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Ken Wise
University of Tennessee - Knoxville, kwise@utk.edu

D. E. Perushek
Northwestern University

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LINEAR GOAL PROGRAMMING FOR ACADEMIC LIBRARY ACQUISITIONS ALLOCATIONS

KENNETH WISE

Business Manager, University Libraries
University of Tennessee
1015 Volunteer Boulevard
Knoxville, TN 37996
Internet: kwise@utk.edu

D. E. PERUSHEK

Assistant University Librarian for Collection Management
Northwestern University
1935 Sheridan Road
Evanston, IL 60208
Internet: perushek@nwu.edu

Abstract — *The allocation of an academic library's acquisitions funds should contribute to the achievement of the library's goals and objectives. The availability of diverse materials and the varying demands of user needs in a variety of subject disciplines may represent a set of conflicting, incommensurate goals. Lexicographic linear goal programming offers an appropriate allocation methodology for determining an optimal solution with conflicting goals. This article applies this methodology to 90 funds representing books and periodicals in 45 subject disciplines at the University of Tennessee, Knoxville (UT). The model's goals incorporate several categories of budget constraints and user needs. The application of this formula resulted in the successful distribution of $3.5 million while taking into consideration ten goals or variables ranging from circulation to number of faculty and students. It also builds in accommodations for political factors and pressures, a unique feature in allocation formulas.*

Keywords — Academic libraries, Allocation formulas, Budgeting, Collection development, Fund allocation, Linear goal programming

INTRODUCTION

For the collection development officer, allocating the materials budget must be an act of balancing limited resources against seemingly limitless needs. At the same time that one must build the existing collection and address the academic programs at the home university (which often leads to allocations based on the historical precedent), one also cannot avoid nurturing new programs and format types (which may be more equitably addressed through a formula approach to allocating funds). The mere consideration of a switch from the historical precedent approach to the formula approach can be a formidable proposition.

At the University of Tennessee, Knoxville, a land grant institution with 26,000 students, over 80 graduate degree-granting programs and a library of about 2,000,000 volumes, continual requests from selectors for a more rational approach to allocations than the historical precedent approach led to a collaboration between the chief collection development officer and the library's business officer to explore the use of a formula for allocating acquisitions funds. Those librarians who wrestle with divergent demands and local political factors may suffer misgivings about the mechanistic nature and restrictions inherent in applying a formula to a materials budget of several million dollars in a setting where the library is charged with satisfying the usual academic vested interests. The use of linear goal programming can serve as a methodology for accommodating all the intricacies of materials allocations.

BACKGROUND

In recent years, the problem of allocating library funds for the purchase of books and periodicals has become increasingly more difficult due to the scarcity of funds and the need to satisfy the interests of groups competing for library resources. The needs and interests of faculty for teaching and research may conflict with those of undergraduates and graduate students as well as with the librarians' own perceptions of collection quality and adequacy. For years, librarians have realized the value of mathematical models in solving a variety of problems in acquisitions fund allocation. Some of the better known methods are outlined in Jasper G. Schad's "Allocating Book Funds: Control or Planning?," *College and Research Libraries*, 31 (1979), 155–59, John M. Budd's "Allocation Formulas in the Literature: A Review," *Library Acquisitions: Practice and Theory*, 15 (1991), 95–197, and Mary Sellen's "Book Budget Formula Allocations: A Review Essay," *Collection Management*, 9(4) (Winter 1987), 13–24. One of the more promising techniques that receives limited attention in library literature is that of linear goal programming. Defined briefly, goal programming is a technique for finding the optimal solution to a mathematical model that is composed solely of goals. Goyal [1] introduces a linear programming model for allocating library funds to different departments within a university. Funds are distributed according to the importance that society attaches to the work of the department, the importance that the university attaches to the work of the department, and the importance due to the size of the department.

In the general literature of computer applications, goal programming appears more prominently. For example, Gross and Talavage [2] develop a planning methodology that applies goal programming to the allocation of scarce resources in public and private information service operations that demonstrates multiple, conflicting objectives and a high degree of ambiguity in the definition of the organization's purpose. They introduce a modified goal programming technique referred to as "goal-range programming." Cole [3] outlines a linear programming technique applicable to several areas of library management. Her acquisitions allocation schedule incorporates goals for fiscal constraints, collection-intensity, and book-periodical ratios within fund groups. Hannan [4] develops a goal programming fund allocation model capable of solving for the optimal solution using a set of constraints that incorporates the cost of books and periodicals, and their research and teaching

worth. Beilby and Mott [5] apply lexicographic linear goal programming to a hypothetical acquisitions budget of $200,000 within a framework of multiple, conflicting collection development goals. Their model incorporates goals relating to information access, user demand, circulation and cost.

With the advent of more powerful computers and the development of specialized software over the past five years, goal programming techniques can be readily applied to larger allocation problems using a complex array of variables and constraints. Objective factors such as faculty size, student body count, degrees granted, circulation statistics, curriculum data, and book costs can be considered in conjunction with the more ambiguous variables like relative worth of academic programs, ad hoc needs, and political factors.

FORMULATION OF THE GOAL PROGRAMMING MODEL

Many of the solution techniques currently available to librarians in collection development decision-making tend to focus on the achievement of a single collection development goal at a time. In these traditional single-objective models, one function is selected as the primary objective and all the others are treated as rigid constraints. Where the objectives are multiple and incommensurable, these traditional models make no provisions for their complexity. In collection development, as in many real-world problems, the decision-making involves multiple and conflicting goals and objectives. This article proposes to use lexicographical linear goal programming to solve the problem of incommensurable collection development goals. The fundamental difference between the approach to single-objective models and lexicographic linear goal programming is that the conventional approach seeks an extreme point that maximizes a single objective, whereas goal programming seeks a region that provides a compromise to a set of conflicting goals.

