Managers of libraries ranging from the Library of Congress and the Library of Medicine, both with national constituencies, through major county or municipal multibranch systems, to the village school library, perceive a need for making their available resources go further. This is also true in the private (not-for-profit) sector, which includes library collections in hospitals, universities, and research institutes.

Much was written (O’Neill and Young 1988) about this need, within the not-for-profit sector in general, during the waning years of the Reagan administration. Moreover, prognoses for the post-Reagan era indicate that the need will still be there for years to come (Salamon and Abramson 1982, Skloot 1987).

Clearly, there are now and there will always be limits to philanthropy. Yet, the demand for services that most nonprofit libraries face is forever increasing. Therefore, it behooves the managers of public and private sector library institutions to become more creative in becoming more cost effective.

Libraries as we know them today have a rich historical background. In the 1730s, Benjamin Franklin (1955) promoted the Free Library Company of Philadelphia not as a philanthropy to serve the poor but as a device for facilitating book exchanges. By “clubbing our books to a common library” (Franklin), he and his literary friends had “each of the advantages of using the books of all the other members, which would be nearly as beneficial as if each owned the whole.” Franklin’s book clubbing among friends has evolved to today’s great interlibrary loan systems.

There are approximately 31,000 institutions that qualify as a library as listed in the American Library Directory (ALD) (1991). These include public libraries with and without branches, academic, armed forces, government, and special libraries. These data do not include the numerous private sector corporate and institutional libraries, which are often networked with the others. More specifically, for the period 1989–1990 the ALD lists 9,060 public libraries, 4,593 academic (post-secondary education) libraries, 9,051 special, and 1,753 government libraries.

Because many libraries cannot break out their operating budgets from that of the larger institution they may be part of, the total library budget expenditures are, at best, estimates. Accordingly, for the 1989–1990 period, 6,389 of the 9,060 above-cited public libraries reported an acquisition budget of $854,203,736. Of the 4,593 academic libraries mentioned above, 3,156 reported an acquisition budget of $1,338,619,065 (Bowker 1991). Also, according to Bowker acquisitions account for 26% of the total budget in academic libraries. Thus, academic libraries budgets alone accounted for roughly $7.5 billion in one year. Over 50% of this figure went into personnel costs for 101,000 full-time equivalents (FTEs), including 25,000 librarians, 34,000 student assistants, and 41,000 other paid staff (Bowker). By extrapolating the

Subject classification: Libraries: survey of OR in libraries; taxonomy of library applications of OR/MS.

Area of review: SURVEY, EXPOSITORY & TUTORIAL.

Operations Research
100,000 FTE jobs in the 4,593 academic libraries to the 9,060 public, 9,051 special, and 1,753 government libraries as well as the private sector corporate and institutional libraries it can be seen that we are talking about a large economic sector indeed.

The above figures are impressive in their magnitude. However, they merely represent one year's worth of transactions. Clearly they do not begin to address the worth of knowledge, wisdom, and fact reposed, nor the impact of same on the quality of life in, and the wealth of our nation.

**DISCUSSION**

For the purposes of this paper “Operations Research in Libraries,” will be considered by first defining in operationally meaningful terms, libraries on the one hand and Operations Research on the other. According to *The American Heritage Dictionary of the English Language* (p. 753), a library is “a repository for literary and artistic materials, such as books, periodicals, newspapers, pamphlets, and prints, kept for reading or reference.” This rather classical notion of a library does not recognize the fact that libraries are now a subset of the broader field known as information systems (IS). Nevertheless, we delimit the scope of this paper to institutions which can be defined as above, albeit with some leeway.

Both the definition and realm of operations research (OR) have been amply discussed elsewhere. Churchman, Ackoff and Arnoff (1957), Ackoff (1961), and Wagner (1969) represent some of the classic texts on the subject. For the purpose of this paper we considered only those contributions to knowledge and/or practice which were published in recognized Operations Research/Management Science/Industrial Engineering journals, co-authored by known operations researchers/systems analysts such as books, periodicals, newspapers, pamphlets, and prints, kept for reading or reference.” This rather classical notion of a library does not recognize the fact that libraries are now a subset of the broader field known as information systems (IS). Nevertheless, we delimit the scope of this paper to institutions which can be defined as above, albeit with some leeway.

