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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, 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 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 run-

ning 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 the 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 most 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 thousands or even millions of times faster than a human being 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. 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.

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 find a *best* solution (referred to as an *optimal* solution) for 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 a 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 or 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.

It appears that the impact of OR will continue to grow. For example, according to the U.S. Bureau of Labor Statistics, OR currently is one of the fastest-growing career areas for U.S. college graduates.

To give you a better notion of the wide applicability of OR, we list some actual award-winning applications in Table 1.1. Note the diversity of organizations and applications in the first two columns. The curious reader can find a complete article describing each application in the January–February issue of *Interfaces* for the year cited in the third col-

TABLE 1.1 Some applications of operations research

Organization	Nature of Application	Year of Publication*	Related Chapters†	Annual Savings
The Netherlands Rijkswaterstaat	Develop national water management policy, including mix of new facilities, operating procedures, and pricing.	1985	2–8, 13, 22	$15 million
Monsanto Corp.	Optimize production operations in chemical plants to meet production targets with minimum cost.	1985	2, 12	$2 million
United Airlines	Schedule shift work at reservation offices and airports to meet customer needs with minimum cost.	1986	2–9, 12, 17, 18, 20	$6 million
Citgo Petroleum Corp.	Optimize refinery operations and the supply, distribution, and marketing of products.	1987	2–9, 20	$70 million
San Francisco Police Department	Optimally schedule and deploy police patrol officers with a computerized system.	1989	2–4, 12, 20	$11 million
Texaco, Inc.	Optimally blend available ingredients into gasoline products to meet quality and sales requirements.	1989	2, 13	$30 million
IBM	Integrate a national network of spare parts inventories to improve service support.	1990	2, 19, 22	$20 million +$250 million less inventory
Yellow Freight System, Inc.	Optimize the design of a national trucking network and the routing of shipments.	1992	2, 9, 13, 20, 22	$17.3 million
New Haven Health Department	Design an effective needle exchange program to combat the spread of HIV/AIDS.	1993	2	33% less HIV/AIDS
AT&T	Develop a PC-based system to guide business customers in designing their call centers.	1993	17, 18, 22	$750 million
Delta Airlines	Maximize the profit from assigning airplane types to over 2500 domestic flights.	1994	12	$100 million
Digital Equipment Corp.	Restructure the global supply chain of suppliers, plants, distribution centers, potential sites, and market areas.	1995	12	$800 million
China	Optimally select and schedule massive projects for meeting the country's future energy needs.	1995	12	$425 million
South African defense force	Optimally redesign the size and shape of the defense force and its weapons systems.	1997	12	$1.1 billion
Proctor and Gamble	Redesign the North American production and distribution system to reduce costs and improve speed to market.	1997	8	$200 million
Taco Bell	Optimally schedule employees to provide desired customer service at a minimum cost.	1998	12, 20, 22	$13 million
Hewlett-Packard	Redesign the sizes and locations of buffers in a printer production line to meet production goals.	1998	17, 18	$280 million more revenue

*Pertains to a January–February issue of *Interfaces* in which a complete article can be found describing the application.
†Refers to chapters in this book that describe the kinds of OR techniques used in the application.

umn of the table. The fourth column lists the chapters in *this* book that describe the kinds of OR techniques that were used in the application. (Note that many of the applications combine a variety of techniques.) The last column indicates that these applications typically resulted in annual savings in the millions (or even tens of millions) of dollars. Furthermore, additional benefits not recorded in the table (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 and 1.3-2.)

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

We will briefly describe some of these applications in the next chapter, and then we present two in greater detail as case studies in Sec. 3.5.



1.4 ALGORITHMS AND OR COURSEWARE

An important part of this book is the presentation of the major **algorithms** (systematic solution procedures) of OR for solving certain types of problems. Some of these algorithms are amazingly efficient and are routinely used on problems involving hundreds or thousands of variables. You will be introduced to how these algorithms work and what makes them so efficient. You then will use these algorithms to solve a variety of problems on a computer. The CD-ROM called **OR Courseware** that accompanies the book will be a key tool for doing all this.

One special feature in your OR Courseware is a program called **OR Tutor.** This program is intended to be your personal tutor to help you learn the algorithms. It consists of many *demonstration examples* that display and explain the algorithms in action. These "demos" supplement the examples in the book.

In addition, your OR Courseware includes many *interactive routines* for executing the algorithms interactively in a convenient spreadsheet format. The computer does all the routine calculations while you focus on learning and executing the logic of the algorithm. You should find these interactive routines a very efficient and enlightening way of doing many of your homework problems.

In practice, the algorithms normally are executed by commercial software packages. We feel that it is important to acquaint students with the nature of these packages that they will be using after graduation. Therefore, your OR Courseware includes a wealth of material to introduce you to three particularly popular software packages described below. Together, these packages will enable you to solve nearly all the OR models encountered in this book very efficiently. We have added our own *automatic routines* to the OR Courseware only in a few cases where these packages are not applicable.

A very popular approach now is to use today's premier spreadsheet package, *Microsoft Excel,* to formulate small OR models in a spreadsheet format. The **Excel Solver** then is used to solve the models. Your OR Courseware includes a separate Excel file for nearly every chapter in this book. Each time a chapter presents an example that can be solved using Excel, the complete spreadsheet formulation and solution is given in that chapter's Excel file. For many of the models in the book, an *Excel template* also is pro-

vided that already includes all the equations necessary to solve the model. Some *Excel add-ins* also are included on the CD-ROM.

After many years, **LINDO** (and its companion modeling language **LINGO**) continues to be a dominant OR software package. Student versions of LINDO and LINGO now can be downloaded free from the Web. As for Excel, each time an example can be solved with this package, all the details are given in a LINGO/LINDO file for that chapter in your OR Courseware.

CPLEX is an elite state-of-the-art software package that is widely used for solving large and challenging OR problems. When dealing with such problems, it is common to also use a *modeling system* to efficiently formulate the mathematical model and enter it into the computer. **MPL** is a user-friendly modeling system that uses CPLEX as its main solver. A student version of MPL and CPLEX is available free by downloading it from the Web. For your convenience, we also have included this student version in your OR Courseware. Once again, all the examples that can be solved with this package are detailed in MPL/CPLEX files for the corresponding chapters in your OR Courseware.

We will further describe these three software packages and how to use them later (especially near the end of Chaps. 3 and 4). Appendix 1 also provides documentation for the OR Courseware, including OR Tutor.

To alert you to relevant material in OR Courseware, the end of each chapter from Chap. 3 onward has a list entitled *Learning Aids for This Chapter in Your OR Courseware.* As explained at the beginning of the problem section for each of these chapters, symbols also are placed to the left of each problem number or part where any of this material (including demonstration examples and interactive routines) can be helpful.

PROBLEMS

1.3-1. Select one of the applications of operations research listed in Table 1.1. Read the article describing the application in the January–February issue of *Interfaces* for the year indicated in the third column. Write a two-page summary of the application and the benefits (including nonfinancial benefits) it provided.

1.3-2. Select three of the applications of operations research listed in Table 1.1. Read the articles describing the applications in the January–February issue of *Interfaces* for the years indicated in the third column. For each one, write a one-page summary of the application and the benefits (including nonfinancial benefits) it provided.