A Preemptive Goal Programming Model for the Sustainability of Growth in Engineering Colleges

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Abstract

Today, ever-decreasing budgets and dynamic variations in the number of both faculty and student bodies are two major challenges that most U.S. universities deal with. In addition to the effort to solve these problems, every higher education institution also concentrates on ensuring its sustainability in the academic and industrial arenas while providing continuous improvements in academic programming, resources and student and Faculty support services. To ensure sustainability and continuous growth, there are various additional parameters that need to be taken into account, such as: revenue from various sources, including tuition, grants from industry and government, and alumni/other donations. Enhancing the technological ability of the University via additional equipment purchases and/or maximizing the utilization of existing technologies can also be counted among the goals of any university. Mathematically, this administrative problem can be addressed using multiple objective modeling techniques. Goal Programming (GP) is a linear programming-based technique that has the ability to handle conflicting objectives in both preemptive and weighted manners. In this paper, we present a preemptive goal programming model for the School of Engineering at the University of Bridgeport. Data and case studies are provided along with a list of objectives for the Engineering School.

Keywords: School of Engineering, Enrollment, Sustainability, Quality of Education, Preemptive Goal Programming, Multiple Criteria Optimization.

1. Introduction

Today, ever-decreasing budgets and dynamic variations in the number of both faculty and student bodies are two major challenges that most U.S. universities deal with. In addition to the effort to solve these problems, every higher education institution also concentrates on ensuring its sustainability in the academic and industrial arenas while providing continuous improvements in academic programming, resources and student and Faculty support services.

In order to ensure sustainability and continuous growth, there are various additional parameters that need to be taken into account, such as: revenue from various sources, including tuition, grants from industry and government, and alumni/other donations. Enhancing the technological ability of the University via additional equipment purchases and/or maximizing the utilization of existing technologies can also be counted among the goals of any university. Mathematically, this administrative problem can be addressed using multiple objective modeling techniques.

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Goal Programming (GP) is a linear programming-based technique that has the ability to handle conflicting objectives in both preemptive and weighted manners. In this paper, we present a preemptive goal programming model for the School of Engineering at the University of Bridgeport. Data and case studies are provided along with a list of objectives for the Engineering School.

The paper is organized as follows: Introduction to the proposed Preemptive Goal Programming methodology is provided in the following section. Model development is the focus of Section 3. Case study data and modeling is provided in Section 4. The paper concludes with considerations regarding future enhancements.

2. Introduction to the Preemptive Goal Programming Model

A large number of real world decision-making and optimization problems are actually multi-objective. Even so, many important optimization models, such as linear programming models, require that the decision maker express his/her wishes as one aggregate objective function that is usually subjected to some constraints. Goal programming (GP), generally applied to linear problems, deals with the achievement of prescribed goals or targets. First reported by Charnes and Cooper[1, 2], it was then extended in the 1960s and 1970s by Ijiri[3], Lee[4] and Ignizio[5]. Since then, there has been an explosion of areas where goal programming has been applied.

Both academicians and practitioners have embraced this technique. The basic purpose of goal programming is to simultaneously satisfy several goals relevant to the decision-making situation. To this end, a set of attributes to be considered in the problem situation is established. Then, for each attribute, a target value (i.e., appraisal level) is determined. Next, the deviation variables are introduced. These deviation variables may be negative or positive (represented by η_i and ρ_i, respectively). The negative deviation variable, η_i, represents the quantification of the under-achievement of the *i*th goal. Similarly, ρ_i represents the quantification of the over-achievement of the *i*th goal[6]. Finally for each attribute, the desire to overachieve (minimize η_i) or underachieve (minimize ρ_i), or satisfy the target value exactly (minimize $\eta_i + \rho_i$) is articulated[6].

Steps for the Preemptive Goal Programming algorithm is provided in Table 1. Figure 1 depicts the flow chart of the overall algorithm.

Table 1. Preemptive Goal Programming Algorithm

Step	Action
1	Embed the relevant data set. Set the first goal set as the current goal set.
2	Obtain a Linear Programming (LP) solution defining the current goal set as the objective function.
3	If the current goal set is the final goal set, **a.** set it equal to the LP objective function value obtained in Step 2, and STOP. Otherwise, go to Step 4.
4	If the current goal set is achieved or overachieved **a.** set it equal to its aspiration level and add the constraint to the constraint set, Go to Step 5. **b.** Otherwise, if the value of the current goal set is underachieved, set the aspiration level of the current goal equal to the LP objective function value obtained in Step 2. Add this equation to the constraint set. Go to Step 5.
5	Set the next goal set of importance as the current goal set. Go to Step 2.

