PART I
MODELLING IN MANAGEMENT SCIENCE

Introduction

Part I is a general introduction to the idea of modelling as a part of Management Science, stressing modelling as a part of Management Science, and stressing modelling as an activity rather than discussing types of model. The idea is to show how models are built and used, rather than exploring different types of model in any detail – there are plenty of books that do that very well. Thus, the approach taken is non-technical, but it does demand some stamina from readers who may not have come across the ideas before.

Part I begins with a discussion of the value of modelling, taking as the theme of Chapter 1 the idea that models are convenient worlds. They are artificial worlds that have been deliberately created to help with understanding the possible consequences of particular actions. It is important to realize that all models, as used in Management Science, are approximations, and that modellers must develop skills that enable them to decide what should and should not be represented in the model. Such models are almost never used without human intervention, but are designed to assist people making complex decisions – hence this book is called *Tools for Thinking*.

The modelling theme continues with Chapter 2, which looks at the role of modelling within organizations. Modelling approaches are often viewed as exemplars of highly rational schemes, and it is important to consider how they can be of use within organizational life, which may be far from rational in any classical or linear sense. Thus, Chapter 2 develops a definition of rationality from Simon's work, and then considers critics of this view, most notably Mintzberg and his colleagues, who argue for a more intuitive approach to the crafting of strategy. Putting these two together suggests that a role for modelling is to attempt to make sense of strategic vision: the vision stemming from processes that are, at least in part, intuitive.

Chapter 3 faces up to the common view that the main role of Management Science is in problem-solving. But this carries with it the idea that, once solved, problems stay that way. Organizational life is rarely so kind, and it is important to recognize that modelling is used as a way of coping with change and turbulence. Chapter 3 discusses various ideas about the nature of problems and suggests the role for modelling within them. It concludes with an extensive discussion of the nature of problem-structuring, taking the view that this 'naming and framing' (Schön, 1982) is fundamental to successful modelling.

Chapter 4 ends Part I on a thoroughly practical note with a discussion of six principles of modelling that I (and others) have found useful. As part of this discussion, it also reviews the different ways in which models are put to use in Management Science, because this affects the

P1: OTA/XYZ P2: ABC
c01 JWBK409-Pidd August 29, 2009 11:58 Printer Name: Yet to Come

amount of simplification possible within a model. There is no sense in which this is a complete list of useful ideas about modelling, but it will at least serve as a starting point from which readers may develop their own ideas.

Reference

Schön D.A. (1982) *The Reflective Practitioner. How Professionals Think in Action*. Basic Books, New York, NY.

1 Models as convenient worlds

Managing complexity and risk

Our lives are increasingly complex, whether we consider only our individual lives, sharing with our families or working in some kind of organization. Those of us in the Western world depend on artificial aids for our survival: we travel long distances by car, boat or plane; we cook food on devices fuelled by gas or electricity; and we take for granted that computers enable us to communicate instantly across the globe. We are very much part of an interconnected world in which our decisions and those of others can have major consequences for us and for other people. This became very clear in the second half of 2008, when overliberal availability of credit, reckless lending, little-understood and complex financial instruments and an out-of-control bonus culture led to the effective insolvency of large banks and finance houses. These symptoms, which first appeared in the USA and the UK, quickly affected all nations in our global economy and blighted the lives of millions, possibly billions. We live in a complex, fast-moving and highly interconnected world in which we must make better use of resources or face a very uncertain future.

When our decisions turn out well, we expect that we and others will benefit from what happens. But we are also aware that, when things go wrong, the consequences can be dire indeed. The same is true of businesses. For example, the costs to a manufacturer that decides to build a new factory on a green-field site, or to re-equip an existing factory, can be huge. Clearly, managers will make such an investment only if they expect the business to gain some return from doing so. But how can they be sure that their decisions will turn out as they intended? How can they be sure that there will be sufficient demand for the products the factory will produce? How can they be sure that the technologies used within the factory will work as intended? The consequences of failures can be very expensive and may even be dangerous. One way to help improve such planning is to find ways to learn from the failures that sometimes occur (Fortune and Peters, 1995). This learning implies that the investigators have something – a model – against which the performance of the system can be compared.

On a different theme, the high population of our planet serves to increase the awful effect that natural and man-made disasters can have. For example, modern societies rely on large-scale chemical plants for the production of materials to be turned into foodstuffs, drugs and components for goods. But these plants can be dangerous to operate, a fact that the people of Bhopal in India are unlikely ever to forget. There, in 1984, poisonous gas drifted over the town after escaping from a nearby chemical plant, killing about 3000 people and injuring another 250 000 (Fortune and Peters, 1995). We rely on electricity to power our factories and our household devices, and many of the generating plants are based on nuclear reactors. As we know from the events of Chernobyl in 1986, an explosion and a major release of radiation may have terrible consequences. How can managers of these plants try to ensure that they have minimized, or reduced to zero, the risks of dangerous accidents? How can those with the task of evacuating an area and cleaning up afterwards be sure that they are working as effectively as possible?

P1: OTA/XYZ P2: ABC
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The effects of natural disasters such as earthquakes and floods also threaten our lives. These disasters affect both highly developed countries – for example, the earthquakes in Kobe in Japan in 1995 and in San Francisco in the USA in 1989 – and poorer countries such as Bangladesh, whose land is very vulnerable to annual floods, lying largely within the Ganges and Brahmaputra deltas. Such natural disasters not only threaten lives but also disrupt normal life and make it impossible for people to live as they would choose. How can natural disaster experts assess the risk of such hazards? How can they ensure that they are able to warn people when a disaster threatens? How can they ensure that they evacuate people quickly and safely from danger zones?

It is, of course, impossible to be sure what will happen when we make changes in complex systems, for we can be sure of what will happen only when we have complete control over events. However, there are ways of minimizing risk and of managing complexity. The complexity of modern life is here to stay, and we must therefore adopt approaches to cope with this. The risks, too, are evident, as are the rewards for being able to manage those risks. The main argument of this book is that the development and use of rational and logical analysis can be a great aid in managing that complexity and in recognizing and managing the inevitable risks.

