

Operations Research

EDWARD T. O'NEILL

LIKE ANY OTHER organization, a library requires competent management. As Morse¹ points out: "Whether or not it ever were so run, the modern library certainly cannot now be operated as though it were a passive repository for printed material." Libraries have become complex systems requiring sophisticated management. Operations research is an important management tool which can aid the library manager in effectively using all available resources. It is also a set of analytical tools which can enable researchers to better understand library and information service.

Early History

Prior to World War II, it was generally accepted that only the generals could contribute to an understanding of military operations. However, operations of far greater size and complexity were introduced in World War II. Interdisciplinary groups of mathematicians, statisticians, psychologists, physicists, and other scientists were formed to solve both strategic and tactical problems. These groups addressed varied topics, including the use of airpower, the estimation of convoy size and movement, and the use of radar.

After World War II, operations research was adopted by industry. A group of Air Force analysts, known as the "whiz kids," moved as a unit to the Ford Motor Company. Members of the group, which included

Edward T. O'Neill is Senior Research Scientist, Office of Research, OCLC Online Computer Library Center, Dublin, Ohio.

Robert McNamara, rose first to important positions in Ford and, later, to other powerful positions in both industry and government. The initial applications of operations research to industry were extensions of those applied to the military, and the results in the private sector were mixed. There were enough successes, however, to draw attention to the field. By the mid-1950s, operations research had received considerable publicity, and it soon became a familiar phrase in the vocabulary of management.

During the 1960s, operations research was integrated into academic work, generally as part of a program in industrial engineering or management. In many respects, operations research was similar to "scientific management," which had earlier been pioneered by Frederick Taylor, Frank and Lillian Gilbreth, and others. Since scientific management was a major component of industrial engineering programs, they were natural academic homes for operations research. Management schools also were quick to incorporate operations research into their curriculums, where it is frequently referred to today as management science.

Definition

Despite its popularity, operations research lacks a satisfactory definition. Leimkuhler² points out that most operations research practitioners prefer the simple truism, "operations research is what operations researchers do." Caywood,³ in a special volume of *Operations Research*, defined operations research as "an experimental and applied science devoted to observing, understanding, and predicting the behavior of purposeful man-machine systems; and operations-research workers are actively engaged in applying this knowledge to practical problems in business, government, and society." More recently, Gass⁴ in a feature article in the same journal defined operations research simply as "the science of decision-making."

No definition seems to describe adequately operations research. What distinguishes it from other related disciplines is not a single unique attribute, but rather the approach that operations research takes to problem solving. However, operations research cannot claim credit for the characteristic systems approach, since it was used long before anyone had ever heard of operations research. Operations research, however, combined the systems approach with solution methodologies to form a new discipline.

Operations Research

Many names are synonymous with operations research. The British prefer the term "operational research." "Management science" is a common term used to describe the study of operations research within business schools. "Systems analysis," "operations management," "quantitative methods," and "operations analysis" are also commonly used to describe operations research. "Systems analysis" is also used to describe the study of a system with the objective of computerizing the process. The two uses of the phrase create considerable confusion.

Since there is no generally accepted definition of operations research, it should not be surprising that library operations research lacks an acceptable definition. As Leimkuhler⁵ explains:

It is difficult to present a unified picture of operations research. Even in the schools where it is taught in a formal way, it is usually offered as a subordinate area of study within some better known field. In practical applications it is often included as an added dimension to a more urgent and specific objective. Thus, operations research is developing today through the collective efforts of many different special interest groups. One part of the melange is library operations research, which includes contributions coming from many different disciplines. The participants include librarians, information scientists, philosophers, mathematicians, engineers, and computer scientists, and many others.

Models

At the heart of operations research methodology is the model. A model is an abstraction, a thought framework for analysis of a system. Operations research uses mathematical models to describe, represent, and imitate aspects of a system's behavior. Mathematical models, which are highly abstract representations, often give librarians the feeling that these models are quite remote and alien. To the contrary, they are really nothing more than an advanced variation of the so-called "word problems" from high school or college algebra courses.

As an illustration of an operations research model, consider the classic newsboy problem. Assume that a newsboy who sells papers on a street corner must decide in advance the number of papers he wants for a particular day. The number of papers he can sell each day is a normally distributed random variable with a mean of ten and a standard deviation of three. Each paper costs him ten cents and sells for twenty-five cents. The newsboy must absorb as a loss any papers not sold at the end of the day. How many papers should he purchase?