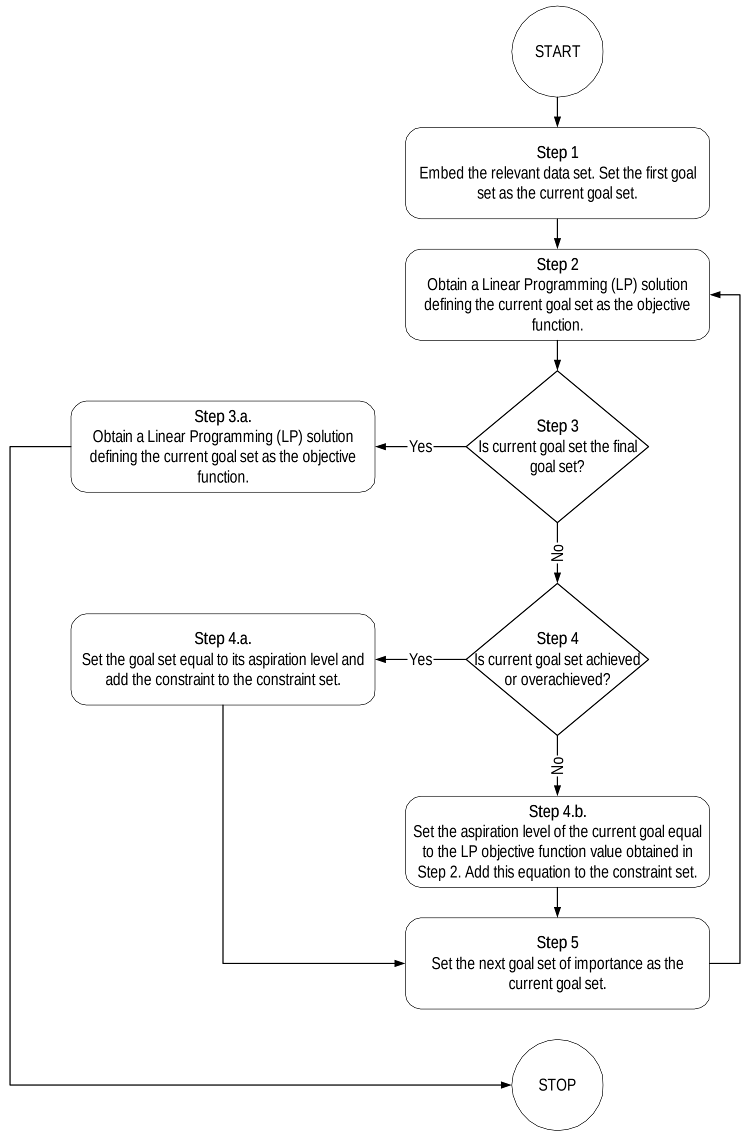

Figure 1. Flowchart of the Preemptive Goal Programming Algorithm

3. Model for the Sustainability of Growth in Engineering Colleges

In this section we introduce the proposed model, including its objective function, technological constraints, and sign restrictions.

3.1. Goals of the Preemptive Goal Programming Model

Goals for the preemptive GP model are provided in Table 2 along with their target, current, and tolerable limits. The priority of each goal is also provided in the table.

The proposed algorithm aims at finding the number of full time faculty members (*xf*), the number of part time faculty members (*xp*), and the number of new students (*xn*).