Thinking about consequences

Whenever we make a decision and take some action, there will be consequences. The consequences may be within our control, or there may be considerable risk or uncertainty. When we have full control of the consequences of our decisions and actions, we have only ourselves to blame when things go wrong and we can take the credit when they turn out well. In these cases, it clearly makes sense to think through the consequences of our actions and our decisions. For simple decisions, this process is itself simple. All we have to do is list the possible outcomes and choose the most desirable, ensuring that we know which course of action will lead to this outcome. Thus, if we wish to invest some cash in one of a small number of investments, all of whose returns are known and are certain over some defined period, simple arithmetic will help us to choose the best investment. In terms that will be defined later, in doing so we have used a simple decision model. We have applied logical analysis to our circumstances.

Often, however, life is not so simple and we are at the mercy of other people's actions or of the intervention of events we cannot control. Decisions about farming and food supplies are, for example, at the mercy of the weather. When our decisions are affected by other people's, this may be because we are in competition with them, and we must try to consider carefully how other people might respond to the actions that we take. As a classic example, consider the game of chess, which has been much studied by students of Artificial Intelligence. Chess has no chance element, everything is determined, and the winner is the player who follows the best strategies. There is considerable evidence (Simon, 1976) that the better players are able systematically to analyse current and possible future positions very quickly by procedures that can be modelled by computer programs. Other competitive situations are much more complex than chess. For example, a manufacturer of fast-moving consumer goods must develop marketing policies, but competitor companies will do the same and customers' responses are not wholly predictable. This situation is, therefore, more complex than that of a game such as chess.

Does this mean that logical analysis is a waste of time? Not really. Consider the example of the captain of a commercial airliner about to make a long-haul light. Before take-off, the captain must file a flight plan specifying the intended route, timings and other aspects. However, few long-haul flights follow their precise flight plans because there may be changes in the weather,

P1: OTA/XYZ P2: ABC
c01 JWBK409-Pidd August 29, 2009 11:58 Printer Name: Yet to Come

turbulence, military flights or emergencies affecting other aircraft during the flight. Nevertheless, the plan has its value for it serves two purposes. First, it serves as a standard against which progress on the flight can be monitored, which is much better than setting off in the vague hope of landing in Australia! Second, it allows the organization (the airline) to build a body of knowledge about flights and how they can be affected by studying why the flight plan could not be followed. That is, it allows an after-the-event audit to occur.

One major argument of this book is that rational and logical analysis is crucial in our complex and complicated world. However, it might be instructive to think about what other ways there might be to take such decisions, and these include the following.

- *Seat of the pants.* This term usually implies rapid decision-making based on intuition, with no real attempt to think through the consequences. Sometimes this approach can be quite effective, but it can also be rather dangerous. Few of us would wish to be flown on a commercial airline flight by a crew who made no attempt whatsoever to plan their route; flying by the seat of our pants can be exciting, but some kinds of excitement are grossly overrated.
- *Superstition.* This term is used here to indicate a mystical belief that examining some other system will shed light on whatever decision we are facing, even when there is clearly no link whatsoever between our decision and the system that we are using as a reference. This is very similar to the attitude people adopt when they read horoscopes in newspapers with a view to planning their day. A related notion is the idea that use of a lucky charm or method of doing something will guarantee a desirable outcome. For example, a soccer player might always put his left boot on before his right in the belief that doing it the other way round will cause him to play badly. It may not be stretching the analogy too far to suggest that some organizations seem to operate in a similar manner.
- *Faith and trust.* This term is used to denote an approach that is close to superstition, but with the one important difference that there is some proper link postulated between the parallel system and the decision to be faced. Thus, there is the idea that proper observance of the one will guarantee a favourable outcome in the other. Some people would argue that certain politico-economic theories could be classified in this way.
- *Do nothing.* This is the classical ‘head in the sand’ approach, closing our eyes and hoping that the problem will go away or that it will be sorted out in some other way. There are times when it may be best to do nothing, but, paradoxically, we can only know this when we have thought through the consequences of doing nothing. An example of this might be sitting tight during an earthquake.

Probably most people use one or more of these approaches in making personal decisions that have no major consequences. But most of us would be unhappy with the thought that they were being used by others to make major decisions that might have a significant impact on us.

It should, of course, be noted that even logical approaches can fail – especially if they are blinkered. There is a wonderful example of this in the Andalusian hills of southern Spain. There, set among beautiful scenery, close to Montejaque, about 30 kilometres from Ronda, is a dam built by the Seville Electricity Company in the 1920s. They had found a valley into which an existing water source flowed. The valley was wide and deep and had a narrow exit – perfect for a dam. Even better, the valley was high in the hills and water flow could be used to generate hydroelectric power as well as providing water supplies. So, with Swiss engineers as the main contractors, work started and continued for several years. Walls were demolished, roads rerouted and the main dam wall, the first U-shaped dam in southern Europe, rose above the valley floor to an impressive height. Eventually, all was completed and the river was diverted back into the valley. A lake began to form behind the dam, and slowly it filled with water. Over weeks, the water level rose and the Seville Electricity Company congratulated itself on its wise planning and its use of the Swiss engineers. Meanwhile, the locals were watching with keen interest, for they knew something that no outsider had thought to consider.

When the reservoir was nearly full, the water level suddenly fell and did so very quickly, leaving just a small pool behind the dam. What the locals knew, and what every visitor can see to this day, is that the hills are mainly composed of limestone. Limestone itself is impervious to water but contains many fissures through which water may pass – which is why there are many caves in this type of rock. Presumably the huge downward pressure of the water opened up small fissures, and, like water in the bath, away it went. So, after all that effort, the water just drained away and the huge expenditure on the dam was wasted. Visitors can still walk across the dam and admire its fine engineering as they smile and look down at the small pool of water several hundred feet below them. The design was wholly logical, its dam was at the forefront of technology, its designers were good and conscientious people – but they forgot to ask the basic questions. Analysis without basic thought and rigour is a waste of time.

Simple physical models

The Lake District is one of the most popular tourist areas of Britain, with rugged mountains and beautiful lakes. Its fells were the site of much early industrial activity that led to the growth of the small villages that are scattered across the landscape. Tracks that connected these villages are now the paths along which walkers explore the area. The Lake District is wet as well as beautiful, and its attractive streams cascade down the fell-sides into the lakes. Many bridges have been built where the tracks cross the streams. The most appealing of these are made from a single self-supporting arch of stones (a good example is to be found behind the Wasdale Head Hotel). Figure 1.1 shows the basic design of these bridges.

A common method of building the bridges was to erect a wooden framework across the stream. This framework would be an arch on which the stones of the bridge would be placed.

