

Introduction

1.1 THE ORIGINS OF OPERATIONS RESEARCH

Since the advent of the industrial revolution, the world has seen a remarkable growth in the size and complexity of organizations. The artisans' small shops of an earlier era have evolved into the billion-dollar corporations of today. An integral part of this revolutionary change has been a tremendous increase in the division of labor and segmentation of management responsibilities in these organizations. The results have been spectacular. However, along with its blessings, this increasing specialization has created new problems, problems that are still occurring in many organizations. One problem is a tendency for the many components of an organization to grow into relatively autonomous empires with their own goals and value systems, thereby losing sight of how their activities and objectives mesh with those of the overall organization. What is best for one component frequently is detrimental to another, so the components may end up working at cross purposes. A related problem is that as the complexity and specialization in an organization increase, it becomes more and more difficult to allocate the available resources to the various activities in a way that is most effective for the organization as a whole. These kinds of problems and the need to find a better way to solve them provided the environment for the emergence of **operations research** (commonly referred to as **OR**).

The roots of OR can be traced back many decades,¹ when early attempts were made to use a scientific approach in the management of organizations. However, the beginning of the activity called *operations research* has generally been attributed to the military services early in World War II. Because of the war effort, there was an urgent need to allocate scarce resources to the various military operations and to the activities within each operation in an effective manner. Therefore, the British and then the U.S. military management called upon a large number of scientists to apply a scientific approach to dealing with this and other strategic and tactical problems. In effect, they were asked to do *research on* (military) *operations*. These teams of scientists were the first OR teams. By developing effective methods of using the new tool of radar, these teams were instrumental in winning the Air Battle of Britain. Through their research on how to better manage convoy and antisubmarine

¹Selected Reference 2 provides an entertaining history of operations research that traces its roots as far back as 1564 by describing a considerable number of scientific contributions from 1564 to 1935 that influenced the subsequent development of OR.

operations, they also played a major role in winning the Battle of the North Atlantic. Similar efforts assisted the Island Campaign in the Pacific.

When the war ended, the success of OR in the war effort spurred interest in applying OR outside the military as well. As the industrial boom following the war was running its course, the problems caused by the increasing complexity and specialization in organizations were again coming to the forefront. It was becoming apparent to a growing number of people, including business consultants who had served on or with the OR teams during the war, that these were basically the same problems that had been faced by the military but in a different context. By the early 1950s, these individuals had introduced the use of OR to a variety of organizations in business, industry, and government. The rapid spread of OR soon followed.

At least two other factors that played a key role in the rapid growth of OR during this period can be identified. One was the substantial progress that was made early in improving the techniques of OR. After the war, many of the scientists who had participated on OR teams or who had heard about this work were motivated to pursue research relevant to this field; important advancements in the state of the art resulted. A prime example is the *simplex method* for solving linear programming problems, developed by George Dantzig in 1947. Many of the standard tools of OR, such as linear programming, dynamic programming, queueing theory, and inventory theory, were relatively well developed before the end of the 1950s.

A second factor that gave great impetus to the growth of the field was the onslaught of the *computer revolution*. A large amount of computation is usually required to deal more effectively with the complex problems typically considered by OR. Doing this by hand would often be out of the question. Therefore, the development of electronic digital computers, with their ability to perform arithmetic calculations millions of times faster than human beings can, was a tremendous boon to OR. A further boost came in the 1980s with the development of increasingly powerful personal computers accompanied by good software packages for doing OR. This brought the use of OR within the easy reach of much larger numbers of people, and this progress further accelerated in the 1990s and into the 21st century. Today, literally millions of individuals have ready access to OR software. Consequently, a whole range of computers from mainframes to laptops now are being routinely used to solve OR problems, including some of enormous size.

1.2 THE NATURE OF OPERATIONS RESEARCH

As its name implies, operations research involves “research on operations.” Thus, operations research is applied to problems that concern how to conduct and coordinate the *operations* (i.e., the *activities*) within an organization. The nature of the organization is essentially immaterial, and, in fact, OR has been applied extensively in such diverse areas as manufacturing, transportation, construction, telecommunications, financial planning, health care, the military, and public services, to name just a few. Therefore, the breadth of application is unusually wide.

The *research* part of the name means that operations research uses an approach that resembles the way research is conducted in established scientific fields. To a considerable extent, the *scientific method* is used to investigate the problem of concern. (In fact, the term *management science* sometimes is used as a synonym for operations research.) In particular, the process begins by carefully observing and formulating the problem, including gathering all relevant data. The next step is to construct a scientific (typically mathematical) model that attempts to abstract the essence of the real problem. It is then hypothesized that this model is a sufficiently precise representation of the essential features of the situation.

that the conclusions (solutions) obtained from the model are also valid for the real problem. Next, suitable experiments are conducted to test this hypothesis, modify it as needed and eventually verify some form of the hypothesis. (This step is frequently referred to as *model validation*.) Thus, in a certain sense, operations research involves creative scientific research into the fundamental properties of operations. However, there is more to it than this. Specifically, OR is also concerned with the practical management of the organization. Therefore, to be successful, OR must also provide positive, understandable conclusions to the decision maker(s) when they are needed.

Still another characteristic of OR is its broad viewpoint. As implied in the preceding section, OR adopts an organizational point of view. Thus, it attempts to resolve the conflicts of interest among the components of the organization in a way that is best for the organization as a whole. This does not imply that the study of each problem must give explicit consideration to all aspects of the organization; rather, the objectives being sought must be consistent with those of the overall organization.