To find the best or optimal solution requires a simple mathematical model. For this problem, there are only a limited number of solutions which require serious consideration. Since he normally can sell ten papers per day, it is safe to assume that he should buy at least six papers and no more than fifteen. Therefore, only ten alternative solutions need to be considered. The probability that he will sell papers on any given day is found by using tables of the normal distribution, which are included in most basic statistics books. Once the probabilities are known, the expected or average profit can be computed assuming that he buys six, seven, ..., or fifteen papers.

When the results are examined, we find that, to maximize his profit, the newsboy should purchase eleven papers, the sale of which will result in an average profit of \$1.21 per day. Purchasing any other number of papers will result in a lower profit. When he buys eleven papers, 42 percent of the time he will sell all his papers and, on the average, he will have less than two unsold papers per day.

The newsboy problem is a classic example of an operations research problem, and variations of it can be found in many texts. The objective is clear—the newsboy wants to make as much money as possible. If he buys too many papers, he will end up paying for papers he cannot sell. However, if he buys too few papers, he will restrict his sales. Although most practical operations research applications are much more complex, the solution to the newsboy problem illustrates the problem-solving approach.

An intuitive approach was adequate to solve the newsboy problem. For most complex problems, a more structured approach is usually required. Most operations researchers follow a similar approach in applying operations research. While there are many variations, the following procedure given by Churchman, Ackoff, and Arnoff,⁶ is still widely accepted:

1. Formulating the problem.
2. Constructing a mathematical model to represent the system under study.
3. Deriving a solution from the model.
4. Testing the model and the solution derived from it.
5. Establishing controls over the solution.
6. Putting the solution to work: implementation.

These steps vary in complexity from problem to problem. In some applications the formulation may be very difficult; in others, the model construction may be the most complex step.

Operations Research

Formulating the problem usually is one of the more difficult steps for library operations. This step requires that the objective be stated in measurable terms, defining the system and identifying any constraints. While operations researchers can assist, formulating the problem is primarily the responsibility of the librarian.

The construction of the mathematical model and the derivation of its solution are the areas in which the operations researcher is most competent. A large portion of operations research education is devoted to these steps. A variety of general models, such as inventory, queueing, linear programming, simulation, networking, and scheduling, have been used extensively. An extensive literature covering both theory and practice exists for these models. Unless the librarian has had some training in operations research, the model construction and solution should be performed by a competent operations research practitioner for all but the simplest models.

Testing the model and its solution require close cooperation between the librarian and the operations research practitioner. A model is never more than a representation of reality. If the model can accurately predict the behavior of the essential aspects of the system, it is a good model. Although there are a variety of technical methods for testing, the librarian's intuition can be valuable. Results which do not "feel right" should be carefully reexamined before they are accepted.

Controls over the solution need to be established. Any solution is valid only as long as there are no significant changes. When conditions change, the solution must be reevaluated. In the newsboy problem, for example, if the price of papers is changed, buying eleven papers may no longer be the best strategy.

The final step in the process is the implementation of the results. If major changes are required, this can be a difficult step, one that may be met with some resistance. It is important that everyone involved in the project—including the librarians, the operations researchers, and the library management—participate in the implementation. As Churchman, Ackoff, and Arnoff⁷ point out: "The steps enumerated are seldom if ever conducted in the order presented. Furthermore the steps may take place simultaneously. In many projects, for example, the formulation of the problem is not completed until the project itself is virtually completed. There is usually a continuous interplay between these steps during the research."

Operations research has developed its own vocabulary, which frequently becomes a communications barrier. A recent issue of *Operations Research* included articles entitled "Stackelberg-Nash-Cournot

Equilibria: Characterizations and Computations," "Implementation and Testing of a Primal-Dual Algorithm for the Assignment Problem," and "Diffusion Approximation for M/G/m Queue." Those who make it beyond the titles will need an extensive mathematical background if they are to understand the articles. The librarian who ventured into the journal literature of operations research has rarely been rewarded. A large portion of the applied operations research is published in the literature of the field to which it was applied. The monographic literature is generally easier for a typical librarian to understand and contains many texts on operations research which require little or no mathematical background. No attempt will be made to review this literature, since it is readily available from most large research libraries under the subject heading **Operations research**. The rest of this article will analyze significant developments in the application of operations research to library and information service.