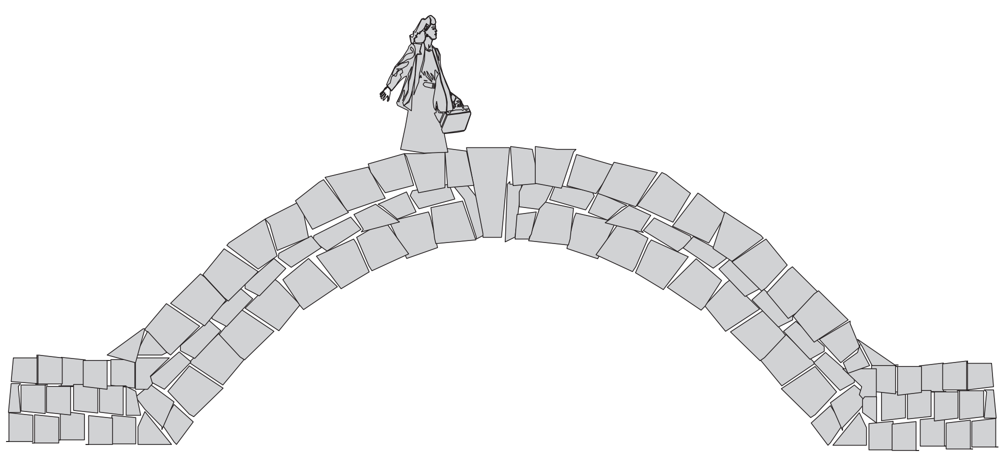

Figure 1.1 A simple stone arch bridge.

P1: OTA/XYZ P2: ABC
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The builders would securely locate the sides of the bridge in the solid ground on the stream banks and would carefully place selected stones on the wooden arch, starting from the banks. Eventually, the builders would reach the stage where only the keystone remained unplaced. The keystone sits at the top of the arch in the centre and would be forced into place to ensure a tight fit. If all the stones were properly fitted tightly together, then the arch would be self-supporting once the keystone was in place.

When the builders were happy that the stone arch was finished, they would set fire to the wooden arch that had supported it while being built. The question in their minds was whether the stone arch would collapse. Would it hold up its own weight, and would it support the weight of the traffic (people and animals) that walked over it? Someone would have to be the first to walk over the bridge and test it. On most occasions, the arch would hold and the bridge would be safe. But there were probably occasions when it collapsed along with the plans and reputations of the builders.

If a newly built bridge did collapse, it was unlikely to be a major catastrophe – apart from the effect on the builder's future prospects. Building such a bridge was not expensive and did not take a long time. The builders could try again until they produced a safe bridge. In the old adage of engineers, they could 'suck it and see'. This 'suck it and see' approach does not imply that the builders did not carefully plan the bridge. Certainly they were careful to select a site and careful in their choice of stones, in preparing these stones and in placing them. They were probably working from a mental image of the bridge. They could probably envisage what it would look like and what size of loads it would bear. Hence, they were able to make the bridge on site and adapt it and rebuild it until it worked as intended.

Small bridges over streams have probably been constructed in this way for centuries, but it would clearly be inappropriate to attempt work on a large-scale civil engineering project such as a motorway bridge in the same way. We take it for granted that the bridge will be planned by qualified engineers and architects who understand how to go about this job. Indeed, in many countries, bridges must be designed and their construction supervised only by fully qualified people. The work of the designers might begin with implicit mental models, their first ideas about the bridge, but we would expect them to move quickly on to formal and explicit models, which would lead to a bridge that would both meet its specification and be safe to use.

There are various types of model the bridge design team might employ. The simplest to envisage are two-dimensional drawings that show, at different levels of detail, how the bridge will look and how its different components will be fastened together. These drawings may exist on paper or might be held in some form of computer-aided design (CAD) system that allows drawings to be displayed on screen and manipulated in different ways. It might also be important to test out the bridge's performance under extreme conditions, such as high winds. For this, the designers may build scale models and test rigs, using wind tunnels and scaled tests to see how their design will perform.

The designers will also be working within cost limits. They will try to ensure not only that the bridge is strong enough to meet its specification but also that it is not overengineered. They will need to consider very carefully the size of the beams and supports that make up the bridge. To do this, they will use well-established mathematical models and equations to describe how the components will perform. They will use these different types of model as ways of managing the sheer complexity of the physical design and to minimize the risk that the bridge will not perform as intended. There is, of course, still no guarantee that the bridge will be safe under all conditions. For example, there is the well-known case of the Tacoma Narrows Bridge which collapsed in 1940 under moderate wind stress after starting to sway. However, in such cases, a model of the bridge may be used to try to discover what went wrong so as to ensure that a similar tragedy does not happen again.

Beyond the physical models

The designers need to go well beyond these models of the physical design for such large-scale projects. If, say, the bridge is part of a larger traffic scheme, they will wish to know what effect their design will have on the overall traffic flow. One way to do this would be to simulate on a computer the likely operation of the bridge. Such a simulation model (see Chapter 10) would allow the designers to develop control strategies for traffic on the basis of the capacities of the bridge and of the rest of the road network.

They will also need to assess how long it will take to build the bridge, and will organize themselves to control the project properly and ensure that it runs according to plan. To do this, they are highly likely to use a model of the different activities that are needed to complete the project, and thus they may resort to network planning tools such as the critical path method (CPM) and the programme evaluation and review technique (PERT) to plan the project and to control its operation. These tools allow the builders to see the effect of possible delays or accelerations in the building works. For example, what happens if the concrete cladding arrives a week late owing to shipping delays? Will that delay the whole project, or are there ways of rearranging the work to catch up the lost time? These are simple questions on small projects but immensely complicated questions in large-scale activities.

The purpose of this book is to demonstrate how different types of model can be useful in helping to manage complexity in order to reduce the risk of wrong decisions. The book also aims to show how different approaches to developing and using models can affect their value in practice. It is perhaps obvious how models and modelling can play a useful part in large-scale civil engineering projects, but it may be less clear how they can be used in other areas of life. After all, complex models must be expensive to build and cannot possibly include the full complexity of a situation, so does this not imply that modelling is a good idea but one that always falls down in practice?

