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An optimization-based study of personell time allocation in a Brazilian Public University to prevent faculty overload crisis.

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ABSTRACT

Faculty time allocation in higher education Institutions is a problem commonly reported in the literature. In this context, the workload dilemma is finding balance amongst the academic demands (e.g., teaching, research, extension, administration, preparation). To address this problem, this paper reports an illustrative application of goal programming to faculty time allocation in a particular case in a Brazilian public university. The optimization model specified considers three scenarios for analyzing the impacts of work hours distribution by the head of the department. The allocation is impacted by managerial preferences and the 40-week regimental journey. The illustrative application studied a department composed of 18 permanent professors. As a result, when undergraduate programs have priority in allocation, the faculty expansion requires at least six and at most seven new positions. However, when the priority changes to graduate programs the hiring requirements range from six to eleven new positions. The scenarios illustrated that despite the priority shifts, new personnel must be acquired to attend to the demand, leading to increases in the departmental expenses. By the end of this paper, research opportunities and managerial implications are presented.

Keywords: Operations Research, Goal Programming, Public Higher Education, Faculty Allocation.

INTRODUCTION

This paper reports the use of a multi-objective optimization model to address the problem of faculty service allocation in a Brazilian public higher education institution (HEI). The teaching workload distribution dilemma is not uncommon in university departments, especially when the demand for undergraduate teaching activities is greater than the number of available professors. The allocation of time for research, extension, graduate studies, and university administration should also be considered. In this context, the natural solution to this dilemma would be to expand the teaching staff. However, in public universities, it is not always possible to hire new permanent personnel to meet the demand of enrolled students. Unlike classic timetabling studies, which focus on the necessary optimization of timesheets, the model described in this study focuses on the allocation of faculty service to meet, at least partially, the demand associated with the three missions of universities.

Note that in many cases, the resolution of this allocation dilemma weighs on the head of the department. In cases when the volume of hours demanded is greater than the department's service capacity, the decision problem may be accompanied by conflicting objectives.

This paper also reports an illustrative application that involves the use of the Goal Programming (GP) technique to estimate a more accurate recommendation of faculty expansion when demand for hours increases. The model specified also allows assessing the amount of unmet demand and estimating the impact on the institution in a range of scenarios. The scenarios can also provide support to spotting opportunities for staff reallocation is also sought with special regard to meeting department's goals set by the rectory.

The scenarios reported a result here are illustrative. They represent a hypothetical context in which demand is greater than the department's installed capacity. The formulation of hypothetical scenarios illustrated the usefulness of the information extracted from the optimization model. The results obtained can support decisions on addressing unmet demands, hiring for faculty expansion, or redistribution of the teaching staff. Information of this type can help meet institutional goals of a university. In Brazil, there is a high variability in the organizational structure of universities.

Consequently, the allocation of professors in Higher Education Institutions (HEIs) has high variability. This peculiarity creates a challenge for the elaboration of a universal model for the distribution of teaching hours. Despite this, some common objectives are observed; for example, meeting the demand for classes at the undergraduate level; the increase in quality teaching scientific production; and the homogenization of the distribution of top administrative functions.

Faculty time allocation studies gained notoriety between the 1970s and 1990s. IGNIZIO (1976); ROMERO (1991) were one of the pioneers in the use of multi-objective optimization models in the allocation of space and personnel in universities. They took into account the levels of demand and productivity of departments. There is a body of research relevant to this topic (MORAIS; CAMANHO, 2011; OLIVEIRA; ZANELLA; CAMANHO, [s.d.], 2019; SCHNIEDERJANS, 1995). More recent applications include, in energy, GP optimizes investments and tariffs, balancing revenue and affordability (SHAABANI et al., 2023) [16]. It also aids in planning off-grid power systems, as demonstrated in a case study on Marinduque Island, Philippines (ARMEA; HSU; YOUNG, 2023). In business, GP enhances customer evaluation and manager assignment, particularly within the Defence industry (DAGISTANLI; ÜSTÜN, 2023). In education, GP-based mentoring programs support students at risk of early school leaving by promoting goal-setting skills (MARTINS et al., 2024). In healthcare, GP enables robust network design for perishable product distribution under disruptions (HASANI; SHEIKH, 2023). These examples illustrate GP's versatility in addressing complex, multi-objective problems across various sectors. For a more in-depth bibliometric revision on Goal Programming, please refer to Jayashree; Harish Babu (2016).