Applications

Interest in the application of operations research methods to libraries started in the early 1960s. In the United States, this early work was done primarily by operations researchers with little or no previous library experience. Philip M. Morse at the Massachusetts Institute of Technology, Ferdinand F. Leimkuhler at Purdue University, and Richard W. Trueswell at the University of Massachusetts started applying operations research to libraries. Morse was one of the early leaders in operations research and the first to develop a sustained interest in libraries. He used the library as a convenient laboratory for student projects in the operations research program. Leimkuhler and Trueswell were both teaching operations research in departments of industrial engineering. Later, major operations research programs were also developed in Great Britain by B.C. Brookes at the University College and Michael K. Buckland at the University of Lancaster. The National Science Foundation supported much of the early work in the United States and was the major factor in influencing operations researchers to address the problems of libraries. By the late 1960s, the application of operations research spread to several other academic institutions.

The work done by the Leimkuhler group at Purdue was probably the most significant, both in terms of impact, size and duration. The Industrial Engineering School at Purdue had a good working relationship with the Purdue University Libraries. As J.H. Moriarty,⁸ former

Operations Research

library director, pointed out, "Industrial Engineering students have done class projects in the Libraries since 1945, usually for motion and time study, sometimes for layout."

The early efforts focused on traditional areas of library operations, particularly those that required a minimum understanding of library science. The work at Purdue began in 1962 with an internally funded operations research study of the university's libraries. Later, the work received funding from the National Science Foundation. An important feature of the Purdue work was the extensive involvement of the librarians. Leimkuhler and Baker⁹ stated that:

During the spring semester of 1963, a weekly library research seminar was initiated for the purposes of making a group study of the operations and organization of the University's libraries, identifying areas of research interest, and discussing applicable research methods and techniques. The seminars have been a unique and continuing feature of the program. Over a period of two and a half years, they have become a university-wide forum for exploring library problems and have contributed enormously to the excellent cooperation between the library staff and outside researchers.

The seminars got off to a very slow start, and it was only through the persistence of Leimkuhler and Moriarty that they eventually became productive. The early seminars could be described as meetings in which engineers talked to engineers with librarians in attendance. Eventually, as the librarians realized that the engineers were naive about library science and as the engineers learned to use English whenever possible, the communications barrier started to come down. These seminars became productive forums where ideas could be tested, discussed and evaluated.

The first major area investigated was storage models. Leimkuhler and Cox¹⁰ developed a model to minimize the amount of shelving required for a given collection. The model, which assumes that books will be shelved by size, can be used to compute the optimum spacing between shelves. While the model was a significant contribution to compact storage of library collections, it was similar to more general inventory models. Furthermore, the formulation of the model required only a limited understanding of libraries.

The focus of the research soon expanded into the more central areas of library operations with Leimkuhler's¹¹ development of the Bradford distribution. The Bradford distribution is a model of information-seeking patterns. It predicts how the demand for materials will be distributed over a library collection. When interest shifted to the Brad-

ford distribution, operations research moved into collection development, a central area of librarianship.

The activities at Purdue continued to expand in the late 1960s, eventually touching on almost all aspects of library operations. The scope of the research activity ranged from course projects to doctoral dissertations. Leimkuhler¹² identified a dozen operations research theses completed at Purdue by 1971 which related to libraries. In the early 1970s, the funding for operations research decreased, and the level of research activity began to slow.

Activities at other institutions followed the general pattern observed at Purdue. Starting in the early 1960s, there was a decade full of library activity. By the end of the period, most aspects of library operations had been investigated, at least superficially. Buckland¹³ provides an excellent review of the progress made during this period. The sheer volume of the work is impressive; Buckland and Kraft¹⁴ identified almost 800 publications relating to the application of operations research methodology to libraries.

The study of library operations research started changing in the early 1970s. By 1975, most of the research activity had shifted from operations research units to libraries or library schools. This shift was assisted by the publication of highly readable books by Buckland;¹⁵ Brophy, Buckland, and Hindle;¹⁶ and Chen.¹⁷ Courses in operations research became part of many library schools' curriculums. Bosler¹⁸ found that seventy-nine different courses in quantitative methods were being offered at sixty-seven ALA-accredited library schools. Approximately 45 percent of these courses dealt with either the techniques or the applications of operations research. To a large extent, operations research had moved to "libraryland," and, in the process, it had lost some of its distinctiveness by being closely associated with other quantitative methods.