Carefully built models can be of great use in areas of life very different from the design of physical structures. An idea central to this book is that one distinguishing characteristic of management scientists (meaning operational research professionals, business analysts and others who use rational and logical methods) is their use of explicit models. In spite of the analogy of the bridge-builders, the work done by management scientists cannot be regarded as a type of straightforward engineering. As will become clear, it is important for management scientists to be very careful in the assumptions that they make about organizations and in their treatment of other human beings.

What is a model?

There are many definitions of ‘model’ in general, and also many definitions of the term as used within Management Science. One of the earliest definitions simply says that ***a model is a representation of reality*** (Ackoff and Sasieni, 1968). This definition is appealing in its simplicity, but it ignores the question of why the model is being built. This aspect is crucial, for a model is always a simplification, and such simplification must be done with an eye on the intended use of the model. If this issue is ignored, a modeller could go on modelling forever in the safe and sure knowledge that parts of reality have been left out. This simple definition must therefore be expanded to consider the purpose for which the model is being built. Thus, a suitable definition for the present discussion is that *a model is a representation of reality* ***intended for some definite purpose***.

This definition is still very wide-ranging and needs a more precise statement of purpose for the model and for modelling as an activity within Management Science. Management scientists aim to help managers to make better decisions and to exercise better control over the things for which they are responsible. It is therefore important that the definition of a model (and consequently of modelling) includes this idea so as to restrict the area of discussion. That is, in Management Science, models are often built to enable a manager to exercise better control or to help people to understand a complicated situation. Thus, a third stage definition is that *a model is a representation of reality intended* ***to be of use to someone charged with managing or understanding that reality***.

This definition, in turn, could be criticized because it suggests that models in Management Science are only of value to those at the apex of a power structure, as in a business organization. Work in the UK in the 1980s and 1990s demonstrated that Management Science could also be of value to people who are not in positions of such power (Ritchie, Taket and Bryant, 1994). It would therefore be sensible to extend the definition yet further so as to include these possibilities. Thus, the definition becomes *a model is a representation of reality intended to be of use to someone* ***in understanding, changing, managing and controlling that reality***.

Any reader who is a trained management scientist may be irritated by this definition and its development. Why does it not mention the term ‘system’? Why not say that ‘a model is a representation of some system’? This is because, to me at least, the term ‘system’ simply has too many connotations, some of which will be explored later in this book. But what, then, about the term ‘reality’ which is included in the definition. Does this assume that everyone will agree about what constitutes reality? Suppose they are wrong? This is an important point and explains why ‘system’ is not used in the definition. However, it also means that the term ‘reality’ must itself be qualified.

It is important to recognize that, in terms used by Checkland (1981), people may have legitimately different ‘Weltanschauungen’. This German word, popular among philosophers, translates into English as ‘world-view’, but it is intended to convey the bundle of ‘taken for granted’ meanings and assumptions most of us employ in our daily lives. Some of us, for example, may take for granted that a car is a means to get from A to B with the minimum hassle. Others may regard it primarily as a status symbol, or as a hobby, or as a necessary evil that drinks away money and pollutes our world. Needless to say, anyone who attempts to consider how road space should be used in our crowded world must think through these different Weltanschauungen. Our world-views affect what we see and how we describe our experiences. They also affect our choices. To cope with this realization that different world-views may lead to different descriptions of reality, we need to adopt an approach to modelling that is, using Zeigler’s (1984) term, multifaceted. That is, we may need to accept that multiple models are possible for a single apparent reality.

We also need to accept, although it is already implicit in the definition, that no model can ever be complete. This is for two reasons. First, were a model to be a complete one-on-one mapping of something, it would be just as complex as the real thing, and we would then have two of those somethings. This may be satisfying for an art-forger, but rather negates what we shall see later to be some of the advantages in modelling. The second reason is that, unless we include the entire universe in our model, there is always the risk that something will be missing.

P1: OTA/XYZ P2: ABC
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There may be some relationship between our area of interest and another part of reality that is missing from the model. This may not matter now, but it may matter later.

Our definition now becomes *a model is a representation of* ***part of reality as seen by the people who wish to use it to understand, to change, to manage and to control that part of reality***. A further criticism might be that this definition has no mention of improvement. Surely people engage in modelling because they wish to improve something? The only sensible answer to that question is to recall that multiple Weltanschauungen are possible, and that one person's improvement may be regarded as a disaster for someone else. Hence, our definition deliberately excludes any statement about improvement.

We have one more refinement to make. This involves the realization that most of us operate our lives with a set of assumptions that form our mindset. This causes us to carry around informal, mental models of our world. These models are modified by experience, sometimes because they fail to deliver and sometimes because they are challenged by other people. But internal and implicit mental models are not the main concern of this book – here we are concerned with models that are explicit and external. Hence, our definition becomes *a model is* ***an external and explicit representation of part of reality as seen by the people who wish to use that model*** *to understand, to change, to manage and to control that part of reality.*

Why bother with a model?

Our definition of a model, as it is to be used in Management Science, includes the idea of the user, for such models are generally built with some use in mind. But what are these uses? Much of the rest of this book will explore those uses and will show how they affect the ways in which models may be built, but it would be as well to discuss here the general reasons for building and using a model. Perhaps the clearest way to do this is to think of the alternatives. What approaches might be followed if a modelling approach is not adopted?

This discussion assumes that some critical issue is being faced that requires a decision to be taken or some control to be exercised. It does not assume that the decision will be taken immediately, nor that rational analysis is the only consideration. Similarly, it does not rule out the notion of 'decision fermentation', said to characterize some successful Japanese companies, nor the gradual process of dealing with issues (see Langley *et al.*, 1995). In such gradual processes, an issue is discussed over considerable time by many people in the organization, at different levels and with different viewpoints. Through this lengthy process, a consensus emerges that develops into a commitment to act. Thus, decisions are often not taken at a definite point in time; they emerge as different considerations and are accounted for by those participating in the process. Nevertheless, when a decision is to be taken, whether immediately or by some emergent process, there are approaches that could be followed that differ from the use of explicit models as advocated here. These options will always include the status quo; that is, we could leave things just as they are.

Do nothing!

This possibility – the favoured option of the lazy and often the only option open to the powerless – has at least the attraction that the analyst will not be blamed for what happens as a result. This is not always an option to be sneezed at, for inaction can sometimes be the best initial response when faced with uncertainty. Sometimes, an overhasty response is much worse than doing nothing. However, if we do have the discretion to act, then we need to ask how we know that inaction is an appropriate response, and the answer, surely, is that we can only know this if some analysis has been conducted. This implies that we have either internal and implicit models or external and explicit models.