Table 2. Goals for the Preemptive Goal Programming Model

Objective	Goal	Target (Desirable)	Current	Tolerable	Priority
Max	# of Journal Publications/year	52.5	31	21	1
Max	Revenue from Research Grants	$2.1M	$0.8M	* $1.05M	2
Max	Revenue from Non-Research Related Activities	$6M	$3.3M	* $4.0M	3
Max	Student Enrollment	1500	1350	1200	4
Max	# of Faculty Members (Full time faculty)	36	21	19	5
Max	Revenue from Tuition and Fees	$16M	$14.8M	$13M	6
Max	Faculty salaries (Current average, all)	$90K	$83K	* $85K	7
Max	Quality of new students (Average incoming GPA)	3.1	2.87	* 3.0	8
Max	Students Graduation GPA (Average)	3.6	3.35	3.1	9
Max	Student employment percentage (job within a year)	100%	97%	95%	10
Max	Conference/Workshop Chairmanships	11	9	7	11
Max	Journal/Book/Editorial Duties	21	12	10.5	12
Max	Technical Committee memberships	42	32	21	13
Max	Student Competition Participants	130	61	* 65	14
Max	Women Faculty	12	4	* 8	15
Max	# of Conference Publications/year	84	76	63	16
Max	Women Students	260	197	182 (14%)	17
Min	Attrition Rate (Max Retention)	3%	5%	7.5%	18
Max	Co-op and internship participation in co-op programs	95%	86%	80%	19
Max	# of Staff (Administrative Personnel)	10	5	5	20
RO*	# of Students per Class (Average)	25	35	* 30	21
Max	# of Projects sponsored by industry/year	50	30	25	22
Max	Faculty professional development funding	$125K	$87K	$75K	23
Max	#GA's and RA's offered per semester (credit hours)	1170	360	300	24
Max	Student professional development funding	$65K	$26K	$25K	25
Max	Staff salaries (current average, all without Dean)	$65K	$61K	$61K	26
Max	Session Chairmanships	42	24	21	27
Max	Tech-related expenditure (s/w, h/w, etc.)	$4M	$2.7M	$2.0M	28
Max	# online courses offered/year	50	28	25	29
Max	# of New courses/semester	15	* 17	10	30
Min	Equivalent # of part-time faculty	10	21	25	31
Max	Actual # of part-time faculty	60	48	38	32

*RO = Range Optimization

The model is applied to a multi-period environment using mixed integer goal programming (GP) method, which allows the introduction of the various priority levels. This GP can be described as follows:

Find [x_f, x_p, x_n, x_s] so as to:

$$\text{lexmin}\, u = \left[(\sum_{\substack{\forall hard \\ const.}} n_i + \sum_{\substack{\forall hard \\ const.}} g_i), (\eta_i, \rho_i) \right].$$

where $(\sum_{\substack{\forall hard \\ const.}} n_i + \sum_{\substack{\forall hard \\ const.}} g_i)$ represents the hard (technological) constraints of the model, and (η_k, ρ_k) represents the goals of the model and,

x_f = number of new Full Time faculty,
x_p = number of new Part Time faculty,
x_s = number of new staff,
x_t = number of new students.

The first goal is to maximize the number of journal publications per full time faculty member in a year. In goal programming terms, our desire for the total number of journals publications (*jpub*) would be to aspire for a total number of at least *jpub** and exceed it as much as possible. Mathematically, this can be achieved by forcing the negative deviation (η_1) from the predetermined value, *jpub**, to secure a value equal to zero. As can easily be observed from Eq. 1, by placing no restrictions on the positive deviation variable (ρ_1), the model would ignore the ceiling on variable *jpub**. In other words, this goal guarantees a highest value for the number of publications while articulating a lower aspiration perimeter.

$$\begin{aligned} &min\ \eta_1 \\ &s.t. \\ &jpub + \eta_1 - \rho_1 = jpub^*. \end{aligned} \tag{1}$$

The second goal is to maximize the Revenue from Research Grants (*rgrt*) . This goal can be expressed mathematically as:

$$\begin{aligned} &min\ \eta_2 \\ &s.t. \\ &rgrt + \eta_2 + \rho_2 = rgrt^*. \end{aligned} \tag{2}$$

The third goal is to maximize the Revenue from non-Research Related Activities (*nrgt*) such as discounts, donations, fund raising activities:

$$\begin{aligned} &min\ \eta_3 \\ &s.t. \\ &ngrt + \eta_3 + \rho_3 = ngrt^*. \end{aligned} \tag{3}$$

The fourth goal is to maximize Student Enrollment (t_t). This goal set is given in Eq. 4.

$$\begin{aligned} &min\ \eta_4 \\ &s.t. \\ &t_t + \eta_4 + \rho_4 = t_t^*. \end{aligned} \tag{4}$$

The fifth goal is to maximize the number of Full Time faculty (*tf*). This goal set is provided in Eq. 5.

$$\begin{aligned} & min\ \eta_5 \\ & s.t. \\ & t_f + \eta_5 + \rho_5 = t_f{}^*. \end{aligned} \quad (5)$$

This completes the introduction of goals in the model. Next, we provide detailed information regarding the technological constraints of the model.

3.2. Technological Constraints of the Preemptive Goal Programming Model

The number of journal publications (*jpub*) is a function of the total number of Full Time faculty members (t_f), and the number of journal publications per faculty member (*jpf*). Hence, related technological constraints can be introduced to the model as in as in Eq. 6.

$$\begin{aligned} & t_f = x_f + c_f \\ & t_f <= u_f \\ & jpub = pcf.t_f. \end{aligned} \quad (6)$$

In Eq. 6, the yearly number of journal publications per faculty is assumed to be $pcf = 1.5$, where as c_f is the current number of Full Time faculty and is equal to 21.