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Because the field of library science (LS) alone and in combination with computer science (CS) has made major contributions to information science (ISc) and hence to information systems (IS), we did not attribute any developments to OR unless they fell within our operational delineation of OR. It will be necessary for OR to have influenced developments in CS and/or IS. Unless that particular contribution can be traced directly to OR in libraries as delineated above, it was not considered to be within the scope of this paper.

Given the above boundaries/constraints for this paper, we can say the the history of operations research in libraries does not provide a very distinguished record of accomplishment. Certainly, it is not as distinguished as military applications, applications in the chemical industry, or applications in health care services. Specifically, OR had a much greater impact on many areas of human endeavor within the public sector, the private/industrial, and the for-profit as well as the not-for-profit service sectors. Contributions in the library field were constrained up to and through the decade of the 1970s by the fact that but a few operations researchers chose libraries as a field of interest. Moreover, librarians have not sought out operations researchers to help in their problem solving, nor did they offer a particularly fertile environment for doing OR studies (Chen 1974). On the other hand, since the 1970s, ISc has made significant inroads into the library field by merging with LS to create today's local and extended area computer networks linking users with comprehensive data bases.

The application of OR in libraries started in the 1960s (Leimkuhler and Cox 1964, Cox 1964, Morse 1968, Cook 1968) and peaked in the early 1970s. A comprehensive review of library operations research was done by Kantor (1979). In that review, Kantor summarized all of the previous review articles. Most noteworthy of these from the OR point of view are the bibliographies by Slamecka (1972) and Kraft and McDonald (1977), and the surveys and/or assessments by Churchman (1972), Morse (1972), Bommer (1975), Kraft and McDonald (1976), and Leimkuhler (1970, 1972, 1977a,b).

Another excellent review of OR in libraries appears in Chapter 4, “Library Models and Empirical Findings” of *Library Planning and Decision-Making Systems* by Hamburg et al. (1974). After introducing the concept of OR-type modeling and its role in both decision analysis and identifying what data need to be collected Hamburg et al. review the literature within each of the following categories:

- ** Provision of building area  
  Centralization versus decentralization  
  Branch location  

- ** Hours  

- ** Seating and space utilization  

- ** Selection of documents  
  Choice of book subject matter and year  
  Number of copies  
  Theoretical foundation of journal selection  
  Journal selection  
  Selection effort  
  Acquisition of documents
- Processing of documents
  - Processing work flow
  - Binding of serials
- Classification and cataloging of documents
  - Indexing
  - Original versus temporary cataloging
  - Dewey and Library of Congress (LC) correlation
  - Cataloging at the Library of Congress
  - Catalog use
- Control of location and use of documents
  - Selection of materials for compact storage
  - Storage of library materials
  - Load period
  - In-library use
- Security guards
  - Return of circulated library materials
- Facilitation of use of documents
  - Photo duplication
- Maintenance and weeding of documents
  - Book relabeling
  - Book weeding
  - Journal weeding
- Aids for location of documents in other libraries
- Facilitation of access to other libraries
  - Interlibrary borrowing decision rules
  - Retrieval systems
  - Networks
  - Personal assistance
- Publications, advertisements and exhibits
  - Library initiative communication
  - Planning and administration
  - Library legislation
  - Library/user/funder analysis
  - Participative decision making
  - Data processing
  - Projecting library growth
  - Overall university library resource allocation
  - Overall public library resource allocation.

Literature on the utilization of OR in libraries has classified the field in several different ways. Hamburg et al. classify the literature in the detailed fashion outlined above. Kantor (1979) classifies papers and projects into five groups according to the purpose of the research: system description; modeling the system; parameter identification; optimization or multivaluation; and application; while Rowley and Rowley (1981) classify the work by the nature of the research (e.g., recurrent problems, on/off decisions). In this paper, we use a three-dimensional classification. In one of the dimensions, we adopt Rowley and Rowley's classification with slight modifications.