Experiment with reality

Considering this option takes us right back to the building of single-arch bridges from stone. The same arguments apply here as they do for bridge-builders. Trying out possible options for real is all very well, and can be very exciting, but it can also be disastrous for the following reasons:

- *Cost.* In most situations in which we need to respond or to exercise some control, we have a range of options open to us. The range may be quite small (do we place the new factory in Wales, or should it be in France?) or it may be almost infinite (what control algorithm should be developed to ensure aircraft safety in crowded airspace?). Trying out any option in practice always incurs cost. The cost per option may be quite small, and, if the range of options is limited, this may be a very sensible way to operate. But if the cost per option is high or the range of options is almost infinite, experimentation with reality can be very expensive.
- *Time.* There is often not enough time to try out all the options in practice, even when the range is small. To be sure where to locate our factory, we may need to see how the option works out over a 10-year period if we are to get a realistic return on the investment. This would clearly be impossible. On a smaller scale, if we need to decide how best to route service vehicles around an urban area, there may be too many options to make it worthwhile even attempting to experiment in practice. Thus, the times taken to conduct the experiments mean that experimentation on reality is likely to lead to very restricted experiments.
- *Replication.* Linked to these two is the need, on occasions, for replication. Sometimes a case has to be argued for a change or for some control to be exercised. This can mean arguing the case at different levels within an organization and with different groups of people. They may wish to see the effects of the policy, and they may wish, entirely legitimately, to try out the same experiments themselves. Another reason for replication is statistical variation. For example, the demand for most products is variable and unpredictable, except in statistical terms. Any policy to be investigated may need to be examined under a wide range of demand patterns to check its sensitivity. Thus, replication may be needed, and this is both time-consuming and costly on the real system.
- *Danger.* When things go wrong, catastrophe may result. The analogy here with bridges is obvious: no one would wish a bridge to collapse, injuring hundreds of people and costing huge sums. The same is true in the realm of Management Science. The result of trying to cram more aircraft into a restricted airspace may be to increase the risk of collision to an unacceptable level. Most of us would rather that this were established by experiments on models of the airspace and the control policies rather than by the use of real aircraft. Especially when we are on those aircraft!
- *Legality.* There are times when we may need to see what effect a change in the law might have. One possibility is to break the law and then see what happens. This may be all very well if you are employed by the Mafia, but is unlikely to endear you to the rest of society. Hence, it is much better to develop a model of how things would be were the law to be different. This can be used to see the effects of various changes and allows us to see whether it might be worth pressing for a change in those laws.

Models as appropriate simplifications

The value of simplification

It is important to understand the limitations of model-building and of model-use, for a model will always be a simplification and an approximate representation of some aspect of reality. This is clearly true even of architects' and engineers' drawings of bridges: for example, they are not usually concerned to show the exact colour of the steel and concrete to be used to build the bridge. They are much more concerned with the general appearance and detailed functioning of the structure. Hence, their models are approximations, and none the worse for that.

Models do not have to be exact to be of use. As an example, consider the problem of navigating the subway systems, which are part of mass transit in many large cities around the world. The operators of these systems usually display their various routes by the use of maps displayed on the subway stations. The interesting thing about these maps is that they allow the reader to understand the possible routings by deliberately distorting reality. This is done in two ways. First, the physical layout of the subway lines is distorted on the map so as to emphasize their general directions and their interchanges. Thus, routes that may share the same tunnels in the physical world are shown as separate on the logical map. Second, careful use of colour allows the reader to identify the various lines from a key. As yet, in spite of adding coloured markers on the station walls, no subway operator has attempted to colour the steel rail track to match their maps!

Therefore, it is not a valid criticism that models are simplifications, for it is precisely such approximation that makes them useful. Hence, the important question to ask is what degree of simplification is sensible and can this be known in advance? As part of an answer to this question, consider Table 1.1, which identifies some of the important differences between a model and reality, using the term 'reality' to represent the part of the real world being modelled.

Complex reality and simple models: Occam's razor

There can be no clear answer to the question of how complicated a model needs to be – it depends, as was discussed earlier, on its intended purpose. One helpful idea is to consider Occam's razor. According to Doyle (1992), 'William of Occam, or Ockham, b. Ockham, England, c. 1285, d. c. 1349, ranks among the most important philosopher–theologians of the Middle Ages'. He is remembered especially for the principle of analysis known as Occam's razor, which he used to dissect the philosophical speculations of others. Two of the many statements of Occam's razor are as follows:

- do not multiply entities unnecessarily;
- a plurality (of reasons) should not be posited without necessity.

A contemporary interpretation of this would be that, if two explanations seem equally plausible, then it is better to use the simpler of the two. In one sense, a model will be used in an attempt

Table 1.1 Reality versus model.

Reality	Model
Complex	Simple
Subtle	Concrete
Ill-defined	Well-defined

P1: OTA/XYZ P2: ABC
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to provide an explicit explanation of something or other, and Occam's razor supports the view that simplification is not merely acceptable, it is desirable. Consider, for example, a model that includes the arrival of customers at a service point. If observation data are available, they might show that the arrival rate can adequately be modelled by a Poisson distribution (a simple way to represent random arrivals). This simple Poisson process may be perfectly adequate for deciding what resources are needed at a service point. To people trained in queuing theory and stochastic processes, the use of such a probability distribution is commonplace. However, in real life, the customers may have their own individual reasons for arriving when they do. Some may be earlier than they intended (less traffic than expected?), others may be later (the bus was late?) and others may have called on the off-chance. Thus, a complete model of the real-life system would need to account for each of these and other factors for each customer. But this detail may be quite unnecessary unless the aim of the model is to study the effect, say, of changing road traffic patterns on the operation of a service centre.

Thus, in modelling terms, the application of Occam's razor should lead us to develop models that are as simple as possible and yet are valid and useful for their intended purpose. That is, whether an element of a model is necessary (in terms of Occam's razor) will depend on its intended purpose. This, too, can be difficult, for only with perfect hindsight can we be sure that a model adequately addresses the reality being modelled. Nevertheless, it is important that management scientists do attempt to assess the degree to which their models are valid. Chapter 12 will deal with this issue in more detail.