Here, c_f is the current number of Full Time faculty numbers ($c_f = 21$), and u_f is the corresponding upper bound ($u_f = 100$).

Revenue from Research Grants (*rgrt*) is a function of number of Full Time faculty (t_f), number of Part Time faculty (t_p), number of staff (t_s), and the number of students (t_t). The corresponding technological constraints can be expressed as in Eq. 7.

$$\begin{aligned} & rgrt = r_f * t_f + r_p * t_p + r_s * t_s + r_t * t_t \\ & t_p = x_p + c_p \\ & t_s = x_s + c_s \\ & t_t = x_t + c_t \\ & t_p <= u_p \\ & t_s <= u_s \\ & t_t <= u_t. \end{aligned} \quad (7)$$

In above equation (Eq. 7), r_{index} variable is the contribution factor ($r_f = 0.01$, $r_p = 0.005$, $r_s = 0.003$, and $r_t = 0.001$); c_{index} indicates the current values, ($c_p = 48$, $c_s = 5$, $c_t = 1350$), and u_{index} is the upper bound for the corresponding variables ($u_p = 100$, $u_s = 20$, $u_t = 3000$).

Revenue from non-Research Related Activities (*nrgt*) such as discounts, donations, fund raising activities, is a function of number of Full Time faculty (t_f), number of Part Time faculty (t_p), number of staff (t_s), and the number of students (t_t). Corresponding technological constraints are provided in Eq. 8.

$$ngrt = n_f * t_f + n_p * t_p + n_s * t_s + n_t * t_t. \quad (8)$$

In Equation 8, n_{index} variable is the contribution factor ($n_f = 0.03$, $r_p = 0.015$, $r_s = 0.009$, and $r_t = 0.003$).

Total number of students (Student Enrollment) (t_t) is a function of the number of current students (c_t) and the number of new students (x_t). Hence, the equation given in Eq. 7 satisfies this constraint.

$$t_t = x_t + c_t. \qquad (from\ 7)$$

Total number of Full Time faculty (t_f) is a function of the number of current Full Time faculty (c_f) and the number of new Full Time faculty (x_f). Hence, the equation given in Eq. 7 satisfies this constraint.

$$t_f = t_f + c_f. \qquad (from\ 6)$$

3.3. Sign Restrictions of the Preemptive Goal Programming Model

In addition to all variables being non-zero, *jpub*, x_f, x_p, x_s, and x_t, are integer variables, hence, corresponding sign restriction set can be expressed via Eq. 8.

$$jpub,\ x_f,\ x_p,\ x_s, \text{ and } x_t, >= 0 \text{ and integer.} \qquad (8)$$

The proposed model contains integer and non-integer variables and was coded as a Mixed-Integer Linear Programming model using Lingo v.9.0, LINDO Systems.

3.4. Financial Constraints

In addition to the given goals and variables, the model is also utilized to calculate the total profit of the School of Engineering. In order to achieve this goal, additional constraints are introduced to the above listed equation set (Eq. 1 – 8), such as the Total Revenue (*rev*), Total Cost (*cst*), and Total Profit (*prf*).

Total Profit (*prf*) is a function of Total Revenue (*rev*) and Total Cost (*cst*). Therefore:

$$prf = rev - cst, \qquad (9)$$

where, *rev* is a function of Revenue from Research Grants (*rgrt*), Revenue from non-Research Related Activities (*nrgt*), and Student Tuition (*rt*). Hence,

$$rev = rgrt + ngrt + rt. \qquad (10)$$

Here, *rt* is a function of the total number of students (t_t), and the tuition amount per student per year (*rpt* = 0.011, in millions). Therefore,

$$rt = t_t * rpt. \qquad (11)$$

Total Cost (*cst*) is a function of Full Time faculty, Part Time faculty and staff salaries, (*slf*, *slp*, and *sls*, respectively) student scholarship expenses (*sct*) and additional School expenses such as Faculty Development Fund (*devf*), Student Development Fund (*devt*), Technological Equipment Investment (*tech*), and Direct and Indirect additional expenses (*addc*). Hence, Eq. 12 can be written as follows:

$$cst = t_f * slf + t_p * slp + t_s * sls + t_t * sct + devf + devt + tech + addc. \qquad (12)$$

where, *slf* = 0.083, *slp* = 0.040, *sls* = 0.061, *devf* = 0.0087, *devt* = 0.026, *tech* = 2.7, and *addc* = 0.5, for the proposed model. Please note that the values are in millions of dollars. *slf*, *slp*, *sls*, and *sct* also indicate the per person values.

