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ABSTRACT

The rapid rate of technological development and the growing complexity of our society in recent years have renewed the awareness of the importance of higher education. The rapid expansion of the size of higher educational institutions as well as the increased demand for instructional quality emphasize the need for systematic and efficient resource allocation procedures on the part of university administrators. This study presents a goal programing model for an optimum allocation of resources -- given certain priorities and constraints -- in a college of an institution of higher learning. (Author/RA)

A GOAL PROGRAMMING MODEL FOR ACADEMIC PLANNING

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A GOAL PROGRAMMING MODEL FOR ACADEMIC PLANNING

The rapid rate of technological development and the growing complexity of the society has brought about the renewed awareness of the importance of higher education. Never in the history of our country, has society directed such attention toward the broad area of higher education. The rapid expansion of higher educational institutions, both in size and quality, has necessitated an astounding increase of expenditures for higher education.[1] The rising expenditure, accompanied with recent unrest in campuses, has caused lawmakers and the public to develop a keener and more critical view of the operational efficiency of educational institutions.

One of the most prominent aspects of higher education that has come under the scrutiny of the "no longer apathetic" public is that of the increasing costs required to provide adequate advanced education. Institutions can no longer request prodigious sums of money from the legislature and the public without clear justification in terms of viable goals, alternatives, and expected results.

Although decision sciences and mathematical models are developed and taught within the confines of academies, the application of the techniques for their own operation has been generally neglected.[2] Perhaps in the past, academic planning was of no significant importance; this is of course no longer the case.

It is the purpose of this paper to present a goal programming model for an optimum allocation of resources in institutions of

higher learning.[3] It is possible to formulate a complex, multi-time period model that serves the purpose of long-range planning for the entire university. The scope of this study is limited, however, to the planning of one college within the university. In addition, the planning horizon under consideration is limited to one year. It is felt that this limited scope will allow a clearer presentation of the development and application of the model. Once it is completed for a year, the basic model can be extended for a longer planning horizon by forecasting parameter changes. When models for each college have been established, the aggregative university model can be derived by combining there models.

The General Model

Variables

x_1 = number of graduate research assistants

x_2 = number of graduate teaching assistants

x_3 = number of instructors

x_4 = number of assistant professors without terminal degree[4]

x_5 = number of associate professors without terminal degree

x_6 = number of full professors without terminal degree

x_7 = number of part-time faculty without terminal degree

x_8 = number of special professors without terminal degree

x_9 = number of staff

y_1 = number of assistant professors with terminal degree

y_2 = number of associate professors with terminal degree

y_3 = number of full professors with terminal degree

y_4 = number of part-time faculty with terminal degree

y_5 = number of special faculty with terminal degree

w = total payroll increase from prior year; comprised of faculty, staff, and graduate assistant salary increases

Constants

a_1 = percentage of the academic staff that is classified as full-time faculty

a_2 = percentage of academic staff at the undergraduate level with terminal degree

a_3 = percentage of academic staff at the graduate level with terminal degree

a_4 = estimated number of undergraduate student credit hours required per session

a_5 = estimated number of graduate student credit hours required per session

a_6 = desired undergraduate faculty/student ratio

a_7 = desired graduate faculty/student ratio

a_8 = desired faculty/staff ratio

a_9 = desired faculty/graduate research assistant ratio

b_{14} = projected undergraduate student enrollment for the coming academic year

b_{15} = projected graduate student enrollment for the coming academic year

b_{16} = desired percentage increase in salary for graduate assistants

b_{17} = desired percentage increase in salary for staff

Maximum teaching loads, desired proportion of each faculty type, and average annual salary are defined as:

Variable	Desired proportion	Teaching Loads		Salary
		Undergrad.	Grad.	
x_1	c_1	b_1	b'_1	s_1
x_2	c_2	b_2	b'_2	s_1
x_3	c_3	b_3	b'_3	s_2
x_4	c_4	b_4	b'_4	s_3
x_5	c_5	b_5	b'_5	s_4
x_6	c_6	b_6	b'_6	s_5
x_7	c_7	b_7	b'_7	s_6
x_8	c_8	b_8	b'_8	s_7
x_9	--	--	--	s_8
y_1	c_9	b_9	b'_9	s_3
y_2	c_{10}	b_{10}	b'_{10}	s_4
y_3	c_{11}	b_{11}	b'_{11}	s_5
y_4	c_{12}	b_{12}	b'_{12}	s_6
y_5	c_{13}	b_{13}	b'_{13}	s_7