An analogy about complexity

Another reason for simplicity in modelling comes from a common joke about complexity. To a mathematician, a complex number is the square root of a negative number; it has two parts, known as the real and imaginary parts. Complex systems also have real and imaginary parts. The problem is to differentiate between the two, which is difficult because one person's reality may be another's imagination. Models, on the other hand, are simple in the sense that they are entirely explicit and can be tested by other people. Models are imagination made explicit.

Subtle reality and concrete models

Although this book takes for granted that reality does exist in a form external to the observer, the modelling of reality is still not straightforward for the reasons identified in the analogy about complex numbers. Even if we accept (as I do) that reality is 'out there', we still have the problem that we must rely on our own perceptions in attempting to understand and to experience that reality. The adversarial principle of justice that is dominant in the UK and USA stems, at least in part, from the view that witnesses to events can produce totally or partially different accounts of events without lying. Two people might enter a street at the same time to see a youth standing over an elderly person lying on the side of the road. One witness might be sure the youth is helping up a frail person who has fallen, the other absolutely certain he is stealing the old person's handbag. In reality, the youth had knocked the woman down, but only because he dashed across the road to push her out of the way of an oncoming car.

The point of a model is to make explicit or concrete whatever aspect of reality is being investigated. In some cases, the model is being developed in order to gain some understanding about how the real world operates. In this sense, the model becomes a theory that tries to explain what has been observed to occur. One test of such a model's validity would be a Turing test of the type devised by the mathematician Alan Turing. He argued that a good test of an artificial

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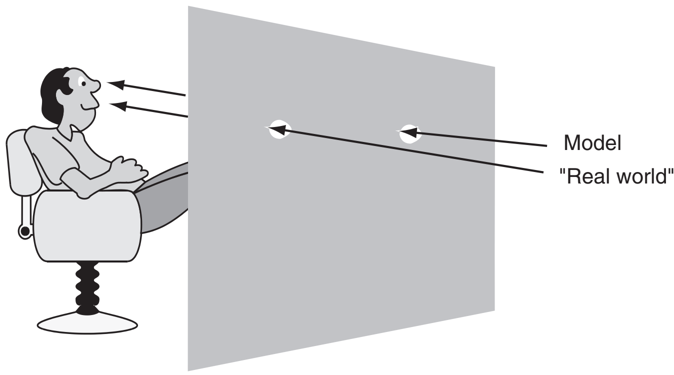

Figure 1.2 A Turing test.

system (model in our case) is to see whether a judge, knowledgeable about the aspect of the real world being modelled, can distinguish between a stream of data coming from the real world and one coming from the model. The basic idea is shown in Figure 1.2.

The problem with this kind of argument is that it assumes that the observer is both omniscient (all-knowing) and unbiased. The observer might simply be wrong in declaring the model to be acceptable or not. This may be because, when most of us talk about reality, what we actually mean is our own impressions about reality. Reality itself lies under those impressions, and the best way to understand it may be to consider carefully many such impressions. On the other hand, the model is concrete and entirely explicit. People may also, of course, misunderstand the model or its output, but its parts can be written down and may be unambiguously addressed. This is one distinct advantage that a model, albeit a simplification, has over the real world.

Ill-defined reality and well-defined model

In one familiar passage in the New Testament, the apostle Paul wrote about perfect love and ended by writing that ‘Now we see but a poor reflection in a mirror, then we shall see face to face’ (I Corinthians 13:12). Our impressions of the world are always partial, both in the sense that we do not experience everything and also in the sense that we may well be biased. Thus, our concept of what is going on in the real world will consist of ill-defined views and arguments unless they are properly codified and documented within a formal and well-defined model. In Figure 1.3, reality is shown inside an ill-defined cloud, and the model is shown as a fully defined box.

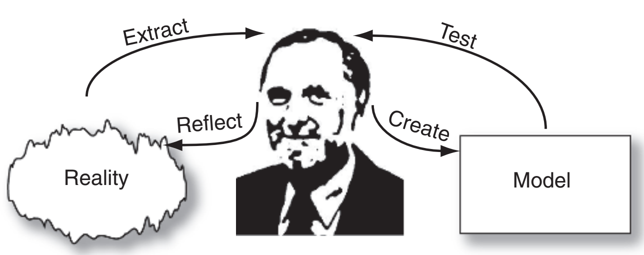

Figure 1.3 Models and reality.

The task of the modeller is to take these ill-defined and implicit views of reality and cast them in some form well enough defined to be at least understood and argued over by other people. In the case of Management Science, this model may need to be represented in some computable form to allow for rapid experiments on the model so as to make inferences about the real world. This can only be done if the model is fully specified, although the specification may only emerge while trying to translate it into a computable form. Thus, one major development in the 1980s was the idea of visual interactive modelling, in which a computer is used as a device to build a model in a stepwise manner. Thus, the analyst develops a simple model by, perhaps, developing some form of representation on a computer screen. This model is then 'run' – that is, used in some way or other – and it will, most likely, be found wanting. Its faults are considered, and these are then remedied until the model is held to be adequate, or valid, for its intended purpose. Thus, the full specification may only emerge from the modelling process.

Models for decision and control

Much of what has been said so far in this chapter could apply to any kind of model, but the main focus of this book is on models and modelling in Management Science. That is, the attempt to use explicit models to improve decision-making and control in organizations, whether they are businesses, charities, social agencies, community groups, churches or whatever. For this purpose, the book takes the view that two important aspects of management are decision-making and control. This does not mean that these are the only important aspects of management; for example, Mintzberg's early work on the realities of managerial life (Mintzberg, 1973) demonstrated that one characteristic of managerial life is a constant stream of meetings and interruptions. Time to think or to take an Olympian perspective is rare, whereas interacting with people is frequent.

Nevertheless, most organizations are made up of people working towards goals of various kinds. Those people sometimes do take decisions and also spend much of their time with other people in trying to achieve those goals. To this end, they establish policies and devise rules, which they then attempt to enforce and implement. It would be extremely foolish to argue that management is wholly about decision-making and control, but some of it is, and it is to these two aspects that a modelling approach can make a very useful contribution.