Lexicographic linear goal programming techniques can be demonstrated graphically as in Figure 1 where hypothetical goals G1–G5, ranked in priority order, are represented as linear equations plotted on the graph. In many instances, fiscal goals are stated in the form of inequalities, such as "achieve a maximum," "do not exceed," "acquire at least," "maintain a level of," etc. Since the solution procedures used in solving linear goal programming models require a set of simultaneous linear equations, all goals must be converted into equations through the addition of goal deviation variables represented by the ηs and ρs on the graph. Linear goal programming seeks a solution that serves to "minimize" all unwanted deviations. Deviation variables reflect either the underachievement (denoted as η) or overachievement (denoted as ρ) for each objective statement. The solution technique involves first determining the solution space for the highest priority goals (G1 in Figure 1) while minimizing the effect of an increase in any deviation variable η or ρ as reflected by the arrows perpendicular to each goal line. After finding a solution to the highest priority goals, the process moves to the set of goals having the next highest priority and determines the "best" solution space for this set of goals, where this "best" solution cannot degrade the achievement values already obtained for higher priority goals. The process repeats these steps until it converges to a single point or all priority levels have been evaluated.

Figure 2 illustrates the solution space after the process has moved through the highest three priority goals. Where the goals are incommensurate, the space between the plotted lines normally shrinks until reaching a compromise solution space.

A commonly-used generalized model for goal programming is as follows [6]:

$$\text{minimize } Z = \sum_{i=1}^{m} w_i P_i (\eta_i + \rho_i)$$

subject to

$$\sum_{j=i}^{n} a_{ij}x_{ij} + \eta_i - \rho_i = b_i \ (i = 1,2,...,m),$$

$$x_{ij}, \eta_i, \rho_i \geq 0$$
$$(i = 1,2,...,m; j = 1,2,...,n)$$

where P_i is the priority level assigned to each relevant goal in rank order (i.e., $P_1 > P_2 > ... > P_n$), and w_i are nonnegative constants representing the relative weights assigned with a priority level to the deviational variables, η_i and ρ_i, for each j-th corresponding goal, b_i. The x_{ij} represents the decision variables for the materials funds, and a_{ij} represents the decision variable coefficients.

In this case, the decision variables represent the individual materials funds at the University of Tennessee, roughly equivalent to UT's academic departments and programs. (Funds for replacements and office copies, for which the selected variables do not exist, were excluded.) The subject funds are listed in Table 1 where

x_j = the number of book titles to be purchased in subject j,
y_j = the number of periodicals to be purchased in subject j.

The purpose of this goal programming model is to allocate a $3.5 million acquisitions budget across the 90 book and periodical funds according to a set of stated priorities. The parameters of the allocation variables and the relationships to the goal achievements are outlined in Table 2.
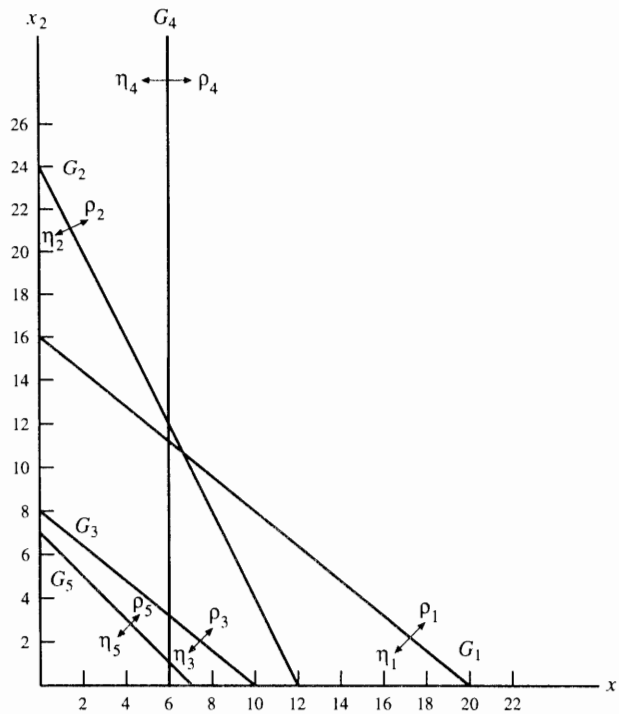
Figure 1. Graphic Representation of Hypothetical Linear Goal Programming Model.
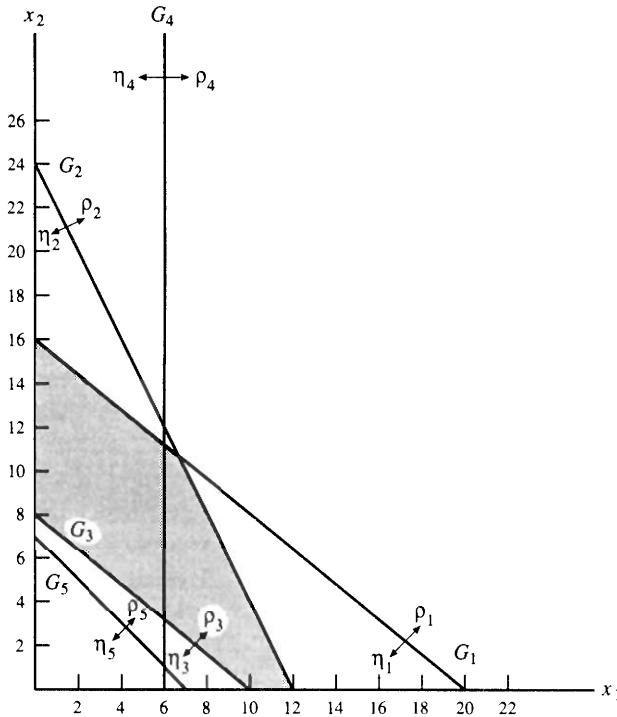
Figure 2. Solution Space After the First Three Priority Goals.