4. Case Study Results

After reading in all the input data and running the model for individual objective functions separately, the results provided in Table 3. The goals of the proposed model is *jpub** = 52.5 units, *rgrt** = \$2.1M, *ngrt** = \$6.0M , t_t*= 1,500 students, and t_f* = 36 faculty.

Table 3. Results of the Proposed PGP Algorithm

Obj. fn.	η_1	η_2	η_3	η_4	η_5	*jpub*	*rgrt*	*ngrt*	t_t	t_f	*prf*	x_f	x_p	x_s	x_t
min η_1	0	0.135	0.105	150	0	54	1.965	5.895	1350	36	14.04	36	0	0	0
min η_2	19.5	0	0	150	14	33	2.1	6.3	1350	22	13.35	1	52	5	0
min η_3	19.5	0.1	0	150	14	33	2.0	6.0	1350	22	13.38	1	26	15	0
min η_4	19.5	0.125	0.075	0	14	33	1.975	6.0	1500	22	16.87	1	0	0	150
min η_5	0	0.135	0.105	150	0	54	1.965	5.895	1350	36	14.04	15	0	0	0

As can easily be observed from Table 3, all target values for individual goal set are obtained by solving each goal alone. The next step is to embed each result of every step of the goal programming model as a constraint to the following model. That is, each result set will be embedded into the PGP model as a constraint for lower priority goal models. Therefore, the constraint Eq. 13

$$jpub >= jpub^* \tag{13}$$

is added to the PGP model where the objective function is provided in Eq. 2. The results of this model are provided in Table 4.

Table 4. Second Preemptive Goal Programming Model with Additional Technological Constraints

Obj. fn.*	η_1	η_2	η_3	η_4	η_5	*jpub*	*rgrt*	*ngrt*	t_t	t_f	*prf*	x_f	x_p	x_s	x_t
min η_2	0	0	0	150	0	54	2.1	6.0	1350	36	12.94	15	18	15	0

*with additional technological constraints Eq. 13.

Table 4 implies that the first two goals of the model (*i* = 1,2) are satisfied. In addition, the model provides the best results for the third and fifth goals as well. Hence, by adding the corresponding technological constraints to the second model one can proceed to solve the fourth PGP model. That is, Equation 13 is to be added, where:

$$rgrt >= rgrt^*. \tag{14}$$

One can also add Eq. 15, where,

$$tf >= tf^*. \tag{15}$$

However, in order to preserve the preemptive structure of the proposed model, it is avoided at this point. The results of the fourth goal programming model is provided in Table 5.

Table 5. Second Preemptive Goal Programming Model with Additional Technological Constraints

Obj. fn.*	η_1	η_2	η_3	η_4	η_5	*jpub*	*rgrt*	*ngrt*	t_t	t_f	*prf*	x_f	x_p	x_s	x_t
min η_2	0	0	0	0	0	54	2.42	7.26	1500	36	14.49	15	52	15	150

*with additional technological constraints Eq. 13.

As can be observed from Table 4 after solving the four consecutive PGP models, all goals are achieved at their corresponding aspiration levels. This also implies that embedding Eq. 15 into the model is not required since the results would remain unchanged.

5. Conclusions and Future Research

The proposed paper attempts to find “best” solutions to factors that would ensure sustainability of the School of Engineering at the University Bridgeport. In this regard, a Preemptive Goal Programming model is applied to the first five goals of the School. Even though it is mathematically cumbersome to formularize the relationships between the goals and model variables given that the model reflects reality, it provides interesting results depicting the effects of various goals on the remaining system variables and goals. Hence, the model can also be utilized as a cause-effect impact analysis tool to understand the sensitive relationships between the variables.

In the future, all the goals of the School of Engineering can be embedded in the model and the model can be adjusted according to the changing variables.

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Dr. Elif Kongar received her BS degree from the Industrial Engineering Department of Yildiz Technical University, Istanbul, Turkey, in June 1995. In June 1997, she received her MS degree in Industrial Engineering from the same university where, she was awarded full scholarship for graduate studies in the USA. She obtained her Ph.D. degree in June 2003. She has been a research associate in the Laboratory for Responsible Manufacturing (LRM) at Northeastern University since September 1999. She has also been employed as an Assistant Professor by Yildiz Technical University till February 2006. Dr. Kongar is currently an Assistant Professor at Bridgeport University. Her research interests include the areas of supply chain management, logistics, environmentally conscious manufacturing, product recovery, disassembly systems, production planning and scheduling and multiple criteria decision making.

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