This work is divided into six sections. In section 2, the Goal Programming method and model specified for this analysis are described. In section 3, the results from the decision scenarios are discussed. Section 4 reports conclusions are outlined and opportunities for improvement in the formulation are presents.

METHODOLOGY

Goal Programming

Goal Programming (GP) is a technique based on linear programming (LP) used to approach multiple and conflicting objectives in the same problem. It can be considered a branch of the multi-objective optimization field in the subdomain of multi-criteria decision-making/analysis (MCDM/A). GP was introduced by CHARNES; COOPER; FERGUSON (1955); CHARNES; COOPER (1961). Soon after, it gained notoriety in a range of applications that included mixed-method optimization (JOHNES; JOHNES,

1995; LEE, 1972; MCGREGOR; DENT, 1993). More recent applications in various sectors are worth mentioning, including integrating of GP with other OR techniques (e.g., OLIVEIRA et al., 2024; PASTANA et al., 2023; ZANELLA; OLIVEIRA, 2021)

A problem involving goal programming must take into consideration a set of target values to be achieved by each equation specified. Potential deviations from the target are highly likely to occur. Therefore, these undesirable deviations are the decision variable to be minimized in the objective function.

Another characteristic of GP models is that there are multiple objectives, which are prioritized according to their relative importance to the decision-maker. The constraints represent the goals to be achieved and they involve both hard constraints and soft constraints. The hard constraints are inequalities representing conditions that need to be satisfied before goal constraints. Flexible constraints are equations that represent organizational objectives and goals to be achieved.

To quantify the prioritization of objectives, flexible constraints accommodate deviation variables, which can be positive or negative. Positive deviation variables greater than zero indicate that a certain target was exceeded. Negative variables represent results below their target. The allocation of faculty service used formulation.

(1) to solve the allocation dilemma.

$$\text{Min } Z = \sum_{i=1}^{I} v_i(d_i^+ + d_i^-) \tag{1}$$

$$s.t.\ f_i(x): \sum_{i=1}^{I} a_i x_i - d_i^+ + d_i^- = g_i\ , \quad i = 1, \dots, m$$

$$AX \geq p_i,\ AX \leq c$$

$$d_i^+, d_i^-, x_i \in R^+$$

In formulation (1), Z is the minimization function aggregating the weight sum of all deviations from the target values (g_i). The decision variables are the positive (d_i^+) and negative (d_i^-) deviation of each g_i. The weights of each deviation (v_i) are defined by at least one decision-maker. These weights can be interpreted as the priority of each managerial goal $f_i(x)$. In formulation (1), x_i is a decision variable that represents the number of hours allocated to demand i ($i = 1, \dots, m$).

The set of strict constraints $A_i X_i \geq p_i$ defines the lower bound of time allocation to be provided for each demand i. This constraint prevents thl activities are allocated with time. The constraint set $A_i X_i \leq\ c$ defines the upper bound of time allocation according to the capacity of the department (c) and the law. Note that these two sets of constraints are represented in matricidal form.

Application

The problem investigated

The allocation dilemma problem of faculty allocation discussed in this section is illustrative, it was elaborated based on the state regulations for the University of Para State (UEPA), an Amazonian Brazilian multicampus public university (UEPA, 2018) [13]. The 200 school days and the 40h work week is consistent with both Brazilian educational and labor regulations (BRASIL, 2017; UEPA, 2019).

Consider a administration faculty composed by 18 professors. Each professor was hired according to a labor regime of 40 hours per week. This 40-h week journey, can be distributed proportionally for planning, teaching, research, extension, graduate and high administration. In Brazil, this work regime is equivalent to 1600 hours per year to conduct their activities at the university ($\mathbf{8}\frac{\boldsymbol{h}}{\boldsymbol{day}} \times \mathbf{200}\frac{\boldsymbol{school\ days}}{\boldsymbol{year}}$= 1600 h).