Constraints

A. Accreditation. (a) A certain percentage of the academic staff must be full-time faculty.

$$(1)\quad \left(\Sigma_{i=3}^{6} x_i + x_8 + \Sigma_{i=1}^{3} y_i + y_5\right) / \left(\Sigma_{i=2}^{8} x_i + \Sigma_{i=1}^{5} y_i\right) \geq a_1$$

(b) A given percentage of the faculty available for undergraduate and graduate teaching duties are usually required to possess the terminal

degree. If we assume for this model that x_2 through x_7 and y_1 through y_3 are available for undergraduate teaching assignments, and x_8 and y_1 through y_5 are available for graduate teaching responsibilities, we may write:

$$(2)\quad \Sigma_{i=1}^{3} y_i/(\Sigma_{i=2}^{7} x_i + \Sigma_{i=1}^{3} y_i) \geq a_2$$

$$\Sigma_{i=1}^{5} y_i/(x_8 + \Sigma_{i=1}^{5} y_i) \geq a_3$$

(c) There is usually a requirement which relates the maximum number of student credit hours per session (for both graduate and undergraduate) that a faculty member may teach. It is not necessary to formulate a separate constraint for this requirement since it is easily incorporated into later constraints by selecting appropriate desired class sizes and teaching loads.

B. Total Number of Academic Staff. One of the most important determinants of the number of academic staff requirements is the estimated number of student credit hours (both graduate and undergradute) needed per session. With this information plus the maximum desired teaching loads of faculty members, the requirement of academic staff can be determined.

$$(3)\quad \Sigma_{i=2}^{7} b_i x_i + \Sigma_{i=1}^{5} b_{i+8}\, y_i \geq a_4 \quad \text{(undergraduate)}$$

$$\Sigma_{i=2}^{7} b'_i x_i + \Sigma_{i=1}^{5} b'_{i+8}\, y_i \geq a_5 \quad \text{(graduate)}$$

(b) Another aspect to be considered in the determination of academic staff requirements is the desired faculty/student ratio.

$$(4)\quad (\Sigma_{i=2}^{7} x_i + \Sigma_{i=1}^{3} y_i)/b_{14} \geq a_6 \quad \text{(undergraduate)}$$

$$(x_8 + \Sigma_{i=1}^{5} y_i)/b_{15} \geq a_7 \quad \text{(graduate)}$$

C. Distribution of Academic Staff. It is necessary to impose some constraints on the distribution of the academic faculty. If there were no constraints, the model would call for the most

productive type of faculty in terms of teaching load, salary, and accreditation, i.e., the assistant professors with terminal degrees and instructors. In this model, we assume that the college desires to minimize the number of faculty without terminal coverage and to maximize those with terminal degrees.

$$(5)\quad \Pi_{i=2}^{8} C_i \cdot T \leq \Pi_{i=2}^{8} x_i$$

$$C_{12} \cdot T \leq y_4$$

$$\Pi_{i=1}^{3} C_i \cdot T \geq \Pi_{i=1}^{3} y_i$$

$$C_{13} \cdot T \geq y_5$$

where, "Π" represents "product" of the indicated terms and "T" represents $\Sigma_{i=2}^{8} x_i + \Sigma_{i=1}^{5} y_i$.