APPLICATION OF THE FORMULA

The number of collection goals and subject disciplines included in the model are typical of an academic library in a medium-sized institution like the University of Tennessee. The variables found in this study were from an original longer list of variables reduced to the ten most relevant to UT's situation. The number of subject disciplines and the mix of collection goals can be changed to accommodate the peculiarities of the individual institution.

Goal 1: Do Not Exceed the Budget Allocation of $3,500,000
In a typical academic library, acquisitions expenditures are usually limited to the amount of funds available. This goal is represented by the constraint

$$\sum_{i=1}^{45} (c_{bi}x_i + c_{pi}y_i) + \eta_1 - \rho_1 = 3,500,000. \tag{1}$$

where c_{bi} is the average cost of a book title in subject i, and c_{pi} is the average cost of a periodical title in subject i.

Goal 2: Allocate Titles According to Circulation Data
This goal is based on the assumption that past circulation use is a predictor of future demand. In a number of research articles dealing with allocation formulas, circulation takes a prominent role

TABLE 1

Subject Disciplines	Books	Periodicals
Agriculture	X_1	Y_1
Anthropology	X_2	Y_2
Architecture	X_3	Y_3
Art	X_4	Y_4
Audiology & Speech Pathology	X_5	Y_5
Biochemistry	X_6	Y_6
Biology	X_7	Y_7
Botany	X_8	Y_8
Business Administration	X_9	Y_9
Cartographic Information	X_{10}	Y_{10}
Chemistry	X_{11}	Y_{11}
Classics	X_{12}	Y_{12}
Communication	X_{13}	Y_{13}
Computer Science	X_{14}	Y_{14}
Education	X_{15}	Y_{15}
Engineering	X_{16}	Y_{16}
English	X_{17}	Y_{17}
Geography	X_{18}	Y_{18}
Geological Sciences	X_{19}	Y_{19}
Germanic & Slavic Languages	X_{20}	Y_{20}
History	X_{21}	Y_{21}
Human Ecology	X_{22}	Y_{22}
Interdisciplinary Studies	X_{23}	Y_{23}
Juvenile Literature	X_{24}	Y_{24}
Latin American Studies	X_{25}	Y_{25}
Library & Information Science	X_{26}	Y_{26}
Mathematics	X_{27}	Y_{27}
Microbiology	X_{28}	Y_{28}
Music	X_{29}	Y_{29}
Nursing	X_{30}	Y_{30}
Philosophy	X_{31}	Y_{31}
Physics & Astronomy	X_{32}	Y_{32}
Planning	X_{33}	Y_{33}
Political Science	X_{34}	Y_{34}
Psychology	X_{35}	Y_{35}
Reference	X_{36}	Y_{36}
Religious Studies	X_{37}	Y_{37}
Romance Languages	X_{38}	Y_{38}
Social Work	X_{39}	Y_{39}
Social Work/Nashville Branch	X_{40}	Y_{40}
Sociology	X_{41}	Y_{41}
Speech Communications	X_{42}	Y_{42}
Theater	X_{43}	Y_{43}
Veterinary Medicine	X_{44}	X_{44}
Zoology	X_{45}	Y_{45}

as an indicator of need and is also seen as a measure of success in accurately selecting materials needed by readers [7].