Decisions

A decision needs to be made when an individual, a group or whatever faces a choice in which there is more than a single option. The range of possible options might be small, or it might be near-infinite. An example of the former might be the decision about whether a confectionery product is priced at 40p or 50p. An example of the latter might be the exact target weight of the pack (assuming that this is not specified in weights and measures legislation). Decisions are further complicated when they turn out to be a sequence of decisions, each of which affects subsequent options. The armoury of Management Science has many weapons to use in fighting this particular modelling battle. Parts II and III of this book are devoted to descriptions of some of these weapons. Some of them are based on mathematical and logical models, others are ways of helping people to think through the consequences of situations as they interpret them. As will be made clearer in Part II, there is no need to assume that a narrow view of rationality dominates organizational decision-making; the point of a model is to explore what might happen if a particular decision were to be taken. Similarly, it is not necessary to assume that decisions happen in an instant after massive and purposeful deliberation; they can occur as streams of issues are dealt with over time (Langley *et al.*, 1995).

Control

Control is related to decision-making. Often, making the decision is the easy bit! What is much harder and takes much more time and energy is getting a decision fully implemented and then managing the continued operation of the new system. In most organizations, whatever their type, this involves a process of persuasion, consultation and argument, which can be very time-consuming. It also involves battling with the changes in the rest of the world as they occur during implementation, and ensuring that the decisions taken are still sensible in the light of those changes.

For example, analysis via a model may make it clear to a group of senior managers of a supermarket chain that it would be best to concentrate their delivery system around a small number of large depots. The problem is that they currently operate with a larger number of small depots, and the transition will take time. In addition, the staff in some of the smaller depots are likely to lose their jobs and so are unlikely to be cooperative in implementing the changes. The implementation of that decision, therefore, is likely to be a fraught process involving many meetings, some formal and some informal, some arranged ahead of time, others on the spot. People will need to be persuaded and to be enthused, and may need to be rewarded in some way for their cooperation. All of this takes time, and all is part of the day-to-day life of management.

As an analogy, consider again the task of the pilot of a long-haul aircraft. The flight may be about 14 hours non-stop, but the pilot (with computer assistance) must file a flight plan specifying the intended route and expected timings, all in advance. This is done with the aid of computer-based models of aircraft performance, computerized navigation systems and computer-based weather forecasts. This supporting technology is designed to make a difficult decision as straightforward as possible. Yet the pilot knows very well that it will be an extremely unusual flight if changes are not made to the plan en route. Winds may be unexpectedly strong, there may be air-traffic-control problems or the plane may be rerouted to avoid turbulence. This does not mean that the original plan is a waste of time; rather, it means that the plan serves as a basis for control, against which progress can be measured.

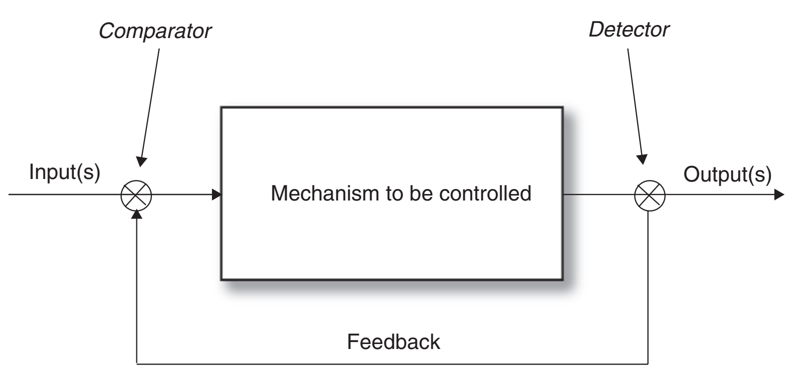

Figure 1.4 A feedback system.

Control systems are usually based on the idea of feedback, as shown in Figure 1.4. This diagram shows a mechanism controlled by the detection of its performance, which is then fed back and compared with some target level of performance. This concept, although mechanistic in appearance, may also be used at a conceptual level to think about control within organizations. Most often the feedback is negative, that is, differences between the target value and the actual value are used to guide the system towards its target. Thus, if the airline pilot realizes that the plane is ahead of schedule, then the air speed can be reduced to bring the flight back on to schedule.

Control systems depend on the availability of information about system performance which is fed back to a manager, who is able to compare it with what is wanted and change the system's performance as necessary. In doing this, organizational managers are using models (often implicit) about what is likely to happen if they take certain action. For example, they may believe that increasing the shelf space devoted to soft drinks in a supermarket may increase sales of those drinks. If increasing sales of those drinks is one of their aims, then making such a change may seem a reasonable thing to do. But a formal and explicit model of the link between sales and shelf space would be so much more useful than a set of hunches for exercising this control.

Soft and hard modelling

Few people would disagree with the notion that some kind of formal model is involved in most Management Science, but many books on Operational Research or Management Science imply that only mathematical models are of interest. One of the aims of this book is to demonstrate that successful Management Science involves the use of other types of formal model, as well as those that are mathematical in form. Mathematics and mathematical models are very useful, and Part III will explore some aspects of their construction and use. But it is important to realize that the value of models and modelling approaches extends way beyond the realm of mathematical models for decision and control. This issue will be discussed in much greater detail in Part II, but some mention needs to be made here of two other types of model that are of great value in Management Science.

Business process models

The 1990s saw an increasing interest in business processes, especially in business process re-engineering (BPR) (Hammer and Champy, 1993). To some extent, such BPR was just another fashionable term for taking a fundamental look at the way a business operates so as to exploit appropriate technologies – not a new idea. Yet there were some new emphases in BPR that are to be much welcomed. The first is the view that managers need to focus on business process as well as business structure. A process is a sequence of dynamic activities needed to get something done that will add value in the business. Thus, the concern is not so much with questions such as 'What departments and managers do we need to serve our customers?', but with ones such as 'What tasks must we do in order to serve them?'. The stress is on verbs rather than on nouns, on actions rather than on static systems, on processes rather than on structure.

These ideas are in vogue because changes in technology have made it possible to imagine ways of carrying out tasks that are radically different from the ways in which they were done in the past. For example, a national post office operates regional sorting centres in which mail is sorted for subsequent distribution. In most countries, addresses have associated postcodes or zip codes to aid this sorting and distribution. One remaining problem, however, is that many

P1: OTA/XYZ P2: ABC
c01 JWBK409-Pidd August 29, 2009 11:58 Printer Name: Yet to Come

envelopes are handwritten or poorly typed, and high-speed character recognition systems cannot be used to sort these automatically. People are employed to mark these envelopes with machine-readable codes to enable automatic sorting. The traditional approach to this task is to employ a number of these coders in each sorting office, but modern technology means that, by using video cameras and remote keyboards, these coders could be located almost anywhere in the world. Hence, shifting workloads might draw on variable pools of labour. The shifted process still involves people reading handwritten codes and marking them with machine-readable ones. This process is needed at the moment. But the changes in technology allow the process to be shifted in space (to another location) or in time (to another time zone).

