A preemptive goal programming for allocating students into academic departments of a faculty

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***Abstract*—**A goal programming model is built to optimize the allocation of students into academic departmentss of a faculty. The goal programming model takes into account the limits of space capacity, financial allocation, the number of instructors and affirmative action quotas as goal constraints that are required to be fulfilled. Each constraint has a priority level and a weight attached. This goal programming model is then applied to the Faculty of Science and Technology, Universiti Kebangsaan Malaysia. The results of the preemptive goal programming model are then compared to that of the current allocation using the weighted mean absolute percentage error. The successful application demonstrates the ability of the goal programming model to comply with the student intake requirement and goal constraints of the academic departments.

***Keywords*—**Affirmative, constraints, priority, weighted mean.

I. Introduction

GOAL programming has been used extensively in many areas such as in bank financial management [1], students enrollment distribution [2-4],management for crops [5]-[8], portfolio of stock market [9], management of tourism activities [10], library acquisition and funding allocation [11]-[12], food product distribution [13] and bakery production [14]. Currently preemptive goal programming models are being applied in minimization of energy consumption on multiprocessor platforms [15], fuzzy investment decisions [16], flood flow model [17], and joint decision making of inventory [18].

Modeling approaches in institutions of higher learning tended to be directed towards aggregate planning of human, financial, and physical resources in the higher levels of academic administration planning [19]-[23]. Current research in education are development of online education [24], theory and practice in laboratory [25], global education framework [26], multichoice goal programming [27], programming coursework to non-computer savvy students [28], e-learning evaluation [29], menu planning model for schools [33], e-activities in pre-university [31], incorporating students' views on computer learning [32], and knowledge management in higher education [33]. Some departmental level modeling techniques dealing with faculty-course assignment required the development of complex utility functions [34]-[37]. The required time consuming modeling efforts, and the complexity and the time necessary to develop utility functions of faculty preferences could however limit their application when used on a practical reoccurring basis on departmental level [38]. However the main academic thrusts of the institutions are left out.

In order to emphasize the thrust of academic institutions, we will determine the number of students to be enrolled based on the expertise of academic staff, student capacity of each department, admission policies and create a racial balance in each department based on the affirmative action policy to be dealt with every semester. Administrators' decisions should indicate the thrust of the academic faculty, limited infrastructure, and the affirmative action requirement for government funded public universities.

In this paper, a preemptive goal programming model is developed which will optimize the allocation of students into academic departments taking into account the expertise of academic staff, student capacity of each department, admission policies and financial allocations. It is further refined to create a racial balance in each department based on the affirmative action policy and provide a fair distribution of student-to-faculty ratio. Weights will be used to apportion the students into academic departments in the faculty that will reflect the research thrust of the faculty. The weighted deviations are then given priority levels in the objective function to emphasize the ranking of goals. Error analysis is established for the preemptive model based on the deviations from the aspired levels and then compared against that of the current allocation using a weighted mean absolute percentage error (MAPE) analysis [39].

II. Model Development

Listed below are the input parameters, constraints and the objective function of the model in allocating students of a faculty, the Faculty of Science and Technology, to its five academic departments of Bioscience and Biotechnology (BB), Physical Science (PS), Chemical Science (CS), Mathematical Science (MS), and Environmental Science (ES), for its three years undergraduate study.

A. Input Parameters

c_j = capacity of first year students in department j
r_j = student to faculty ratio required for department j

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q_j = minimum ratio of native students over the total students entering department j
z_j = number of drop-out native students from department j
t_j = total capacity of students in department j proportionate to the number of classes
e_j = number of students enrolling into year two
h_j = number of students enrolling into year three

B. Variables

x_j= number of native students admitted into department j
y_j = number of non-native students admitted into department j
a_j = total number of first year students in department j
d_j = total number of students enrolled in department j
f_i = total number of students in department i
l_j = number of faculty required for department j
B = faculty budget
J_j = budget for department j
J = sum of departmental budget
X = total number of first year native students admitted into the faculty
Y = total number of non-native students admitted into the faculty
A = total number of first year students admitted into the faculty.

C. Constraints

The constraints involved in the Faculty of Science and Technology with five departments are as follows.

$$\sum_{j=1}^{M} x_j = X_i,\quad \sum_{j=1}^{M} y_j = Y_i,\quad \sum_{j=1}^{M} a_j = A_i, \tag{1}$$

where $M = 5$, $X_i = 765$, $Y_i = 465$ and $A_i = 1230$.
For $j = 1,\ldots, 5$, we have

$$a_j - x_j - y_j = 0, \tag{2}$$

$$a_j + d_{1j}^{-} - d_{1j}^{+} = c_j, \tag{3}$$

where $c_1, c_2, c_{13}, c_4,$ and c_5 are 260, 210, 260, 230 and 300.

$$d_j + d_{2j}^{-} - d_{2j}^{+} = t_j, \tag{4}$$

where t_1, t_2, t_3, t_4 and t_5 are 740, 640, 760, 650 and 900.