TABLE 2
Coefficients Determining Variable/Goal Relationships

Variables	Cost	Circulation	FTE	Enrollment	Courses	Lower Limit of Titles	Upper Limit of Titles	30/70 Ratio of Books/ Periodicals	Minimum Percent Level	Maximum Percent Levels
X_1	56.09	1.49	4.08	3.59	5.36	1	1	−39.26	5.28	6.46
X_2	37.45	1.01	1.09	1.72	1.33	1	1	−26.2	1.53	1.53
X_3	55.26	1.76	2.08	2.01	1.17	1	1	−38.93	2.41	2.61
X_4	43.81	2.81	2.39	1.40	3.47	1	1	−30.67	2.83	3.63
X_5	35.80	0.62	1.23	2.11	1.69	1	1	−25.06	0.46	0.55
X_6	104.50	0.57	0.78	0.70	0.56	1	1	−73.15	1.22	1.35
X_7	81.45	1.14	0.31	0.00	0.56	1	1	−57.02	0.97	1.07
X_8	81.45	0.60	1.46	0.49	0.69	1	1	−57.02	0.82	0.95
X_9	42.90	7.57	8.47	17.63	6.25	1	1	−30.03	3.79	4.42
X_{10}	29.72	0.25	0.00	0.00	0.00	1	1	−20.80	1.58	1.75
X_{11}	104.50	0.57	2.39	1.98	1.62	1	1	−73.15	1.05	1.23
X_{12}	31.39	0.62	0.47	0.11	0.48	1	1	−21.97	1.05	1.16
X_{13}	39.17	0.65	1.85	2.64	2.30	1	1	−27.42	1.81	1.99
X_{14}	49.33	2.00	1.23	1.01	1.25	1	1	−34.53	2.05	2.49
X_{15}	34.39	3.47	9.85	13.37	15.52	1	1	−24.07	2.18	2.67
X_{16}	67.55	5.25	10.23	10.61	11.77	1	1	−47.29	4.06	4.74
X_{17}	31.39	12.74	5.47	3.33	2.98	1	1	−21.97	4.15	4.37
X_{18}	54.54	0.28	0.85	0.99	0.00	1	1	−38.18	1.22	1.41
X_{19}	70.69	0.54	1.32	0.51	1.01	1	1	−49.48	2.39	2.76
X_{20}	31.39	1.83	0.85	0.47	1.34	1	1	−21.97	2.09	2.44
X_{21}	36.25	8.82	1.77	1.65	1.61	1	1	−25.38	3.08	3.57
X_{22}	30.06	2.36	3.46	2.42	4.31	1	1	−21.04	1.98	2.40
X_{23}	35.00	0.28	0.00	0.00	0.00	1	1	−24.50	1.94	2.33
X_{24}	20.07	2.14	0.00	0.00	0.00	1	1	−14.05	2.99	3.14
X_{25}	36.25	2.06	0.00	0.00	0.00	1	1	−25.38	1.02	1.07
X_{26}	49.70	0.95	0.63	0.92	0.85	1	1	−34.79	1.18	1.38
X_{27}	49.33	2.00	4.62	1.33	2.86	1	1	−34.53	1.25	1.38
X_{28}	81.45	1.28	0.92	1.00	0.82	1	1	−57.02	1.17	1.29
X_{29}	43.81	1.20	3.54	1.42	7.34	1	1	−30.67	8.01	8.61

(Continued)

TABLE 2 Continued

	Goals									
Variables	Cost	Circulation	FTE	Enrollment	Courses	Lower Limit of Titles	Upper Limit of Titles	30/70 Ratio of Books/ Periodicals	Minimum Percent Level	Maximum Percent Levels
X_{30}	44.93	5.40	2.32	3.11	1.45	1	1	−31.45	1.93	2.23
X_{31}	35.71	2.09	1.08	0.88	1.21	1	1	−25.00	0.79	0.87
X_{32}	71.74	2.05	4.16	0.79	1.85	1	1	−50.22	1.05	1.17
X_{33}	55.62	0.74	0.38	0.36	0.57	1	1	−38.93	0.85	0.93
X_{34}	39.92	2.14	1.86	2.94	1.77	1	1	−27.94	1.29	1.35
X_{35}	39.14	2.74	2.00	4.66	1.98	1	1	−27.40	2.21	2.32
X_{36}	72.70	0.00	0.00	0.00	0.00	1	1	−50.89	5.99	7.26
X_{37}	35.71	3.06	0.77	0.88	0.97	1	1	−25.00	1.54	1.86
X_{38}	31.39	2.55	2.93	1.04	2.39	1	1	−21.97	1.46	1.76
X_{39}	36.31	2.19	1.85	3.22	1.61	1	1	−25.42	2.36	2.61
X_{40}	36.31	0.90	1.00	1.58	1.29	1	1	−25.42	0.64	0.74
X_{41}	36.31	4.71	1.23	1.92	1.53	1	1	−25.42	1.55	1.80
X_{42}	43.81	1.31	0.93	0.56	1.49	1	1	−30.68	0.58	0.58
X_{43}	43.81	1.53	1.00	0.44	1.49	1	1	−30.68	0.56	0.67
X_{44}	82.17	0.67	5.23	2.92	1.69	1	1	−57.52	4.35	5.32
X_{45}	79.91	1.06	1.92	1.29	1.57	1	1	−55.94	1.60	1.85
Y_1	42.36	1.76	4.08	3.59	5.36	1	1	12.71	7.27	8.89
Y_2	88.69	1.46	1.09	1.72	1.33	1	1	26.61	1.31	1.37
Y_3	48.22	1.88	2.08	2.01	1.17	1	1	14.47	0.53	0.58
Y_4	38.61	1.17	2.39	1.40	3.47	1	1	11.58	0.94	1.09
Y_5	35.22	0.24	1.23	2.11	1.69	1	1	10.57	0.40	0.48
Y_6	472.84	0.97	0.78	0.70	0.56	1	1	141.85	1.07	1.18
Y_7	209.55	2.59	0.31	0.00	0.56	1	1	62.87	2.42	2.68
Y_8	209.55	0.79	1.46	0.49	0.69	1	1	62.87	1.09	1.27
Y_9	70.87	6.97	8.47	17.63	6.25	1	1	21.27	7.52	8.77
Y_{10}	0.00	0.00	0.00	0.00	0.00	1	1	0.00	0.00	0.00
Y_{11}	472.84	0.97	2.39	1.98	1.62	1	1	141.85	2.73	3.19

