direct mail.

Calls received by the centre fall into three categories: enquiries from new customers, enquiries from existing customers, and trivial calls. The call lengths vary, from more than 10 minutes for the first category to less than half a minute for the third.

It is the first category of calls that generates new business and hence profits. If any of these callers renege because too long on hold, potential business is lost, something the firm tries to avoid. So the firm wants to find staffing levels that balance two costs which vary in opposite directions: the cost of staff and the 'cost' of lost business.

Reliable forecasts of call rates over time for each category are the most crucial input into planning best staffing levels. Determining such forecasts is subject to a number of complicating factors. For all categories, there are pronounced intra-day, intra-week, and seasonal variations. The call rates are also affected by bank holidays, seasonal festivities, and 'national' events, such as important football matches. Furthermore, promotional drives cause spikes in new customer calls, followed by a gradual decline. Different advertising media have different response rates. And there is the vexing problem that it is impossible to know to which category abandoned calls belong. Generating reliable call rate forecasts is thus far from simple.

This is a type of problem faced by many organizations, private or public, called a **waiting line** problem. Here are other examples:

- the number of tellers or cashiers a bank, an insurance office, a post office, a supermarket, etc., should have during various times of the business day;
- the number of crews needed by a repair or service outfit, like an appliance service firm or a photocopying machine service firm;
- the number of nurses and/or doctors on duty at an emergency clinic during various hours of the week;
- the degree of redundancy built into equipment to prevent breakdowns.

Vehicle scheduling

Pick-up and delivery firms, like courier services, collect and drop off goods at a number of places. The locations of these pick-ups and drop-offs may differ daily. New pick-up requests may be generated during the day, the mix of requests and their number varying by the hour. Certain of the customers may specify a given time period or 'time window' during which the visit must occur. The vehicles used may have different carrying capacities. The length of time drivers can be on the road in one shift may be subject to legal restrictions. Add to this the fact that traffic densities on various city roads, and hence the travel times between locations, fluctuate during the day. It is also clear that, even for a small problem, the number of possible distinct sequences for visiting all locations is very large. For example, for 10 locations, there are $10! = 3{,}628{,}800$ different itineraries, while for 20 the number grows to $2{,}432{,}902\times10^{12}$. Although a majority can be ruled out as bad, it is still no trivial task to select the best combination or sequence of pick-ups and deliveries from those that remain, such that all complicating factors and constraints are taken into account. It may even be difficult to decide which criterion should be chosen for 'best'. Is it minimum distance, or minimum time, or minimum total cost, or a compromise between these considerations?

Example 1-2: Bulk beer deliveries by tankers

The brewery in this case supplies tap beer in tankers to pubs, bars, and hotels scattered over a large rural area. A few large customers receive deliveries twice a month, while most others only receive on average one delivery a month. A beer tanker has several compartments of differing sizes where the liquid is kept under pressure. Delivery is always made in full compartment quantities. The beer slopping around in partially filled compartments would lose its fizz and endanger the stability of the truck. A trip usually makes deliveries to more than one customer. The person in charge of scheduling deliveries has to take several factors into account:

- customers must not run out of tap beer; there are latest delivery deadlines;
- the size of storage tanks may differ from customer to customer;
- tanker trucks in the fleet have different compartment configurations with different capacities;
- some of the larger customers insist that delivery may not made outside specific time windows;

- parts of the road network from the brewery to customers and between customers include hilly countryside; there are maximum weight restrictions on some road sections, particularly bridges;
- average travel times for fully loaded, partially loaded, and empty tankers, as well as corresponding fuel costs, are known for each road section of the network;
- a trip may exceed eight hours only under exceptional circumstances.

The task of the scheduler is to develop a delivery schedule that takes all these factors into account, while trying to minimize total delivery costs. These consist of fuel costs, tanker driver wages, and other variable vehicle costs that vary depending on the schedules chosen.

Similar types of combinatorial sequencing problems are faced by airlines for the scheduling of aircraft and air crews, public bus or railroad companies for the scheduling of buses or engines and drivers, or the city rubbish collectors for determining their collection rounds.

Environmental and economic considerations

Commercial and industrial activities are often in direct conflict with protecting and safeguarding the natural environment from being adversely affected. While economic activities can easily be measured in monetary terms, the loss or degradation of the natural environment, such as water and air pollution, the loss of native flora and fauna, the loss of wilderness areas, scenic beauty, and so on defy being captured in dollars, pounds, euros, or yuan. How should national and local governmental agencies deals with such issues? What are the responsibilities of private enterprise in this respect?

Furthermore, such situations often involve entrenched political aspects, as the next example shows.

Example 1-3: The Deep Cove project

The waters discharged into Deep Cove from the Manapouri Power Station in Fiordland National Park at the bottom of New Zealand's South Island is so pure that it does not need any chemicals to neutralize harmful bacteria or other contaminants. Several years ago, a US firm applied for the rights to capture this water and transport it with large ocean-going tankers to the US West Coast and the Middle East. It would have entailed the building of a floating dock close to the tail race of the power station, where up to two tankers could berth simultaneously. The project would provide employment for about 30 people in an economically depressed area of New Zealand, and the New Zealand government would collect a water royalty. It would thus make a substantial contribution to both the local and national economy.

The firm showed considerable responsibility in planning the whole operation to keep the environmental impact in the fiord as low as economically feasible. For instance, all staff would be flown into Deep Cove daily, allowing no permanent residence. All rubbish would be removed. No permanent structures would be erected. Tanker speed in the fiord would be reduced to keep swells low. There would be extensive safety measures to avoid oil spills, etc. Not surprisingly, environmental groups were opposed to this project. Here are some of their reasons: first, it would have introduced non-tourist commercial activities in the waters of a national park, which is against the charter of national parks. They feared that the removal of up to 60% of the tail race water for extended periods would

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