D. Number of Staff. Due to the ever-increasing amount of stenographic services required by the academic staff, it is imperative, if backlogs and bottlenecks are to be avoided, that an adequate staff be provided. This objective may be incorporated into the model by designing a constraint which reflects an optimum desired faculty/staff ratio.

$$(\Sigma_{i=2}^{8} x_i + \Sigma_{i=1}^{5} y_i)/x_9 \geq a_8$$

E. Number of Graduate Research Assistants. To provide adequate research support for the academic staff, it is desired to assign graduate research assistants to faculty members. This can be handled by introducing a constraint for desired faculty/graduate research assistant ratio.

$$(6)\quad (\Sigma_{i=3}^{8} x_i + \Sigma_{i=1}^{5} y_i)/x_1 \geq a_9$$

F. Salary Increase. To maintain an adequate staff, it is necessary to provide periodic salary increases. Any academic community must be cognizant of the fact that there exists a keen competition for members of its academic staff. One of the most viable means of meeting this competition is to offer salary increases according to the policy of the institution. The payroll increase constraint is:

$$(7) \quad b_{16} \left(s_1 \Sigma_{i=1}^{2} x_i\right) + b_{17} \left(s_2 x_3 + \Sigma_{i=3}^{7} s_i x_{i+1} + \Sigma_{i=3}^{7} s_i y_{i-2}\right) + b_{18} \left(s_8 x_9\right) \leq w$$

G. The Total Payroll Budget. The increase in the salaries of the faculty, the staff and graduate assistants represents only one facet of the entire budget. The total payroll budget is a major concern in a situation where limited resources are involved. The total payroll constraint can be expressed:

$$(8) \quad s_1 \Sigma_{i=1}^{2} x_i + s_2 x_3 + \Sigma_{i=3}^{7} s_i x_{i+1} + \Sigma_{i=3}^{7} s_i y_{i-2} + s_8 y_9 + w = p$$

where, p represents the total payroll budget.

Objective Function

The objective funcation is to minimize deviations, either negative or positive, from set goals with certain "preemptive" priority factors assigned by the dean of the college in accordance with the university policies and existing conditions.

A Numerical Example

A highly simplified numerical example will be presented to demonstrate the application of the general model.[5] Let us assume that

the Dean of the College of Business in a university provided the following priority structure for academic goals and information on constants:

A. Priority Structures

m_7 = Maintain the necessary requirements for accreditation.

m_6 = Assure adequate salary increases for the academic staff, graduate assistants, and general staff

m_5 = Assure adequate number of faculty by meeting desired faculty/student ratios and by having instruction available for the needed student credit hours. The graduate faculty/student requirements is considered to be twice as important as the undergraduate requirement.

m_4 = Attain a desirable distribution of the academic staff with respect to rank.

m_3 = Maintain desired faculty/staff ratio.

m_2 = Maintain desired faculty/graduate research assistant ratio.

m_1 = Minimize cost.

B. Teaching Loads, Average Salaries, Desired Proportions of Total Staff

Variable	Teaching Load Undergrad.	Grad.	Desired Proportion Maximum	Minimum	Salary
x_1	0	0	-	-	$ 3,000
x_2	6	0	7%	-	3,000
x_3	12	0	7	-	8,000
x_4	9	0	15	-	13,000
x_5	9	0	5	-	15,000
x_6	6	0	2	-	17,000
x_7	3	0	1	-	2,000
x_8	0	3	-	1%	30,000

x_9	-	-	-	-	4,000
y_1	6	3	-	21	13,000
y_2	6	3	-	14	15,000
y_3	3	3	-	23	17,000
y_4	0	3	2	-	2,000
y_5	0	3	-	2	30,000

The constraints in the model needed for accreditation were given the highest priority by the dean of the hypothetical college. These goals will be considered first in the goal programming model. Then the lower priority goals will be considered in turn.

<u>Constraints for Accreditation</u>

It is required that 75 percent of the academic staff be full-time faculty according to AACSB. Since in our model x_3 to x_6, x_8, y_1 to y_3 and y_5 are considered full-time, we may write:

$$(9)\quad \Sigma_{i=3}^{6} x_i + x_8 + \Sigma_{i=1}^{3} y_i + y_5 - .75 \left(\Sigma_{i=1}^{8} x_i + \Sigma_{i=1}^{5} y_i\right) + d_1^- - d_1^+ = 0$$

It is also required tht at least 40 percent of the academic teaching staff at the undergraduate level possess terminal coverage. This is expressed as:

$$(10)\quad \Sigma_{i=1}^{3} y_i - .40 \left[\Sigma_{i=2}^{7} x_i + \Sigma_{i=1}^{3} y_i\right] + d_2^- - d_2^+ = 0$$