Y_{12}	32.99	0.12	0.47	0.11	0.48	1	1	9.90	0.52	0.57
Y_{13}	62.81	0.19	1.85	2.64	2.30	1	1	18.84	0.65	0.75
Y_{14}	209.55	0.83	1.23	1.01	1.25	1	1	62.87	1.13	1.31
Y_{15}	62.43	3.20	9.85	13.37	15.52	1	1	18.73	4.18	5.11
Y_{16}	160.13	3.27	10.23	10.61	11.77	1	1	48.04	8.15	9.51
Y_{17}	32.99	4.59	5.47	3.33	2.98	1	1	9.90	3.79	4.21
Y_{18}	77.65	0.34	0.85	0.99	0.00	1	1	23.30	1.23	1.42
Y_{19}	170.88	0.86	1.32	0.51	1.01	1	1	51.26	2.71	3.14
Y_{20}	32.99	0.98	0.85	0.47	1.34	1	1	9.90	2.10	2.45
Y_{21}	38.55	3.20	1.77	1.65	1.61	1	1	11.57	3.06	3.54
Y_{22}	74.11	1.97	3.46	2.42	4.31	1	1	22.23	1.59	1.92
Y_{23}	38.55	0.07	0.00	0.00	0.001	1	1	11.57	2.48	2.98
Y_{24}	22.00	0.12	0.00	0.00	0.00	1	1	6.60	0.22	0.24
Y_{25}	38.55	1.45	0.00	0.00	0.00	1	1	11.57	0.00	0.00
Y_{26}	62.73	1.17	0.63	0.92	0.85	1	1	18.82	2.35	2.75
Y_{27}	209.55	0.84	4.62	1.33	2.86	1	1	62.87	2.58	2.85
Y_{28}	209.55	2.39	0.92	1.00	0.82	1	1	62.87	0.96	1.06
Y_{29}	38.61	0.16	3.54	1.42	7.34	1	1	11.58	1.79	1.88
Y_{30}	33.33	5.95	2.32	3.11	1.45	1	1	10.00	3.42	3.97
Y_{31}	32.91	0.57	1.08	0.88	1.21	1	1	9.97	1.05	1.16
Y_{32}	209.55	4.44	4.16	0.79	1.85	1	1	62.87	2.37	2.62
Y_{33}	36.14	0.24	0.38	0.36	0.57	1	1	10.84	0.45	0.50
Y_{34}	52.81	1.29	1.86	2.94	1.77	1	1	15.84	1.95	2.04
Y_{35}	135.40	2.58	2.00	4.66	1.98	1	1	40.62	2.70	2.83
Y_{36}	0.00	0.00	0.00	0.00	0.00	1	1	0.00	4.25	5.15
Y_{37}	32.91	26.33	0.77	0.88	0.97	1	1	9.87	1.51	1.83
Y_{38}	32.99	1.58	2.93	1.04	2.39	1	1	9.90	1.67	2.02
Y_{39}	88.69	1.31	1.85	3.22	1.61	1	1	26.61	1.59	1.76
Y_{40}	88.69	0.37	1.00	1.58	1.29	1	1	26.61	0.84	0.98
Y_{41}	88.69	3.88	1.23	1.92	1.53	1	1	26.61	1.24	1.44
Y_{42}	38.61	1.69	0.93	0.56	1.49	1	1	11.58	0.26	0.26
Y_{43}	38.61	1.52	1.00	0.44	1.49	1	1	11.58	0.45	0.54
Y_{44}	164.03	2.14	5.23	2.92	1.69	1	1	49.21	3.64	4.45
Y_{45}	172.56	1.54	1.92	1.29	1.57	1	1	51.77	1.08	1.25

$$x_1 - circ_1 \sum_{i=1}^{45} x_i + \eta_2 - \rho_2 = 0 \tag{2}$$

$$x_2 - circ_2 \sum_{i=1}^{45} x_i + \eta_3 - \rho_3 = 0 \tag{3}$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

$$x_{44} - circ_{44} \sum_{i=1}^{45} x_i + \eta_{45} - \rho_{45} = 0 \tag{45}$$

$$x_{45} - circ_{45} \sum_{i=1}^{45} x_i + \eta_{46} - \rho_{46} = 0 \tag{46}$$

$$y_1 - circ_1 \sum_{i=1}^{45} y_i + \eta_{47} - \rho_{47} = 0 \tag{47}$$

$$y_2 - circ_2 \sum_{i=1}^{45} y_i + \eta_{48} - \rho_{48} = 0 \tag{48}$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

$$y_{44} - circ_{44} \sum_{i=1}^{45} y_i + \eta_{90} - \rho_{90} = 0 \tag{90}$$

$$y_{45} - circ_{45} \sum_{i=1}^{45} y_i + \eta_{91} - \rho_{91} = 0 \tag{91}$$

where $circ_i$ = the percentage of total circulation for subject i.

Goal 3: Allocate Titles According to the Size of the Faculty Within A Subject Area

This factor indicates both desired breadth and depth in the collection. It is assumed that faculty teach courses that generate widespread student use of the collection and also conduct research that plumbs the depths of specialized primary resources in the collection [8]. (Formula statements for goals number 3, 4, 5, 9, and 10 follow the same sequence as goal number 2. For the sake of brevity, only the first and last equations are shown.)

$$x_1 - fte_1 \sum_{i=1}^{45} x_i + \eta_{92} - \rho_{92} = 0 \tag{92}$$

•
•
•

$$y_{45} - fte_{45} \sum_{i=1}^{45} y_i + \eta_{181} - \rho_{181} = 0 \qquad (181)$$

where fte_i = the percentage of teaching and research faculty associated with subject i.