An additional characteristic is that OR frequently attempts to search for a *best* solution (referred to as an *optimal* solution) for the model that represents the problem under consideration. (We say *a* best instead of *the* best solution because there may be multiple solutions tied as best.) Rather than simply improving the status quo, the goal is to identify the best possible course of action. Although it must be interpreted carefully in terms of the practical needs of management, this "search for optimality" is an important theme in OR.

All these characteristics lead quite naturally to still another one. It is evident that no single individual should be expected to be an expert on all the many aspects of OR work on the problems typically considered; this would require a group of individuals having diverse backgrounds and skills. Therefore, when a full-fledged OR study of a new problem is undertaken, it is usually necessary to use a *team approach*. Such an OR team typically needs to include individuals who collectively are highly trained in mathematics, statistics and probability theory, economics, business administration, computer science, engineering and the physical sciences, the behavioral sciences, and the special techniques of OR. The team also needs to have the necessary experience and variety of skills to give appropriate consideration to the many ramifications of the problem throughout the organization.

1.3 THE IMPACT OF OPERATIONS RESEARCH

Operations research has had an impressive impact on improving the efficiency of numerous organizations around the world. In the process, OR has made a significant contribution to increasing the productivity of the economies of various countries. There now are a few dozen member countries in the International Federation of Operational Research Societies (IFORS), with each country having a national OR society. Both Europe and Asia have federations of OR societies to coordinate holding international conferences and publishing international journals in those continents. In addition, the Institute for Operations Research and the Management Sciences (INFORMS) is an international OR society. Among its various journals is one called *Interfaces* that regularly publishes articles describing major OR studies and the impact they had on their organizations.

To give you a better notion of the wide applicability of OR, we list some actual applications in Table 1.1. Note the diversity of organizations and applications in the first two columns. The third column identifies the section where an "application vignette" devotes several paragraphs to describing the application and also references an article that provides full details. (You can see the first of these application vignettes in this section.) The last column indicates that these applications typically resulted in annual savings in the many millions of dollars. Furthermore, additional benefits not recorded in the table

TABLE 1.1 Applications of operations research to be described in application vignettes

Organization	Area of Application	Section	Annual Savings
Federal Express	Logistical planning of shipments	1.3	Not estimated
Continental Airlines	Reassign crews to flights when schedule disruptions occur	2.2	\$40 million
Swift & Company	Improve sales and manufacturing performance	3.1	\$12 million
Memorial Sloan-Kettering Cancer Center	Design of radiation therapy	3.4	\$459 million
United Airlines	Plan employee work schedules at airports and reservations offices	3.4	\$6 million
Welch's	Optimize use and movement of raw materials	3.6	\$150,000
Samsung Electronics	Reduce manufacturing times and inventory levels	4.3	\$200 million more revenue
Pacific Lumber Company	Long-term forest ecosystem management	6.7	\$398 million NPV
Procter & Gamble	Redesign the production and distribution system	8.1	\$200 million
Canadian Pacific Railway	Plan routing of rail freight	9.3	\$100 million
United Airlines	Reassign airplanes to flights when disruptions occur	9.6	Not estimated
U.S. Military	Logistical planning of Operations Desert Storm	10.3	Not estimated
Air New Zealand	Airline crew scheduling	11.2	\$6.7 million
Taco Bell	Plan employee work schedules at restaurants	11.5	\$13 million
Waste Management	Develop a route-management system for trash collection and disposal	11.7	\$100 million
Bank Hapoalim Group	Develop a decision-support system for investment advisors	12.1	\$31 million more revenue
Sears	Vehicle routing and scheduling for home services and deliveries	13.2	\$42 million
Conoco-Phillips	Evaluate petroleum exploration projects	15.2	Not estimated
Workers' Compensation Board	Manage high-risk disability claims and rehabilitation	15.3	\$4 million
Westinghouse	Evaluate research-and-development projects	15.4	Not estimated
Merrill Lynch	Manage liquidity risk for revolving credit lines	16.2	\$4 billion more liquidity
PSA Peugeot Citroën	Guide the design process for efficient car assembly plants	16.8	\$130 million more profit
KeyCorp	Improve efficiency of bank teller service	17.6	\$20 million
General Motors	Improve efficiency of production lines	17.9	\$90 million
Deere & Company	Management of inventories throughout a supply chain	18.5	\$1 billion less inventory
Time Inc.	Management of distribution channels for magazines	18.7	\$3.5 million more profit
Bank One Corporation	Management of credit lines and interest rates for credit cards	19.2	\$75 million more profit
Merrill Lynch	Pricing analysis for providing financial services	20.2	\$50 million more revenue
AT&T	Design and operation of call centers	20.5	\$750 million more profit

(e.g., improved service to customers and better managerial control) sometimes were considered to be even more important than these financial benefits. (You will have an opportunity to investigate these less tangible benefits further in Probs. 1.3-1, 1.3-2, and 1.3-3.) A link to the articles that describe these applications in detail is included on our website, www.mhhe.com/hillier.

Although most routine OR studies provide considerably more modest benefits than the applications summarized in Table 1.1, the figures in the rightmost column of this table do accurately reflect the dramatic impact that large, well-designed OR studies occasionally can have.