Based on the type of problems being tackled, the application areas are grouped as involving operational or recurrent problems, such as book storage problems; strategies or on/off decisions, such as library location problems; and control/design problems, such as loan policy problems (Rowley and Rowley). The application of OR in libraries can also be classified according to the type of OR techniques used:

1. **Queueing models.** Given the average book circulation time (1/μ) and the mean number of persons who borrow the book (λ), the expected circulation rate of that particular book is derived using queueing theory (Morse 1968).

2. **Simulation.** With the number of staff, the volumes of various jobs (e.g., users' requests, new issues, overdue fees) and the job processing times specified, simulation is used to estimate the delays, processing times, and utilization of each member of the staff and the whole facility (Thomas and Robertson 1975).

3. **Facility location algorithms.** The library facilities and relocation problems are discussed by Min (1988).

4. **Mathematical programming.** If there are two types of information services, both of which share the same set of resources (e.g., staff time in scanning, indexing, abstracting), and each of them has a different "unit profit," a linear programming problem is used to find out how many services of each type to produce in order to maximize the total profit (Rowley and Rowley, pp. 58-64).

5. **Network flow models.** Given the heights and thicknesses of a given collection of books and the cost of different shelf heights, a network model is developed to determine the optimal number of shelf heights for minimizing shelving costs through finding the shortest path in a directed network (Gupta and Ravindram 1974).

6. **Decision theory.** A decision regarding whether or not to install a library security system is addressed given the installation cost and the probabilities of success and failure (Rowley and Rowley, pp. 91-92).

7. **Search theory.** Patterns of browsing in libraries are addressed in Morse (1970).

8. **Transportation models.** A routing problem is explored for a vehicle delivering materials to branches (Heinitz and Hsiao 1969, McClure 1977).

9. **Inventory control theory.** An EOQ model is used to determine the optimal order quantity for the stock of a certain library supply (Rowley and Rowley, pp. 111-116).

10. **Probability and statistics.** Library book circulation and individual book popularities are considered as probabilistic processes by Gelman and
### Table I

**Taxonomy of OR/MS Applications to Library Management**

<table>
<thead>
<tr>
<th>Model</th>
<th>Strategic/On-Off Decisions</th>
<th>Control/Design Problems</th>
<th>Operational/Recurrent Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queueing models</td>
<td></td>
<td></td>
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<tr>
<td>GR*</td>
<td>Bookstein 1974</td>
<td></td>
<td>Taylor 1987, 1988</td>
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<tr>
<td>LD*</td>
<td></td>
<td></td>
<td>Morse 1968, pp. 54–82</td>
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<tr>
<td>Simulation</td>
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<tr>
<td>GR</td>
<td>Cook 1968</td>
<td>Shaw 1975</td>
<td>Buckland 1972</td>
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<tr>
<td>LD</td>
<td></td>
<td>Main 1987</td>
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<td>Facility location algorithm</td>
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<td>Reed 1976</td>
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<tr>
<td>GR</td>
<td></td>
<td>Thomas &amp; Robertson 1975</td>
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<tr>
<td>LD</td>
<td>Buckland et al. 1970</td>
<td>Baumlner &amp; Baumlner 1975</td>
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<tr>
<td>Mathematical programming</td>
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<tr>
<td>GR</td>
<td></td>
<td>Leimkuhler 1968a</td>
<td>Schniederjans &amp; Santhan 1989</td>
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<td>LD</td>
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<td></td>
<td>Pitt &amp; Kraft 1974</td>
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<td>Network flow models</td>
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<td></td>
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<tr>
<td>GR</td>
<td>Nance 1970</td>
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<tr>
<td>LD</td>
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<td>Gupt &amp; Ravindram 1974</td>
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<td>Decision theory</td>
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<tr>
<td>GR</td>
<td></td>
<td>Reisman et al. 1972</td>
<td>Lister 1967</td>
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<td>LD</td>
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<td>Search theory</td>
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<td>GR</td>
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<td></td>
<td>Morse 1970</td>
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<td>LD</td>
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<td>Leimkuhler 1968b</td>
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<tr>
<td>Transportation models</td>
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<tr>
<td>GR</td>
<td>Beeler et al. 1973</td>
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<td>LD</td>
<td></td>
<td>Herling et al. 1974</td>
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<td>Inventory control theory</td>
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<td>Probability/statistics</td>
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<td>GR</td>
<td>Elston 1966</td>
<td>Morse &amp; Chen 1975</td>
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<td>Bommer 1971</td>
<td>Gelman &amp; Sichel 1987</td>
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<td></td>
<td>Morse &amp; Elston 1969</td>
<td>Morse 1968, pp. 123–151</td>
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<tr>
<td>LD</td>
<td>Buckland et al. 1970</td>
<td>Morse 1968 pp. 9–42</td>
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<td></td>
<td></td>
<td>Morse 1976–77</td>
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<tr>
<td>Benefit-cost analysis</td>
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<tr>
<td>GR</td>
<td>Williams et al. 1968</td>
<td>Leimkuhler &amp; Cooper 1971</td>
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<td></td>
<td>Palmour &amp; Wiederkehr 1970</td>
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<td></td>
<td>Reynolds et al. 1971</td>
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<tr>
<td>LD</td>
<td></td>
<td>Sinha 1971</td>
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</tbody>
</table>