Goal 4: Allocate Titles According to Enrollment Data As a Proportion of the Number of Upper Division and Graduate Credit Hours Supported by a Subject Area
    Generally lower level and survey courses do not require much use of the library collection; however, upper-level undergraduate courses, which often require papers and research, and graduate courses put certain demands on the collection that militate for special consideration when allocating the budget [9].

$$x_1 - hour_1 \sum_{i=1}^{45} x_i + \eta_{182} - \rho_{182} = 0 \qquad (182)$$

•
•
•

$$y_{45} - hour_{45} \sum_{i=1}^{45} y_i + \eta_{271} - \rho_{271} = 0 \qquad (271)$$

where $hour_i$ = the percentage of total upper division undergraduate and graduate student credit hours associated with subject i.

Goal 5: Allocate Titles According to Courses Taught
    This goal takes into account such phenomena as lower division classes with heavy enrollments that may assign concentrated work in a few titles from the collection. "Courses" in this context include all sections taught in a certain class [10].

$$x_1 - cor_1 \sum_{i=1}^{45} x_i + \eta_{272} - \rho_{272} = 0 \qquad (272)$$

•
•
•

$$y_{45} - cor_{45} \sum_{i=1}^{45} y_i + \eta_{361} - \rho_{361} = 0 \qquad (361)$$

where cor_i = the percentage of total unique courses associated with subject i.

Goal 6: Acquire at Least 25,000 Titles

This goal insures a minimum growth in the collection of 1.25%. This number and that in Goal 7 are based on growth patterns found in the annual *ARL Statistics.*

$$\sum_{i=1}^{45} (x_i + y_i) + \eta_{362} - \rho_{362} = 25,000 \tag{362}$$

Goal 7: Acquire No More than 40,000 Titles

This goal limits the growth in the collection to 2.0% to reflect staff levels and building capacities.

$$\sum_{i=1}^{45} (x_i + y_i) + \eta_{363} - \rho_{363} = 40,000 \tag{363}$$

Goal 8: Periodical Subscriptions Represent a Continuing Financial Commitment for the Library

Since this condition is exacerbated by the escalating cost of journals, many libraries attempt to limit the percentage of the allocation dedicated to periodicals. In this model periodical expenditures are limited to 70% of the total acquisitions expenditures. (This is not representative of UT's current proportion of periodicals to monographs.)

$$\sum_{i=1}^{45} c_{pi}y_i - 0.7 \sum_{i=1}^{45} (c_{bi}x_i + c_{pi}y_i) + \eta_{364} - \rho_{364} = 0 \tag{364}$$

Goal 9: Establish Minimum Limits for Each Subject Fund

This goal insures that each fund receives a minimum proportion of the titles based on the professional judgement of the collection development officer and the political pressure brought to bear by faculty or administration.

$$x_1 - low_{b1} \sum_{i=1}^{45}(x_i + y_i) + \eta_{365} - \rho_{365} = 0 \tag{365}$$

$$\bullet$$
$$\bullet$$
$$\bullet$$

$$y_{45} - low_{p45} \sum_{i=1}^{45}(x_i + y_i) + \eta_{454} - \rho_{454} = 0 \tag{454}$$

where low_{bi} = the minimum acceptable percentage of monograph titles to be acquired in subject i, and low_{pi} = the minimum acceptable percentage of periodical titles to be acquired in subject i.

Goal 10: Establish Maximum Limits for Each Subject Fund

This goal assures that each fund receives no more than its fair share of the budget, as expressed in titles, based on the professional judgment of the collection development officer. It reinforces and complements the flexibility introduced in Goal 9 to strengthen funds for expanding subject areas and departments or controlling expenses for waning ones.

$$x_1 - up_{b1} \sum_{i=1}^{45}(x_i + y_i) + \eta_{455} - \rho_{455} = 0 \tag{455}$$

$$\vdots \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \vdots$$

$$y_{45} - up_{p45} \sum_{i=1}^{45}(x_i + y_i) + \eta_{544} - \rho_{544} = 0 \tag{544}$$

where up_{bi} = the maximum acceptable percentage of titles to be allocated to books in subject i, and up_{pi} the maximum acceptable percentage of titles to be allocated to periodicals in subject i.

SUMMARY OF PRIORITIES AND SOLUTION

Lexicographic goal programming models allow preemptive priorities to be assigned to the goals. The model is solved according to a specific achievement function to minimize the underachievement of the lower limit goals and the overachievement of the upper limit goals. The following schedule summarizes the seven levels of priority assigned in rank order: $P_1 > P_2 > P_3 > P_4 > P_5 > P_6 > P_7$.

P_1 Limit acquisitions expenditures to $3.5 million.
P_2 Acquire at least 25,000 titles and no more than 40,000.
P_3 Maintain a 70%–30% ratio between periodicals and books.
P_4 Acquire titles by subject within the minimum and maximum limits established.
P_5 Allocate titles by subject according to circulation data.
P_6 Allocate titles by subject according to number of teaching and research faculty.
P_7 Allocate titles by subject according to course hours and courses taught.

The optimal solution is determined by finding x and y so as to minimize lexicographically the achievement function

$$w = [(\eta_1), (\eta_{362} + \rho_{363}), (\rho_{364}), (\eta_{365} + \eta_{366} + \dots + \eta_{453} + \eta_{454} + \rho_{455} + \rho_{456} + \dots + \rho_{543} + \rho_{544}), \\ (\eta_2 + \eta_3 + \dots + \eta_{90} + \eta_{91}), (\eta_{92} + \eta_{93} + \dots + \eta_{180} + \eta_{181}), (\eta_{182} + \eta_{183} + \dots + \eta_{360} + \eta_{361})]$$

such that all of the objective statements (1) through (544) are satisfied for x, y, η, $\rho \geq 0$. Each element η or ρ in the achievement function corresponds to an unwanted goal deviation, which the goal programming procedures attempt to minimize.