There is a confirmed annual demand of 14,500 teaching hours for undergraduate education. There is also an annual demand for 90 teaching hours for graduate programs. It is also mandatory to include in the planning the preparation time of the lessons. The rules for these procedures are the following: one teaching hour requires another 0.5 h planning for undergraduate lessons, and 1h for planning graduate lessons teaching.

Therefore, 14,500h for undergraduate effective teaching requires an annual availability of 21,750 h ($\boldsymbol{i.e.}, \mathbf{14\ 500\ h} \times \mathbf{1.5} = \mathbf{21750h}$). Similarly, for graduate teaching, the availability must be of 180 h ($\boldsymbol{i.e.}, \mathbf{90}\boldsymbol{h} \times \mathbf{2} = \mathbf{180}\boldsymbol{h}$).

The teaching hours demands for both undergraduate and graduate courses are considered a priority in this faculty allocation problem. However, in order to meet the scientific production goals and funding grants, the head of the department is required to allocate at least 10% of total installed capacity ($\boldsymbol{c}$) for activities associated with research, extension and MBA programs.

Finally, high administration activities (e.g., commissions, coordination’s, heads, directors or senior administration) must be considered on a case-by-case basis and in accordance with the HEI 's rules.

Specification of goals and constraints

Four goals were formulated for the department, reflecting the demand for undergraduate classes, for graduate classes, and thesis supervisions. The results the following in equations (2) - (5).

$$f_1(x): x_{grad} - d_1^+ + d_1^- = g_{grad} \quad (2)$$
$$f_2(x): x_{Pos-grad} \text{-} d_2^+ + d_2^- = g_{post-grad} \quad (3)$$
$$f_3(x): x_{TCC} \text{-} d_3^+ + d_3^- = g_{TCC} \quad (4)$$
$$f_4(x): x_{Tese} \text{-} d_4^+ + d_4^- = g_{Tese} \quad (5)$$

The hard constraints were formulated to reflect the limits of the 40-hour workweek per faculty member, as well as the department's capacity limit. Some preferences of the department were also included in the formulation regarding the allocation of hours for the coordination and execution of university projects (research, extension, graduate programs).

The constraint (6) of the model guarantees that at least 50% of the demand for teaching undergraduate programs is met. In cases of unmet demand due to the de-department's capacity limit. In constraint (7), it is defined that at least 10% of the weekly installed capacity in the department must be destined to the execution of research, extension and specialization projects. This restriction was added to encourage the raising of external funding to the HEI.

$$C_{1:} \quad AX \geq p_i \iff \quad x_{grad} \geq 0.5 \times g_{grad} \quad (6)$$
$$C_2: \quad AX \geq p_i \iff \quad 4x_{proj} \geq 0.1 \times C_{dpto} \quad (7)$$
$$C_3: \quad AX \leq c_{dpto} \iff \quad 1.5\, x_{grad} + 2x_{post-grad} + 2\, x_{TCC} + 4\, x_{thesis} + 4x_{proj} \leq C_{dpto} \quad (8)$$

Constraint (8) defines that the total allocation of hours in the department cannot exceed the installed capacity($\boldsymbol{C_{dpto}}$). The coefficients in constraints (6)-(8) were defined to reflect regulations at UEPA. Taking this UEPA's as example, to teach 1 class-hour at graduation ($\boldsymbol{i.e., 1\, x_{grad}}$) half an $\boldsymbol{1.0\, x_{grad} + 0.5\, x_{grad} = 1.5\, x_{grad}}$hour-class of planning $(\boldsymbol{0.5\, x_{grad}})$is required. In the case of TCC guidelines, 2 class hours per week (i.e., $\boldsymbol{2\, x_{TCC}}$) must be allocated for each job.

Decision scenarios of capacity and demand

For illustrating the application of formulation (1), target setting (2)-(5), and constraint (6)-(8) setting formulated in (2)–(8), the following three scenarios were specified. Three scenarios were selected scenarios for exploring potential impacts on the faculty allocation by variations in the faculty capacity, and changes in the demand due to modifications in the target values. The data are reported in Table 1.

Table 1. Dataset of capacity scenarios.