Recalling that one popular definition of operations research is "what operations researchers do," it is easy to extend that definition to define library operations research as, "the study of libraries by practitioners of operations research." As librarians and information scientists started applying operations research methodology, it became more difficult to distinguish operations research studies from other quantitative library research.

By the mid-1970s, bibliometrics became an accepted term to describe quantitative research on libraries. Pritchard¹⁹ originally defined bibliometrics as, "the application of mathematics and statistical methods to books and other media of communication." Fairthorne²⁰

Operations Research

used bibliometrics to denote “quantitative treatment of the properties of recorded discourse and behaviour appertaining to it.” Much of the research which would have been called operations research in the 1960s was called bibliometrics by the late 1970s. Bibliometrics is not, however, just a new name for library operations research. It also encompasses a wide variety of other quantitative methods—including probability and statistics, information retrieval, citation analysis, and computing—forming a new subdiscipline that is more than just a sum of its parts. Hjerppe²¹ identified over 2000 publications relating to bibliometrics. A large number of these are applications of operations research, and many more are closely related to operations research, either by methodology or philosophy.

Impact

Over twenty years have passed since the first applications of operations research to libraries. The results are impressive in terms of both the number of studies performed and the quality of the research. Have these studies changed the way we understand libraries and the way these institutions are operated? The answer seems to be a qualified “yes.” Library operation has been affected, but not dramatically.

It is difficult to find a library that has been significantly affected by operations research. Collection management—including obsolescence, scattering and availability—has been the focus of much of the research. Yet, few libraries today have adopted the operations-research-based collection management techniques. One can find examples where operations research was successfully applied to a limited aspect of the library system. The shelving models have been successfully used, for example, to estimate shelving requirements. Estimates of shelving requirements, however, were made previously. While operations research may have improved the accuracy of the estimates, it certainly does not constitute a major change.

The most positive interpretation of the slow acceptance is that operations research has been assimilated into library science through bibliometrics. Operations research has had a major impact on library education. Bosler's²² study indicated that over half of the accredited library schools offered at least one course on operations research methods and many others included it as a major part of a more general course on qualitative methods. It appears that most library students are at least being exposed to operations research, and many are receiving a good background in operations research methodology. The full impact

of the research done in the 1960s may not be realized until students with a knowledge of operations research rise to senior library management positions and use operations research to help make decisions.

The past decade has been a period of restricted budgets for most libraries. Few libraries could afford to apply operations research. It is generally assumed that to successfully apply operations research, a library needs either to hire someone familiar with operations research or to make extensive use of consultants. In the 1970s, many libraries viewed automation as the most important new area for development and some may have viewed their automation efforts as a substitute for operations research. Leimkuhler²³ also raises the question of scale. Generally, the savings resulting from an operations research study is proportional to the size of the library, while the cost of the study varies little. This would seem to limit the libraries that potentially could benefit from undertaking operations research projects to the larger libraries or groups of libraries.

There may be an even more fundamental reason for the lack of widespread application. Operations research has developed sound methods for building, solving and testing complex models. It is an effective methodology for determining *how* to do something; however, operations research cannot determine *what* should be done. Buckland²⁴ provides the following illustration:

A library serves a variety of different groups with different values, with different behavior patterns, and expressing different needs. A chemist urgently needs to know the thermo-physical properties of a compound; a historian is enquiring after an obscure document—whose name has been forgotten and which may not, in fact, exist; a bedridden senior citizen may be lonely, bored, and wanting a novel; a disadvantaged citizen wants to know who to contact about food stamps; a student is sitting in a library carrel with a book. It may not be a library book. The student is asleep.

Buckland raises the question of how operations research can deal with these diverse demands for library service. There is no accepted means, either in library science or operations research, to determine the relative importance of these needs. Yet, Buckland continues, "library administrators are continuously making decisions based on assumptions, explicit or implicit, on precisely these matters."²⁵

There are many ways to measure the service provided by libraries. There is the quality of the service, the quantity of the service and the value of the service. There is not, however, an accepted way to estimate value. Should the value be based on how much good the service does?

