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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 \textit{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.

\textbf{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 $2,432,902 \times 10^{12}$. 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?

\begin{center}
\textbf{Example 1-2: Bulk beer deliveries by tankers}
\end{center}

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;
Chapter 1—Management science/operations research and systems thinking

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
alter the balance between fresh water and salt water, and affect the sound’s unique flora and fauna, which has evolved over millions of years. The big tankers would speed up the mixing of the fresh water layer on top of the salt water base, affecting the ecological balance even further. Due to the severe weather conditions in that part of the country, accidents resulting in oil spills would be difficult to prevent, even with the best of intentions, with potentially disastrous consequences. It could introduce rats, thereby endangering rare birds. It would make poaching of rare birds and lizards easier.

The New Zealand government had the final say. What should it do? Given the potential environmental impact, a decision could not be made on economic grounds alone. It required a careful balancing of important economic, political, and environmental factors. There were conflicting objectives, i.e., maximizing the economic welfare of New Zealand, versus minimizing irreversible environmental impacts to preserve a unique wilderness area for the enjoyment of future generations, as well as limiting the intrusion of commercial activities into a national park.

Problems of multiple and conflicting objectives occur frequently, particularly in the public sector. Multicriteria decision making approaches may help in dealing with such conflicts. They explore trade-offs between monetary and intangible objectives. Similarly, problem structuring methods can be used for clarifying different viewpoints and helping to find accommodations between conflicting aims.

Disease control and eradication

Towards the end of the twentieth century, national health services stepped up efforts to combat various types of cancer through early diagnosis — breast cancer, cervical cancer, bowel cancer. New vaccines for various diseases have been and are being developed, such as for the several types of hepatitis, the ever-modifying flu strains, and so on. Both these developments give rise to nationwide campaigns to reach the population affected. Some involve considerable investments in equipment, recruitment, and training of staff. Their full roll-out may take months, even years.

Example 1-4: Cancer screening policies

Breast cancer is currently the biggest single cause of mortality for women in developed countries. Recent statistics show that in the UK about 1 in 11 women will develop breast cancer during her life and of those afflicted a substantial number will die as a result of the disease.

Breast cancer incidence and aggressiveness varies with the age of the patient. It starts usually with a small growth or lump in the breast tissue. In its early stages, such a growth is usually benign. If left untreated, it will enlarge and often become malignant, invading adjacent tissue, and ultimately spread to other parts of the body — known as ‘metastasis’. The rate of progression varies from person to person and with age. The age specific incidence of breast cancer rises steadily from the mid-twenties through the reproductive years. At menopause there is a temporary drop, after which the rate climbs again.

About 95% of all potentially cancerous growths discovered at a pre-invasive stage can be cured. It is thus crucial that it can be detected as early as possible. In the 1970s, screening trials were made in Sweden, England, and the US in an effort to reduce breast cancer mortality. It is now generally accepted that mammography is the most effective method for detecting abnormal tissue growth. Research shows that for women aged 50
and over mammography can detect about 85% of all abnormal tissue growths that could develop into breast cancer within the subsequent 12 months after a screening. This is significantly higher than for other methods of screening. The percentage of potentially cancerous growths detected at an early stage drops substantially as the time interval between screenings becomes longer. Note, that there is, however, a small risk that repeated screening itself may cause a cancer to develop — another factor to be considered.

As the need for the introduction of an effective screening policy finally became recognized by both health professionals and governments, there was still some controversy as to the ‘best’ screening policy to use. A screening policy is defined by the age range of women to be screened and the frequency of screening, e.g., all women between the ages of 50 and 65 at yearly intervals.

In addition to the medical factors and partially avoidable loss of human lives involved, there were economic aspects to be considered. In 2000, the cost of a screening was between £50 and £100, while the equipment cost was in the range of £200,000 to £300,000. Each machine used full-time can perform around 6400 screenings per year. As the age range and frequency of screening is increased, the number of machines and trained personnel needed also increases. Acquiring these machines and training the personnel required thus involved an enormous capital outlay and could not be done ‘overnight’. So, the problem faced by health providers was (and still is for new programmes): what policy offers the best compromise between economic considerations and human-suffering, and what strategy should be adopted for introducing the policy chosen to the whole country, given budget considerations that affect the rate of equipment procurement and staff training. The National Health Service Screening Programme in the UK began in 1988, inviting women aged 50 to 64 for screening every three years. By 2005, the programme was extended to age 70. The mortality rate from breast cancer for women screened regularly is estimated to be about 35% lower than for those who opt out of screening.