	Scenario 1			**Scenarios 2 and 3**		
Faculty	N#	Week hours	Annual	N#	Week hours	Annual
Full-time	17	40	27 200	12	40	19 200
Part-time	1	12	480	3	12	1 440
Full Leave	-	-	-	3	-	-
Partial leave	-	20	0	-	20	-
Installed capacity(C)	18	-	27 680	18	-	20 640

In scenarios 1-3, it was taken into consideration that one of the professors performs the function of head of department. The allocation of time for this position requires 20h per week. As a consequence, the head of department can only be allocated to 8h of teaching per week (UEPA, 2018). The specificities of each scenario, is reported in the next paragraphs. Consider for scenarios 1 and 2 a demand is 14,500 h for undergraduate programs and 90h hours for graduate programs without considering the preparation time.

Scenario 1 reports an installed capacity of 27680h. There are 17 professors (95% of installed capacity) to be allocated for education and research tasks and 1 professor is the head of department. Scenario 2 has the same demand reported in the previous scenario. However, there three professors occupying high administration positions. Another set of three professors was grant with temporary leaves (sabbatical, study or health issues). Finally, scenario 3 have three professor occupying high administration positions, 3 professors on partial leave. And there is an increase by 360 class hours per year in undergraduate demand due to the opening of a new program the next academic year.

Table 2 reports the target values reflecting the demand expressed in hours per week according to the HEI regulations. Taking scenario 1 as an example, the scheduling considered undergraduate teaching hours (g_{grad}) and up to 3 three undergraduate thesis (TCCs) supervision per professor. For instance, $g_{TCC} = 108h$ ($i.e.$ n 3 **thesis** x **2h** x 18 **professors** $= 108$. The other goals can be calculated using a similar rationale. And Table 3 reports the weights v_i representing administration priorities.

Table 2. Demand per scenario in week hours.

Reference	Scenario 1	Scenario 2	Scenario 3
$f_1(x) = g_{grad}$	356	356	365
$f_2(x) = g_{post-grad}$	4.5	4.5	4.5
$f_3(x) = g_{TCC}$	108	108	108
$f_4(x) = g_{Thesis}$	28	28	28
$R_{1:}\ 0.5 \times g_{grad}$	178	178	182.5
$R_{2:} 0.1 \times C_{dpto}$	69.2	51.6	51.6
$R_{3:} C_{dpto}$	692	516	516

Table3. Weights reflecting administration priorities.

Goal $f_i(x)$	Likert score	Normalized weight (v_i)
$f_1(x)$: g_{grad}	5	0.3125
$f_2(x)$: $g_{post-grad}$	3	0.1875
$f_3(x)$: g_{TCC}	5	0.3125
$f_4(x)$: g_{Thesis}	3	0.1875
Total	16	1

The priorities of the goals were selected based on expert's opinion. Their preferences were collected during an interview, when the expert used a likert-type scale to rate the goals from 1 (lowest) to 5 (highest). The expert interviewed is the head of the department and has approximately 35 years of experience as manager. After the interview, a ranking was elaborated to reflex the expert's opinion on the relative importance of each goal according to a. On this scale, grade 5 represents the highest priority and grade 1 represents the lowest priority. The scores were than normalized and used in formulation (1) as weights (v_i) for the deviations (d_i^+, d_i^-) in the objective function of the goal programming model.

Exploring scenarios

Table 4 summarizes the results generated from the model (1) for the three scenarios. Note that, since all positive model deviations were equal to zero ($d_i^+ = 0$), these were not reported in Table 4. The results reported prioritized meeting demand for teaching undergraduate programs as recommended by the expert interviewed.

Table 4. Results in week hours.