At least 75 percent of the academic staff teaching graduate studies are required to possess terminal coverage. This is expressed as:

$$(11)\quad \Sigma_{i=1}^{5} y_i - .75 \left[x_8 + \Sigma_{i=1}^{6} y_i\right] + d_3^- - d_3^+ = 0$$

Constraint for Number of Academic Staff

For the next constraint it is necessary to forecast the total constraints for number of student credit hours of instruction needed. We forecast 910 hours by means of the following formula: (Projected enrollment) · (Number of credit hours/student)/(desired class size). The projected student enrollment is 1,820, the average number of credit hours/students taken at the college is 10, and the desired class size is set at 20.

(12) $6x_2 + 12x_3 + 9x_4 + 9x_5 + 6x_6 + 3x_7 + 6y_1 + 6y_2 + 3y_3 + d_4^- - d_4^+ = 910$

For the graduate student credit hours of instruction, we forecast 100 hours per session. The procedure is similar to the undergraduate forecast and the constraint becomes:

(13) $3x_8 + 3y_1 + 3y_2 + 3y_3 + 3y_4 + 3y_5 + d_5^- - d_5^+ = 100$

The next aspect to be considered in the determination of the required academic staff is the desired faculty/student ratio at both the graduate and undergraduate level. We forecast in the next year undergraduate student enrollment as 1,820 and graduate student enrollment as 100. The desired undergraduate faculty/student ratio is about 1/20 and the desired graduate faculty/student ratio is about 1/10. These constraints then become, for the undergraduate requirement:

(14) $\Sigma_{i=2}^{7} x_i + \Sigma_{i=1}^{3} y_i + d_6^- - d_6^+ = (.05)\ (1,820) = 91,$

and for the graduate faculty:

(15) $x_8 + \Sigma_{i=1}^{8} y_i + d_7^- - d_7^+ = (.10)\ (100) = 10.$

Constraints for the Distribution of Academic Staff

It was necessary to impose some constraints on the distribution of the academic faculty according to the desired proportion of the total faculty for each type of staff.

$$(16)\quad \begin{aligned}
.07T - x_2 + d_8^- - d_8^+ &= 0\\
.07T - x_3 + d_9^- - d_9^+ &= 0\\
.15T - x_4 + d_{10}^- - d_{10}^+ &= 0\\
.05T - x_5 + d_{11}^- - d_{11}^+ &= 0\\
.02T - x_6 + d_{12}^- - d_{12}^+ &= 0\\
.01T - x_7 + d_{13}^- - d_{13}^+ &= 0\\
.01T - x_8 + d_{14}^- - d_{14}^+ &= 0\\
.21T - y_1 + d_{15}^- - d_{15}^+ &= 0\\
.14T - y_2 + d_{16}^- - d_{16}^+ &= 0\\
.23T - y_3 + d_{17}^- - d_{17}^+ &= 0\\
.02T - y_4 + d_{18}^- - d_{18}^+ &= 0\\
.02T - y_5 + d_{19}^- - d_{19}^+ &= 0
\end{aligned}$$

where $T = \sum_{i=2}^{8} x_i + \sum_{i=1}^{5} y_i$

Number of Staff

In order to insure adequate staff for clerical and administrative work, the desired faculty/staff ratio is set at 4 to 1 by the dean. The constraint is then:

$$(17)\quad T - 4x_9 + d_{20}^- - d_{20}^+ = 0$$

Number of Graduate Research Assistants

We set the desired faculty/graduate research assistant ratio at 5 to 1. The constraint then becomes:

$$(18)\ \Sigma_{i=3}^{8} x_i + \Sigma_{i=1}^{5} y_i - 5x_1 + d_{21}^- - d_{21}^+ = 0$$

Cost of Academic Staff, Graduate Assistants, and Staff

The first constraint pertains to the salary increases and may be expressed as:

$$(19)\ .06 \left[3{,}000\ \Sigma_{i=1}^{2} x_i\right] + .08\ (8{,}000\ x_3 + 13{,}000\ x_4 + 15{,}000\ x_5 + 17{,}000\ x_6 + 2{,}000\ x_7 + 30{,}000\ x_8 + 13{,}000\ y_1 + 15{,}000\ y_2 + 17{,}000\ y_3 + 2{,}000\ y_4 + 30{,}000\ y_5) + .06\ (4{,}000\ x_9) - w + d_{22}^- - d_{22}^+ = 0,$$

where there is a 6 percent increase for graduate students and staff and an 8 percent increase for faculty.