*Grounded Research.

^ Logico Deductive Research.

^ This reference concisely presents a number of OR methodologies in a textbook format. It could therefore justify being placed in several rows in the above matrix.
Sichel (1987) who demonstrated the superiority of beta over negative binomial distribution.

11. **Benefit cost analysis.** Library planning is addressed by Leimkuhler and Cooper (1971).

Each of these categories, in turn, could be characterized further by whether or not the research work was *grounded*, e.g., based on "real-world" library systems involving real data and/or bonafide librarians in the study as opposed to models which were basically what might be called *logico/deductive*.

Table I provides a taxonomic summary of a representative bulk of the literature in the field. As can be seen from the above delineation and from Table I, the utilization of OR in libraries is far from achieving its full potential. This is especially true in the "grounded" studies category. Except for simulation and probability and statistics based applications, the bulk of the literature is not particularly grounded in real-life settings. The literature reflects the gap between the complex mathematical models in OR and the not very quantitatively educated library workers (Stueart and Moran 1987). Moreover, Churchman (1972) is critical of OR analysts for idealizing the existing library systems, gathering data, and building models on faulty bases. To enhance the application of OR in libraries, Bommer (1975) suggests a closer working relationship between operations researchers and library managers.

**CONCLUSION**

We are living in an information age. The classical notion of a library is very much part of it. It will serve as a worthwhile contributor to enhancing our quality of life and of knowledge for the foreseeable future. Yet, libraries compete for the dwindling resources, respectively, in the public and the private sectors. They can downsize acquisitions, reduce services provided, and/or become more cost effective. If done correctly, OR/MS can help library managers to better cope with the opposing goals of service enhancements and cost containments. There is much to be done, as indicated by the empty cells of Table I and by revisiting the categories of work that had been attempted. The payoffs to society are great. Yet, the recent record of accomplishment in this area is especially sparse. This then presents a challenge to those in the OR/MS community who are not satisfied by just creating a new or enhancing an old algorithm.

**NOTE**

1. The literature search included the use of: ABI/Inform CD ROM: (ERIC); the CWRU online library catalogue (EUCLID PLUS); Library and Information Sciences Abstract (LISA); Bowker Annual of Library and Book Trade Almanac; American Library Directory (R. R. Bowker Publishers); and searching in the relevant literature by following up on references cited (cycling).

**ACKNOWLEDGMENT**

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