Operations Research

Should it be based on the market value; that is, how much someone is willing to pay for it? Most successful applications of operations research have involved systems where there was broad acceptance of the objective of the system and suitable measures to evaluate the outcome. In business applications, the objectives are usually straightforward. Frequently, as in the newsboy problem, the objective is as simple as maximizing the profit. It should not be surprising that, if there is not agreement on the objective, there will not be agreement on the solution.

Conclusions

The application of operations research to libraries has been similar to the applications of operations research to social services. The theoretical work done in the past twenty years has been very significant and has led to a better understanding of both libraries and library users. Operations research has become an established part of library science education. And, while the impact on library operations has been significant, it has been less than most of us had hoped.

References

1. Morse, Philip M. *Library Effectiveness: A Systems Approach*. Cambridge, Mass.: MIT Press, 1968, p. 1.
2. Leimkuhler, Ferdinand F. "Operations Research: Applications to Library Management." In *Library Research Round Table: 1977 Research Forums Proceedings*, edited by Charles C. Curran, p. 114, fn. 1. Ann Arbor, Mich.: University Microfilms, 1979.
3. Caywood, T.E., ed. "Guidelines for the Practice of Operations Research." *Operations Research* 19(Sept. 1971):1138.
4. Gass, Saul I. "Decision-Aiding Models: Validation, Assessment, and Related Issues for Policy Analysis." *Operations Research* 31(July-Aug. 1983):603-31.
5. Leimkuhler, "Operations Research," p. 120.
6. Churchman, C. West, et al. *Introduction to Operations Research*. New York: Wiley, 1957, p. 13.
7. *Ibid.*, p. 15.
8. Moriarty, J. H. "Library Design and Operations Study" (proposal letter by Ferdinand F. Leimkuhler and Norman R. Baker to the National Science Foundation, 14 Dec. 1965) (unpublished).
9. Leimkuhler, Ferdinand F., and Baker, Norman R. "Library Design and Operations Study" (Proposal to the National Science Foundation, Dec. 1965, unpublished).
10. Leimkuhler, Ferdinand F., and Cox, J. Grady. "Compact Book Storage in Libraries." *Operations Research* 12(May-June 1964):419-27.
11. Leimkuhler, Ferdinand F. "The Bradford Distribution." *Journal of Documentation* 23(Sept. 1967):197-207.
12. _____. "Library Operations Research: A Process of Discovery and Justification." In *Operations Research: Implications for Libraries*, edited by Don R. Swanson and Abraham Bookstein, pp. 84-96. Chicago: University of Chicago Press, 1972.

13. Buckland, Michael K. "Ten Years' Progress in Quantitative Research on Libraries." *Socio-economic Planning Sciences* 12(no. 6, 1978):333-39.
14. Buckland, Michael K., and Kraft, Donald H. "A Bibliography on Operations Research in Libraries." In *Reader in Operations Research for Libraries*, edited by Peter Brophy, et al., pp. 355-92. Englewood, Colo.: Information Handling Services, 1976.
15. Buckland, Michael K. *Book Availability and the Library User*. New York: Pergamon Press, 1975.
16. Brophy, Peter, et al., eds. *Reader in Operations Research for Libraries*. Englewood, Colo.: Information Handling Services, 1976.
17. Chen, Ching-chih. *Applications of Operations Research Models to Libraries: A Case Study of the Use of Monographs in the Francis A. Countway Library of Medicine, Harvard University*. Cambridge, Mass.: MIT Press, 1976.
18. Bosler, Lisa. "A Study of Information Science Curricula in ALA-accredited Library Schools." Master's thesis, State University of New York at Buffalo, 1980, p. 15.
19. Pritchard, A. "Statistical Bibliography or Bibliometrics?" *Journal of Documentation* 25(Dec. 1969):349.
20. Fairthorne, Robert A. "Empirical Hyperbolic Distributions (Bradford-Zipf-Mandelbrot) for Bibliometric Description and Prediction." *Journal of Documentation* 25(Dec. 1969):319.
21. Hjerpe, Roland. *A Bibliography of Bibliometrics and Citation Indexing & Analysis*. Stockholm, Sweden: The Royal Institute of Technology Library, 1980.
22. Bosler, "A Study of Information Science Curricula."
23. Leimkuhler, "Library Operations Research," p. 91.
24. Buckland, "Ten Years Progress," p. 337.
25. *Ibid.*