The total payroll constraint can be expressed as:

$$(20)\ 3{,}000\ x_1 + 3{,}000\ x_2 + 8{,}000\ x_3 + 13{,}000\ x_4 + 15{,}000\ x_5 + 17{,}000\ x_6 + 2{,}000\ x_7 + 30{,}000\ x_8 + 13{,}000\ y_1 + 15{,}000\ y_2 + 17{,}000\ y_3 + 2{,}000\ y_4 + 30{,}000\ y_5 + 4{,}000\ x_9 + w + d_{23}^- - d_{23}^+ = 0.$$

Objective Funcation

$$(21)\ \text{Min.}\quad Z = M_7\Sigma_{i=1}^{3} d_i^- + M_6 d_{22}^- + 2M_5 d_5^- + 2M_5 d_7^- + M_5 d_4^- + M_5 d_6^- + M_4\Sigma_{i=8}^{13} d_i^- + M_4 d_{18}^- + M_4\Sigma_{i=14}^{17} d_i^+ + M_4 d_{19}^+ + M_3 d_{20}^+ + M_2 d_{21}^+ + M_1 d_{23}^+$$

The model was solved by the goal programming computer program written at Virginia Polytechnic Institute. The results of the model are presented below:

Results - First Run

Goals

Accreditation	Achieved
Salary increase	Achieved
Faculty/student ratios	Achieved
Faculty distribution	Achieved
Faculty/staff ratio	Achieved
Faculty/graduate assistant ratio	Achieved
Minimize cost	$2,471,000

Variables

$x_1 = 32$	$x_8 = 1$
$x_2 = 10$	$x_9 = 38$
$x_3 = 10$	$y_1 = 42$
$x_4 = 22$	$y_2 = 20$
$x_5 = 7$	$y_3 = 34$
$x_6 = 0$	$y_4 = 0$
$x_7 = 1$	$y_5 = 3$

$w = \$176,000$

All goals were achieved at the total costs of $2,471,000. However, as is usually the case, the desired faculty distribution may be impossible to obtain. Also, the total cost may be quite a bit more than the funds the academic administrator will be able to obtain.

Suppose, for example, that one percent of the academic staff are professors with no terminal coverage. The optimum solution called for

zero. There is nothing that can be done about this situation so the constraint for this type of academic staff must be changed to read:

$$.01T - x_6 - d_{12}^- + d_{12}^+ = 0.$$

Further suppose the administrator believes his maximum allocation of funds will be \$1,850,000. Or in fact, suppose this is all the funds allocated. This forces the right hand side of equation (20) to become \$1,850,000 instead of 0 and we are no longer considering the cost minimization as the lowest priority. Let us assume that the dean treats the cost minimization as the second priority, after meeting accreditation requirements.

The new objective function is then:

$$(22)\ Z = M_7\sum_{i=1}^{3} d_i^- + M_6 d_{23}^+ + M_5 d_{22}^- + 2M_4 d_5^- + 2M_4 d_7^- + M_4 d_4^- + M_4 d_6^- + M_3\sum_{i=8}^{11} d_i^- + M_3 d_{13}^- + M_3 d_{18}^- + M_3 d_{12}^+ + M_3\sum_{i=14}^{17} d_i^+ + M_3 d_{19}^+ + M_2 d_{20}^+ + M_1 d_{21}^+$$

Results - Second Run

Goals

Accreditation	Achieved
Salary increase	Achieved
Faculty/student ratio	Achieved
Faculty distribution	Not Achieved - several ranks were not represented in this solution
Faculty/staff ratio	Not Achieved - no staff
Faculty/graduate research assistant ratio	Not Achieved