RESULTS

The model was solved using the linear programming procedures of the SAS/OR goal programming code. The model required a large matrix, and thus the goal and constraint statements were configured on a VAX mainframe with the matrix subsequently loaded into the SAS/OR software. The program allocated the titles to meet the defined collection development goals as outlined in Table 2, in accordance with the stated priorities. The results of the allocation are outlined in Table 3 (and are graphically represented in Figure 3). All of the priorities P_1 through P_4 were fully achieved. The degree of achievement of the remaining priorities was:

P_5: The proportion of titles allocated was less than the proportion of circulations for twenty-one book and fifteen periodical subject categories. The proportional allocation was higher for the remaining categories.

TABLE 3
ALLOCATION RESULTS

Funds	Number Book* Titles	Percent Book Titles	Budget Allocation Books ($)	Number Periodical Titles	Percent Periodical Titles	Budget Allocation Periodicals ($)	Percent of Total Budget Allocation
	Books			Periodicals			Total Budget
Agriculture	1,322	6.46%	$74,151	1,420	7.27%	$60,151	3.84%
Anthropology	313	1.53	11,722	256	1.31	22,705	0.98
Architecture	532	2.60	29,590	104	0.53	5,015	0.99
Art	579	2.83	25,366	184	0.94	7,104	0.93
Audiology & Speech Pathology	94	0.46	3,365	78	0.40	2,747	0.17
Biochemistry	276	1.35	28,842	231	1.18	109,226	3.94
Biology	219	1.07	17,838	524	2.68	109,804	3.65
Botany	194	0.95	15,801	248	1.27	51,968	1.94
Business Administration	776	3.79	33,290	1,469	7.52	104,108	3.93
Cartographic Information	323	1.58	9,600	0	0.00	0	0.27
Chemistry	252	1.23	26,334	1,460	7.47	690,346	20.48
Classics	215	1.05	6,749	102	0.52	3,365	0.29
Communication	370	1.81	14,493	127	0.65	7,977	0.64
Computer Science	419	2.05	20,669	256	1.31	53,645	2.12
Education	446	2.18	15,338	817	4.18	51,005	1.90
Engineering	970	4.74	65,524	1,592	8.15	254,927	9.16
English	849	4.15	26,650	740	3.79	24,413	1.46
Geography	250	1.22	13,635	240	1.23	18,636	0.92
Geological Sciences	565	2.76	39,940	529	2.71	90,396	3.72
Germanic & Slavic Languages	428	2.09	13,435	410	2.10	13,526	0.77
History	630	3.08	22,838	598	3.06	23,053	1.31
Human Ecology	405	1.98	12,174	311	1.59	23,048	1.01
Interdisciplinary Studies	397	1.94	13,895	484	2.48	18,658	0.93
Juvenile Literature	612	2.99	12,283	43	0.22	946	0.38
Latin American Studies	209	1.02	7,576	0	0.00	0	0.22
Library & Information Science	241	1.18	11,978	459	2.35	28,793	1.16
Mathematics	256	1.25	12,628	557	2.85	116,719	3.70
Microbiology	264	1.29	21,503	207	1.06	43,377	1.85
Music	1,639	8.01	71,805	350	1.79	13,514	2.44
Nursing	395	1.93	17,747	668	3.42	22,264	1.14
Philosophy	162	0.79	5,785	205	1.05	6,747	0.36
Physics & Astronomy	239	1.17	17,146	644	3.30	134,950	4.35
Planning	174	0.85	9,678	88	0.45	3,180	0.37
Political Science	264	1.29	10,539	381	1.95	20,121	0.88
Psychology	452	2.21	17,691	527	2.70	71,356	2.54
Reference	1,486	7.26	108,032	830	4.25	0**	3.09
Religious Studies	315	1.54	11,249	295	1.51	9,708	0.60
Romance Languages	299	1.46	9,386	326	1.67	10,755	0.58
Social Work	483	2.36	17,538	311	1.59	27,583	1.29
Social Work/Nashville Branch	131	0.64	4,757	164	0.84	14,545	0.55
Sociology	317	1.55	11,510	242	1.24	21,463	0.94
Speech Communications	119	0.58	5,213	49	0.25	1,892	0.20
Theatre	115	0.56	5,038	88	0.45	3,398	0.24
Veterinary Medicine	1,089	5.32	89,483	711	3.64	116,625	5.89
Zoology	379	1.85	30,286	211	1.08	36,410	1.91