$$x_j - z_j - q_j a_j + d_{3j}^{-} - d_{3j}^{+} = 0\ , \tag{5}$$

where q_1, q_2, q_3, q_4 and q_5 are 0.75, 0.66, 0.51, 0.60 and 0.59.

$$d_j - a_j = e_j + h_j \tag{6}$$

where $e_j + h_j$ are 476, 427, 497, 427 and 602 .

$$f = \sum_{j=1}^{5} d_j = 3659. \tag{7}$$

$$r_j . l_j - d_j + d_{4j}^{-} - d_{4j}^{+} = 0, \tag{8}$$

where r_1, r_2, r_3, r_4 and r_5 are 17, 18, 17, 15 and 12.

$$l - \sum_{j=1}^{5} l_j = 0. \tag{9}$$

For the budget estimation in department j, we note that the students cost in a department varies with the number of students enrolled in that department. A piecewise linear relationship represents the students cost as a function of the number of students.
However, if the linear segment has been determined and the cost per student is averaged, then the budget estimation can be simplified as follows.

$$J_j = \alpha_j d_j \quad \text{and} \quad \sum_{j=1}^{5} J_j - B + d_5^{-} - d_5^{+} = 0,$$

where $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ and α_5 are 397, 1298, 666, 140 and 966.

D. Objective Function

The criterion of optimization aims at maximizing the allocation of students accepted into the department by maximizing first year admission and enrollees in the department while minimizing affirmative action quota, number of faculty members, and budget constraints.

$$\max \sum_{j=1}^{M} a_j = \sum_{j=1}^{M} x_j + y_j \tag{10}$$

$$\max \ f = \sum_{j=1}^{M} d_j \tag{11}$$

$$\min \sum_{j=1}^{M} x_j - q_j a_j \tag{12}$$

$$\min \sum_{j=1}^{M} l_j \tag{13}$$

$$\min \sum_{j=1}^{M} J_j \tag{14}$$

Note that the objective function in this case, has to be rewritten as a single function of deviations and prioritized accordingly.

$$\begin{aligned} Z = {} & P_1 \sum_{j=1}^{M} k_{1j}(d_{1j}^{-} + d_{1j}^{+}) + P_2 \sum_{j=1}^{M} k_{2j}(d_{2j}^{-} + d_{2j}^{+}) \\ & + P_3 \sum_{j=1}^{M} k_{3j}(d_{3j}^{-} + d_{3j}^{+}) + P_4 \sum_{j=1}^{M} k_{4j}(d_{4j}^{-} + d_{4j}^{+}) \\ & + P_5(k_{51} d_5^{-} + k_{52} d_5^{+}). \end{aligned} \tag{15}$$

Note that the weights k_{ij} have values 1, 2, 3, 4 or 5. For budget expenditure having the fifth priority P_5, the values of $k_{51} = k_{52} = 1$ implies that underexpenditure and overexpenditure of budget spending d_5^- and d_5^+ are equally restrained with the same weightage.

In our case the first priority goal P_1 was admission requirement, the second priority goal P_2 was the capacity requirements of each department, the third priority goal P_3 was the affirmative action ratio, the fourth goal P_4 was student-staff ratio, whilst the fifth goal P_5 is the budget expenditure. The values of the weights of deviations are based on their rank, the higher the rank the higher would the value of the weight be.

$k_{11} = 5$, $k_{12} = 4$, $k_{13} = 2$, $k_{14} = 3$, $k_{15} = 1$,
$k_{21} = 3$, $k_{22} = 2$, $k_{23} = 1$, $k_{14} = 5$, $k_{15} = 4$,
$k_{31} = 1$, $k_{32} = 3$, $k_{33} = 5$, $k_{14} = 4$, $k_{15} = 2$,
$k_{41} = 5$, $k_{42} = 4$, $k_{43} = 3$, $k_{14} = 2$, $k_{15} = 1$,
$k_{51} = 1$, $k_{52} = 1$. (16)

III. Analysis of Results

The output obtained for the preemptive goal programming model with regard to the enrollment into five departments in the Faculty of Science and Technology is shown in Table 1.

From the second column of the Table 1, the model suggest a mix of 195 native and 65 non-native students to be admitted into the Bioscience and Biotechnology department in order to fulfil the admission capacity of 260 students. Compare these values to that of the last column where the mix of 164 native and 113 non-native students will only fill up 277 of the 300 places available.

This situation arises because filling up the capacity of the Environmental Science department is given least priority, compared to that of Bioscience and Biotechnology. The fifth row displays the number of staff required in each department corresponding to the total number of students in that particular department. The values of the deviational variables with their priorities and respective weights are listed below. Note that the objective value is 285048.10.