Variables

$x_1 = 0$

$x_2 = 9$

$x_3 = 20$

$x_4 = 20$

$x_5 = 7$

$x_6 = 1$

$x_7 = 1$

$x_8 = 0$

$x_9 = 0$

$y_1 = 28$

$y_2 = 18$

$y_3 = 30$

$y_4 = 0$

$y_5 = 0$

$w_1 = 135,000$

cost = 1,850,000

Now, let us suppose that the dean of the college presented the result of the second run to the president of the university and that he was successful in obtaining an additional fund of $120,000. Based on the result of the second computer run, the dean is aware of the fact that he should assign higher priorities to the faculty/staff and faculty/graduate research assistant ratios for an efficient operation of the college. He again assigned the highest priority to the accreditation requirements, and the second priority factor on the cost minimization to $1,970,000. To insure an adequate staff support he assigned the third priority to the faculty/staff ratio and the fourth priority to the faculty/graduate research assistant ratio. The faculty/student ratio was assigned the sixth priority, followed by the faculty distribution ratios given the lowest priority factor.

The objective funcation for the third program is:

$$(23)\quad \text{Min.}\quad Z = M_7\Sigma_{i=1}^{3} d_i^- + M_6 d_{23}^+ + M_5 d_{22}^- + M_4 d_{20}^+ + M_3 d_{21}^+ + 2M_2 d_5^- + 2M_2 d_7^- + M_2 d_4^- + M_2 d_6^- + M_1\Sigma_{i=8}^{11} d_i^- + M_1 d_{13}^- + M_1 d_{18}^- + M_1 d_{12}^+ + M_1\Sigma_{i=14}^{17} d_i^+ + M_1 d_{19}^+$$

Result - Third Run

Goals

Accreditation	Achieved
Salary increase	Achieved
Faculty/staff ratio	Achieved
Faculty/graduate research assistant ratio	Achieved
Faculty/student ratios	Achieved
Faculty distribution	Not Achieved - again several ranks were not represented in this solution

Variables

$x_1 = 26$	$x_9 = 32$
$x_2 = 9$	$y_1 = 27$
$x_3 = 22$	$y_2 = 18$
$x_4 = 19$	$y_3 = 26$
$x_5 = 6$	$y_4 = 0$
$x_6 = 1$	$y_5 = 0$
$x_7 = 0$	$w = 144{,}000$
$x_8 = 0$	cost = 1,970,000

As is apparent from the result above, the most important academic goals of the college are met by restructuring the priority levels and by acquiring an additional $120,000.

Conclusion

Goal programming is not the ultimate solution for all budgeting and planning problems in an academy. It requires that administrators be capable of defining, quantifying, and ordering objectives. The goal programming model simply provides the best solution under the given constraints and priority structure. Therefore, if management assigns incorrect priorities to various goals, the model solution will not provide the optimum solution.

Developing and solving the goal programming model points out where some goals cannot be achieved under the desired policy and hence where trade-off must occur due to limited funds. The goal programming model allows the administrator to review critically the priority structure in view of the solution derived by the model. Indeed, the most important property of the goal programming model is its great flexibility which allows model simulation with numerous variations of constraints and goals.

It is hoped that this sample model will provide a guide for more complete models closer to reality which will perhaps encompass an entire university or a university system.

FOOTNOTES

1. Annual current expenditure (1962-63 dollars) by institutions of higher education rose from \$3.6 billion in 1954-55 to an estimated \$9.7 billion in 1964-65 -- an increase of 169 percent. It is expected that current expenditures will reach \$20.1 billion in 1974-75 -- an increase of 107 percent over the 1964-65 figure (6).
2. Recently there have been several meaninful attempts to develop a dynamic planning system for university administration. See references (1), (5), (7), and (8).
3. For a detailed explanation of goal programming, see (2) and (3).
4. The terminal degree represents Ph.D., D.B.A., J.D., and LL.B.
5. The first draft of this numerical example was presented at the Southern Management Association Meeting, November, 1969. See (4).

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