As for the Deep Cove project, decisions by publicly funded health providers cannot be made on costs alone. Social, cultural, and equity issues have to be addressed, and inevitably there are also political considerations to take into account.

**Differing perceptions of issues and conflicting aims**

There are many decision situations where the specific events or issues that raise concerns and trigger an intervention are not well-understood. The various people involved or affected may not only have different perceptions of what the issues or concerns are in the first place, but also disagree about appropriate aims. Furthermore, the decision making powers of those involved may differ. Hidden agendas and internal politics may come into play, adding more complexity. For such situations, accommodations can only be found with the help of analytical methods or methodologies that specifically cater for these aspects. The next example, reported by M. Winter (2006) ‘Problem structuring in project management,’ *J. of the Operational Research Society*, 57(1): 802-12, demonstrates this within the context of branch retail merchandising.
1.2 Common features

What have all these problem situations in common? A number of things! First, there is somebody who is dissatisfied with the current situation or mode of operation and sees scope for doing something better or more effectively, or sees new opportunities or new options. In other words, this somebody would like to achieve one or several goals, or maintain currently threatened levels of achievement.

Second, the answer to the problem, or the solution, is not obvious. The problem situation is complex. The interested parties may disagree on what the relevant problem is. There may be conflict on objectives. They may not have enough information about the situation to know or discover all the consequences of decision choices. Elements of this are present in the Deep Cove, the breast cancer and the BSR projects.

Third, the interactions between various elements or aspects may exhibit high computational complexity that the human mind cannot evaluate in the detail desirable to make an informed decision. All, except the BSR project, have aspects of this nature.

Finally, the settings within which these problems exist are systems.

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Example 1-5: Branch specific ranging

In the mid-1990s, Tesco, the UK’s leading food retailer, explored means for tailoring the various products and services offered in its retail stores much more specifically to the local social, cultural, and economic conditions of the store location. The project team set up to look into this concept called it ‘branch specific ranging’ (BSR). It also discovered early on that BSR was not simply a matter of developing relevant data files on the local conditions in which each store operated and then using this information as a basis for product selection. It was more than just an information technology project.

In fact, the team quickly discovered serious disagreements within the organization about a number of aspects: What was the essence of BSR? What did the firm want to achieve by BSR? What were the likely problems in operating BSR? And last, but not least, if Tesco went ahead with introducing BSR nationwide, what problems might arise and how should they be managed? Should the concept first be trialed at one store to gain greater insight?

The situation the team faced exhibited all the nasty attributes that define complexity: differing views on the meaning of BSR, conflicts on its wider aims, conflict between different product branches about the nature of local conditions, disagreement on how to go about analysing the situation, and, if it ever came to it, on how to implement BSR.

Unless Tesco top management dictated a ‘solution’ to be implemented, possibly against the preferences and wishes of lower levels of management, progress could only be made by a meeting of minds, which first developed a strategy of how to go about investigating the issues associated with BSR and then applied that strategy to come to an agreement on actions which all ‘players’ involved could live by.

This is usually achieved by a lengthy process, starting out with canvassing the views of all people intimately involved in BSR, followed by one or more workshops under the guidance of a skilled facilitator. In the Tesco case, the soft systems methodology, one of the soft operations research approaches or problem structuring methods surveyed in Chapter 7, was applied to find an acceptable strategy.
What is a system?

Chapters 2 and 3 explore various system concepts in detail. So, for now, we define a system as a collection of things, physical or abstract, entities, or people that relate to each other in specific ways, i.e., that are organized and follow specific rules of interaction. Collectively, they have a given purpose, i.e., they aim to achieve or produce outcomes that none of its parts can do in isolation. However, we should also quickly add that in the real world systems do not exist or create themselves spontaneously, ready-made for us to discover. No!

- Systems are human inventions.
- We conceive or view something as a system for our own purposes.

This is an important insight to which we will return in subsequent chapters.