Before such a process is re-engineered in this way, it makes great sense to model it in order to discover the essential and sensitive components where improvement will make a difference. As another example, insurance companies in the UK must meet certain deadlines in responding to requests and in allowing leeway on contracts for different types of insurance. When launching new products, which these companies do surprisingly often, they need to plan staffing levels and computerized support to meet these legal requirements. In order to be able to operate quickly in the marketplace, the companies need rapid ways to assess the likely support levels needed to service a product. To this end, they sometimes use computer-based simulation models as an aid to this business process engineering (not re-engineering this time) (for an example of this, see Davies, 1994).

Soft modelling in Management Science

Whereas the affinity between business process modelling and the models used in engineering may be fairly clear – indeed the term 're-engineering' in BPR gives much of the clue – other types of much less concrete modelling are also carried out under the Management Science banner. A detailed treatment of these appears in Part II, but some discussion is important here so as to set things in context. These approaches are usually known as 'soft OR/MS' [Operational (or Operations) Research/Management Science], and they have a number of features distinguishing them from decision modelling, control modelling and business process modelling. Most of them are intended to aid in strategic management and planning, a field that has a number of distinctive features.

A strategic decision is one that will have a large effect on the continued survival of the organization. Indeed, it could be argued that the development of a strategy is an attempt to take control of the future by managing or creating that future. Strategic decision-making is rightly considered to be complex, and this complexity has a number of different dimensions:

- A huge quantity of both quantitative and qualitative data and information that could be considered. This does not mean that such data are immediately to hand, but that it is easy to conceive of huge amounts of data that one or more participants might consider to be important. Usually, the available data are incomplete and may be ambiguous in their interpretation.
- Considerable confusion and lack of clarity about problem definition except at the basic level (we want to continue to exist). This stems from disagreement and uncertainty about what should constitute legitimate issues for inclusion in decision-making.
- The different participants who make up the strategic team may have conflicting objectives and may be in direct opposition to one another. Within this conflict, power relationships are important and need to be considered if any kind of negotiated consensus is to be reached.

The aim of soft OR/MS is to explore the disagreements and uncertainties that exist so that an agreed consensus and commitment to action can be reached among the senior management team. In such approaches, the modeller must act in a facilitative role and cannot take for granted that the participants share the same view about reality, and must, instead, work with the perceptions of those who are involved. The resultant models are used to show the consequences of these different perceptions and the relationships between them. This allows for exploration of areas in which consensus and commitment to action may be possible. A good introduction to these methods is given in Rosenhead and Mingers (2001).

Part II of this book is devoted to some of these 'soft' methods, which will be summarized as interpretive approaches. This is because they are attempts to enable people to understand how other people interpret their experience and what is happening. It is common for different people at the same event to interpret it in quite different ways. Take, for example, the case of a scandal within the Church of England over a radical church in the North of England whose vicar was accused of the sexual abuse of women from the congregation. There were calls for an inquiry to uncover how this could have happened and to suggest what might be done to prevent this happening again. Interviewed on TV, the bishop in whose diocese the church was located said, in all sincerity, that there would be no point in such an inquiry as everything was known already. This did not satisfy those who were calling for the inquiry. Why should this be? One possibility is that those calling for the inquiry did not believe that the bishop and his colleagues knew all there was to know about what happened. But it is more likely that the bishop and those calling for the inquiry interpreted its purpose in quite different ways. The bishop may well have been logically correct to say that the inquiry would uncover nothing new; on the other hand, setting up the inquiry would have shown that the issue was being taken seriously. The two parties interpreted their reality very differently, even without accusing one another of lying or of distortion.

In contentious areas of life and in strategic management, such differences of interpretation are not unusual. Part II shows that these interpretations can be modelled and can be used to help people find enough agreement and consensus to agree to take action. Of course, in one sense, any model can represent only a perspective on what is happening, and, as mentioned earlier, different perspectives will lead to different models. The interpretive approaches are distinctive because they are deliberately designed to work with multiple interpretations and aim to make use of these differences. By contrast, although quantitative models do embody different perspectives, they are usually not, of themselves, multifaceted. Multiple quantitative models can be used, but this is rarely a deliberate strategy. It is an essential part of interpretive approaches.

Summary: models as tools for thinking

In an increasingly complex and interconnected world, it seems vital that we find ways to explore the possible consequences of decisions and plans before taking any action. One way of doing this is to use an approach that is based on external and explicit models that capture the essence of some situation. The models are simplifications, abstractions of features deemed to be important, and there can be no guarantee that they will be valid. However, used sensibly, models and modelling approaches provide one way of managing risk and uncertainty. In this sense, models are 'tools for thinking'. Just as hand and power tools add to the physical power and aptitude of humans, so these tools for thinking may be used to add leverage to human thought and analysis. But there are some obvious dangers.

P1: OTA/XYZ P2: ABC
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The first danger is summarized in the anonymous comment that 'if the only tool you have is a hammer, then you tend to treat everything as if it were a nail'. In Birmingham, in the West Midlands of the UK (known as Brummagem to the locals, or Brummies), a common joke is that a hammer is a 'Brummagem screwdriver', the idea being that screws can always be hammered into place if you can't be bothered to do the job properly. The result is that the assembly looks OK at first, but the problems come later. In a similar way, models may be grossly misused in the name of OR/MS, and there are no substitutes for intelligence, humanity and intellectual rigour in developing appropriate models and in using them properly.

The second danger is that of 'nothing-but-ism'. As has been repeated many times in this chapter, models are simplifications, and that is part of their power and attraction. There are therefore always things missing from a model, and the analyst and those using the models need to be well aware of this. Even if the model is substantially valid for the task in hand, there may be things missing from it that mean that analysis based on it can be safely and sensibly ignored. As used in OR/MS, models show the rational and logical consequences that are known or expected to follow from certain actions. Given that reality is multifaceted, a model and its results should be as open to question as any other product of the human mind. In spite of these dangers, models within OR/MS have much to contribute to improving the worlds in which we live. The rest of this book aims to give sensible advice about how they can be built and how they might be used.

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