Demand for faculty (variable)	Scenarios		
	SC 1	**SC2**	**SC3**
Undergraduate demand met (x_{grad})	277.8 (77%)	206.4 (58%)	206 (56%)
Undergraduate demand unmet (d_1^-)	79.2	149.6	159
Graduate demand met ($x_{post-grad}$)	-	-	-
Graduate demand unmet (d_2^-)	4.5	4.5	4.5
Undergraduate thesis met demand (x_{TCC})	-	-	-
Undergraduate thesis unmet demand (d_3^-)	108	72	72
Graduate thesis met demand (x_{Thesis})	-	-	-
Graduate thesis unmet demand (d_4^-)	28	28	28
Hours for projects ($x_{project}$)	69h (10%)	51.6h (10%)	51.6h (10%)
Total hours not supplied ($\sum_{i=1}^{I} d_i^{-*}$)	219.7	254.1	263.5
People to hire and meet all the demand ($\frac{\sum_{i=1}^{n} d_i^-}{40h}$)	6	7	7

Considering that meeting all the demand is not possible given the installed capacity (c), expanding the faculty by hiring personnel can be necessary. The sum of all negative deviations (weekly unmet demand) divided by the 40-hour shift per week will indicate the number of professionals to be hired. tanking scenario 1 as example, the estimation of personal to hire is given by the following expression $\frac{\sum_{i=1}^{n} d_i^-}{40h} = \frac{219.7}{40} = 5.4925 \approx 6$ teachers.

Exploring a different perspective, if the administration decides that graduate programs have priority over undergraduate programs, the unmet demand in work hours would increase (see Table 5). To reflect that change in priorities, the set of needs require adjustment and there will be changes in the results of the scenarios. Scenario 3 (SC3) is the most recommendable but there 11 new positions will need to be opened for hiring. After the foreseen hirings, it would be possible to meet the demand for teaching and supervising graduation. However, there would still be deficits in the allocation of research and supervision of undergraduate thesis.

Table 5. Results when graduate program is prioritized.

Demand for faculty (variable)	Scenarios (SC)		
	SC 1	SC2	SC3
Undergraduate demand met (x_{grad})	196 (55%)	178 (50%)	183 (50%)
Undergraduate demand unmet (d_1^-)	160	178	183
Graduate demand met ($x_{post-grad}$)	4.5	4.5	4.5
Graduate demand unmet (d_2^-)	-	-	-
Undergraduate thesis met demand (x_{TCC})	-	-	-
Undergraduate thesis unmet demand (d_3^-)	108	108	108
Graduate thesis met demand (x_{Thesis})	28	28	28
Graduate thesis unmet demand (d_4^-)	-	-	-
Hours for projects ($x_{project}$)	69h (10%)	32 (6%)	30 (5%)
Total hours not supplied ($\sum_{i=1}^{I} d_i^{-*}$)	240	267	436
People to hire and meet all the demand ($\frac{\sum_{i=1}^{n} d_i^-}{40h}$)	6	10	11

This change in allocation priorities can prevent the reduction in the supply of research grants at the graduate level. The granting of scholarships depends on the functioning of classes and research activities. However, if graduate courses are prioritized, the need to hire professors would be even greater.

The recommendation to solve the problem would be to hire at least 7 more teachers, to guarantee the provision of critical teaching services and thesis supervision. However, to ensure the faculty operation in the long term and meeting the demand from new courses, the need to hire 11 more professors is necessary. For this department, it represents an increase of 61% in the staff.

CONCLUSION

This paper reported the specification and application of Goal Programming model to support the allocation of personnel within the context of a Brazilian public university located in the Brazilian Amazonian region.

The linear programming-based model (1) was developed to minimize the deviations between the demand for work hours in the faculty and the actual activities conducted in the Higher Education Institution (HEI) in terms of Teaching, Research, Extension, and Administration.

Results revealed that the installed capacity (C) was insufficient to meet the existing demand regardless the scenario specified, necessitating the estimation of hiring requirements as an outcome of the model formulation. The study explored various base scenarios, demonstrating that the reallocation of personnel to administration positions can significantly affect short-term hiring needs.

Additionally, the impact of unmet demand in graduate programs was examined by adjusting administration priorities through a new set of weights. Another critical aspect discussed was the influence of changing hiring priorities on these positions.

The results indicated as well that expanding the faculty was a requirement across all scenarios, with an ideal solution involving a 61% increase in faculty size. Although the problem was presented illustratively, it is a common challenge faced by Brazilian public universities.

Future research should consider budget constraints for hiring and the realities of precarious work conditions in HEIs to develop more humanized personnel allocation strategies. Potential research opportunities include conducting capacity studies across multiple departments within universities. Finally, further refinement of the modeling approach should be pursued to provide tailored solutions for real-world faculty needs.

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