Systems thinking

If we are to deal effectively with the complexity of systems and decision making within systems, we need a new way of thinking. This new way of thinking has evolved since about 1940 and could be labelled ‘systems thinking’. Management science/operations research (MS/OR), systems engineering and systems analysis are strands of this mode of thinking that are particularly suitable if most of the interactions between the various parts of a system can be expressed in quantitative terms, such as mathematical expressions.

Since the early 1970s, MS/OR analysts and systems thinkers, mainly in the UK, have complemented the mathematics based MS/OR toolbox — renamed hard OR/hard systems approaches — with a number of analytic, but non-quantitative methods and methodologies that go under the label of soft OR/soft systems approaches. Some are based on formal systems ideas, whereas others use ad hoc processes that have proved successful for certain types of structures or problems, while still being rooted in systems thinking. All are decision processes which help decision makers to explore problems in much of their complexity with a view to developing an acceptable and sometimes even best compromise solution. They frequently give answers to important ‘what if’ questions, such as for example ‘How is the best solution affected by significant changes in various cost factors?’ or ‘What is the effect of uncertainty in a critical aspect?’ They provide the decision maker(s) with valuable information and insights on which to base an informed decision, rather than their being mainly guided by intuitive, emotional, or political considerations alone.

Although political considerations may be unavoidable and may, in the end, sway the decision one way or another, the use of such decision processes increases the degree of rationality in decision making, be it in the private or public sector. Note, however, that they are not intended to replace the decision maker, with whom must rest the final decision.
1.3 Overview of what follows

As we have seen, most decision making in today’s world deals with complex problem situations. They are often ill-defined, subject to conflicting forces and goals. One of the major reasons for this complexity is that these problem situations occur within a system context. The systems we are interested in are created and controlled by humans. The human element can therefore not be excluded from the decision process.

Although we, as humans, are endowed with amazing faculties of reasoning and insight, most of us are unable to cope with more than a few factors at the same time. Without computers, our computational abilities are slow and limited. We have difficulties processing and digesting large quantities of information and tracing complex interrelationships and interactions. Professor Herbert Simon, the 1978 Nobel Prize Laureate in Economics, coined in his acceptance speech the concept that human decision making is limited by bounded rationality. It is therefore all the more important that decision making is guided by systematic and comprehensive methodologies that helps us make effective use of our extensive but still limited powers of reasoning.

This text is an introduction to MS/OR methodologies. MS/OR approaches are not a panacea, capable of developing solutions or improvements for all problematic decision situations. However, they have proved successful for problem situations that involve management problems which lend themselves to rational analysis. Usually, they deal with questions of the effectiveness and/or efficiency of various activities or operations. The discussion looks at how systems thinking forms the basis for MS/OR approaches and what is good and bad practice. The methodologies are not intended to deal with dilemmas of a psychological or ethical nature.

Part I covers systems thinking and system models, regardless of which specific problem solving approach is applied. This implies an understanding of essential system concepts. Problems do not occur in a vacuum, but are embedded in problem situations — their context. In order to identify the problem correctly, we need to understand this context in much of its richness and complexity. The analyst who takes short-cuts in this crucial phase of any MS/OR project, risks solving the wrong problem.

Part II gives an overview over the two prominent strands of MS approaches: hard OR, where problems lend themselves to quantification, and soft OR, where the problem situation has high human complexity with conflicting values, and where the stakeholders involved may have different perceptions about the problem situation.

Much decision making involves costs and benefits. Which costs and benefits are relevant for a particular decision? Some costs and benefits occur over time. How should their timing be correctly included in the analysis? And many decision making problems involve not simply a single decision point, but a sequence of decisions over time, where later decisions are dependent on earlier ones. These aspects are the topics of Part III.

Finally, Part IV explores how constraints on the decision choices affect decision making, how to deal with uncertainty and incorporate it into the decision making process, and how to balance conflicting multiple objectives. Several of the best known hard OR techniques — marginal analysis, linear programming, queueing, simulation
and system dynamics, decision and risk analysis, and multicriteria decision making methods — are used to demonstrate these aspects. In order to gain greater insight for informed, rational decision making, the emphasis is not primarily on the intricacies of the mathematical models and their solution methods, but rather on conceptual aspects of the approach.

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