* Includes audio and visual materials as well as monographs in all formats
** Due to the unique nature of reference materials, only one fund exists including the allocation for both monographs and periodicals.
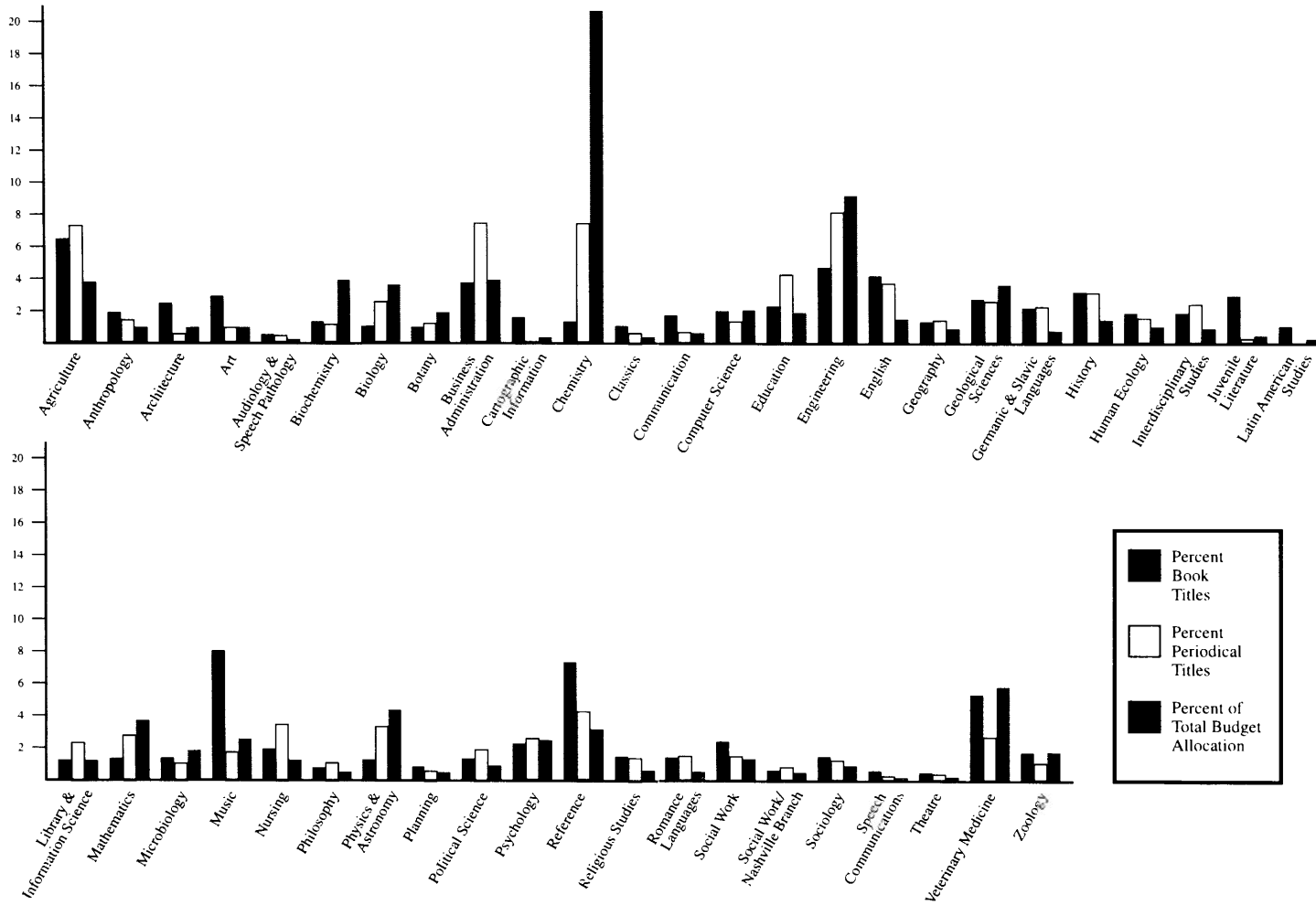
Figure 3. Results of Applying Linear Goal Program to $3.5 Million Budget.

P_6: The proportion of titles allocated was less than the proportion of teaching and research faculty for nineteen book and twenty-one periodical subject categories. The proportional allocation was higher for the remaining categories.

P_7: The proportion of titles allocated was less than the proportion of course hours for sixteen book and fifteen periodical subject categories and less than the proportion of the number of courses taught for sixteen book and nineteen periodical subject categories. The proportional allocations were higher for the remaining categories.

The variable coefficients, achievement goals, and priority structure of the goal programming model can be adjusted to observe differences under varying circumstances. If, for example, a budget reduction were anticipated, the matrix could be solved assuming a lesser budget achievement goal. Similarly, the priority structure could be rearranged to reflect a different set of management priorities.

Although linear goal programming solves for the optimal solution, in some instances the result may not be acceptable. A solution providing a zero allocation to a particular subject category would likely be unsatisfactory and would necessitate appropriate changes in the model.

CONCLUSION

The stringency of funding for higher education and the escalating cost of library materials demand that collection development officers satisfy the goals and priorities of a variety of constituents. The traditional approach to fund allocation of historical precedent may fail to establish a relation between the collection development goals and allocations. The drawback of goal programming in an academic library setting is its ability to deal with a certain number of goals while a collection development officer may desire to accommodate many more. The program also cannot expeditiously accommodate minor alterations. However, linear goal programming has the capability to address with objectivity and considerable breadth the multiple, conflicting, and incommensurable goals inherent in academic collection development.

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8. See note 1 above. This article addresses faculty size and enrollment as factors in applying the Simplex Method to fund allocation.

9. Student FTE data are the main variable applied in David C. Genaway's "The Q Formula: The Flexible Formula for Library Acquisitions in Relation to the FTE Driven Formula," *Library Acquisitions: Practice & Theory*, 10 (1986), 293–306. Charles B. Lowry's "Reconciling Pragmatism, Equity and Need in the Formula Allocation of Book and Serial Funds," *College & Research Libraries*, 53 (March 1992), 121–37, explains in-depth considerations for using credit hours to indicate library needs.

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