Table 1: Results of the Preemptive Model

Departments	BB	PS	CS	MS	ES
Number of first year native students	195	139	133	134	164
Number of first year non-native students	65	71	127	89	113
Number of first year students to be admitted	260	210	260	223	277
Number of academic staff in each department	43	35	45	43	73
Number of students in each department	736	637	757	650	879

Table 2: Error Calculations for the Preemptive Goal Programming Model

Priority	Weights w	Aspiration X	Preemptive Model	Error	Current	Error
1	5	260	260	0	257	3
	4	210	210	0	205	5
	2	260	260	0	254	6
	3	230	223	7	222	8
	1	300	277	23	292	8
2	3	740	736	4	733	7
	2	640	637	3	632	8
	1	760	757	3	751	9
	5	650	650	0	649	1
	4	900	879	21	894	6
3	1	0.75	0.750	0	0.755	0.005
	3	0.66	0.662	0.002	0.663	0.003
	5	0.51	0.512	0.002	0.512	0.002
	4	0.60	0.601	0.001	0.604	0.004
	2	0.59	0.592	0.002	0.586	0.004
4	5	17	17.12	0.12	17.05	0.05
	4	18	18.20	0.20	18.06	0.06
	3	17	16.82	0.18	16.33	0.67
	2	15	15.12	0.12	15.09	0.09
	1	12	12.04	0.04	11.61	0.39

First priority is student admission, with declining weights in BB, PS, MS, CS and ES. The corresponding deviational variables are $d_{11}^- = 0$, $d_{12}^- = 0$, $d_{14}^- = 7$, $d_{13}^- = 0$, $d_{15}^- = 23$. Note that the preemptive model ensures that admission into the Physical Science is optimum. The Environmental Science department on the other hand has an underachievement of 23 students since admission into it is accorded the least weight.

Second priority is student capacity with declining weights in the MS, ES, BB, PS and CS. The corresponding deviational variables are $d_{24}^- = 0$, $d_{25}^- = 21$, $d_{21}^- = 4$, $d_{22}^- = 3$, $d_{23}^- = 3$. The value of d_{25}^- is quite high, due to the high underachievement $d_{15}^- = 23$ of the admission capacity of the ES, weighted the least in the first priority above.

Third priority is affirmative action with declining weights in CS, MS, PS, ES and BB. The corresponding deviational variables are $d_{33}^+ = 0.4$, $d_{34}^+ = 0.2$, $d_{32}^+ = 0.4$, $d_{35}^+ = 0.57$, d_{31}^+

= 0. The model indicated a small deviation from the affirmative action mix. It maintained that no more than one student will exceed the required mix of the affirmative action requirement.

Fourth priority is the student-faculty ratio with declining weights in the BB, CS, PS, MS and ES, with $d_{41}^- = 5$, $d_{42}^- = 7$, $d_{43}^+ = 8$, $d_{44}^- = 5$, $d_{45}^- = 3$. In optimizing student admission into Bioscience and Biotechnology as our first priority, we ended up with five students more than the required number if the 17 to 1 ratio of student to faculty is to be abided.

Fifth priority is the budget deviation. Note what the values $d_{51}^- = 0$ and $d_{51}^+ = 284804$ imply. The aspiration level for budget expenditure of RM 2278490 is exceeded by RM 284804 as indicated by the variable d_{51}^+. The Faculty of Science and Technology should seek an allocation of RM 2563294 to run the faculty.

Error analysis is established based on the error deviations from the aspired levels, of our models and those of current values as indicated in Table 2 by using the weighted Mean Absolute Percentage Error (MAPE) analysis [39].

For our preemptive model, the weighted MAPE

$$\frac{\sum w_i \frac{|e_i|}{X_i} \times 100}{\sum w_i} = \frac{0.503824613}{60} \times 100 = 0.8397\ \%,$$

Comparing this value to the MAPE of the current practice which is 1.268 %, we note that the MAPE value for our model gives better result which is closer to the aspiration values compared to that of the current allocation practice. If we are to categorize the MAPE values according to priorities, then the weighted MAPE values of the preemptive model can be found as in Table 3.

Table 3: MAPE values based on priorities

Priorities	Preemptive Model %	Current %
Student admission	1.1198	2.2007
Student capacity	0.8191	0.6639
Affirmative action	0.6877	0.5342
Student-staff ratio	0.8722	1.2718

Note that the first priority weighted MAPE value of the preemptive model is significantly lower by a half of the current value, inadvertently raising a small percentage of the MAPE values of the second and third priority. This is understandable since the model seeks to optimize the first priority objective at the risk of other objectives.

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IV. Conclusion

We have successfully obtained the results of the preemptive goal programming model and error analyses in the form of weighted Mean Absolute Percentage Error (MAPE) were conducted. Based on the results obtained, we were able to undertake an in-depth discussion on the deviation variables based on the given priorities and relate the findings to the weights and priority levels assigned to these variables. From the discussion of these deviational variables, we can verify that the results of the models conform to our requirement of fulfilling the highest priority goals in accordance to the corresponding weights of the five departments in the Faculty of Science and Technology. Thus we believe the preemptive goal programming model can be used for policy-making in the decision process of future allocation of students to academic departments of faculties.

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