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Project Report

Optimization Systems Science Courses

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Abstract

Universities are facing funding concerns as state education boards pursue cuts to help meet increasingly restrictive budgetary requirements imposed by the national economic crisis. To remain effective in light of these funding cuts, universities are hiring more adjunct professors to meet a growing student demand as more people elect to return to school rather than pursue already limited employment opportunities in progressively more competitive employment environments. Our project focused on the Systems Science Graduate Program at Portland State University, which served as a microcosm of this growing trend in education. Our aim was to create a decision support tool to optimize the System Science Graduate Program class schedule, to assist the program director in assigning classes to professors, and to support the decision to hire adjunct professors as the need arises.

1 INTRODUCTION

1.1 Research Context

In light of an increasingly competitive and shrinking employment environment, universities nationally are faced with an influx of students returning to further their education. Unfortunately, the same economic crisis that is driving people to seek degrees rather than employment also results in smaller university budgets as tax revenues decrease [1]. Cuts across state level university systems are limiting the ability of these systems to meet the increasing demand of growing enrollment [2].

In order to meet this growing demand, the Oregon University System (OUS), like many systems nationwide, is moving towards a Responsibility Centered Management (RCM) model [3], [4] to meet budgetary restrictions while attempting to best serve the growing student populations. RCM modeling decentralizes budgetary and management decision making processes, disturbing these responsibilities to those accountable for performance [5]. RCM promotes competitive income generation incentives, cost controls and rewards effective resource management.

This is particularly detrimental to smaller departments that must operate on reduced budgets and much more limited resources and thus cannot perform as well as larger programs. Despite efforts to better distribute funding, cuts in services and faculties are still prevalent state-wide and growing student populations are forced to compete for a shrinking number of classes taught by a shrinking number of tenured professors. At Portland State University (PSU) and the six other OUS campuses, this is reflected in a large increase in adjunct faculty hired to help close the gap between available instructors and growing student demand [6]. In fact, of the total number of classes taught at these seven campuses, nearly 50% are taught by part-time adjuncts and non-tenure-track instructors [7], which is only projected to grow as funding cuts increase [8].

Current efforts in law departments [9], and large scale efforts at the College of Business Administration at Texas A&M [10] exemplify the widespread nature of this problem and the various solutions that are being undertaken to address it. Various existing software solutions and network-based decision support tools offer a robust and highly generalized methodology to a typical assignment-based (class time, professor, room, etc.) problem [10]. These approaches however are much more suited for "safer" programs – law schools and business administration programs are in no danger of being eliminated due to budgetary constraints.

The ability of small programs that are subject to harsher funding requirements and for which funding is less readily available to hire adjuncts or conduct large scale optimizations is limited. They must operate within these funding constraints to maintain effective performance levels and thus garner funding in the RCM model being implemented by OUS. As a microcosm of a general trend in decreasing university resources, we focused our research efforts on the current situation facing the System Science Graduate Program (System Science) at Portland State University.

Our efforts in the scope of this current problem are centered on creating a decision support tool that, while applicable on a small scale, offers a scalable procedure and methodology encompassing cases where funding, instructor availability, class popularity and instructor specialty are the primary considerations. The methodology and the related knowledge generated therein may be the most valuable for graduate programs of small to moderate size, as these programs are the most susceptible to university resource restrictions. Thus, implementing this methodology can allow model-supported decisions on the best utilization of available resources to meet student demands.

1.2 Problem Context

The Systems Science Graduate Program at PSU is a small graduate program that has approximately fifty degree-seeking students at this time. The program is focused on trans-disciplinary research and general problem solving methods, and draws students from a variety of academic backgrounds including the social sciences, humanities, natural sciences and engineering.

The program confers PhDs, Master of Science degrees, and two graduate certificates. The PhD programs offered are of three types: *core*, *multidisciplinary* and *departmental options*. *Core* students are required to take mostly systems science courses, with a few selections from other departments. *Multidisciplinary* track students are required to take half of their classes from the system science program. *Departmental option* students need only take four system science classes. Master of Science students take a required number of system science classes and then select electives either from the system science class list or an approved list of classes taught in other departments. Finally, students can receive graduate certificates in computer modeling (GCCM) or computational intelligence (GCCI). Each certificate requires students to take four classes from an approved list comprised mostly of system science classes.

Since students come from a variety of academic backgrounds and because system science methods can be applied broadly, students are given a relatively free hand in designing their own programs of study within these guidelines. With few exceptions, classes do not have course prerequisites beyond suggested mathematic competency and may be taken in any order.

At the time of writing, Systems Science is undergoing a major transition. While System Science has always been a small program, budget concerns had historically been overlooked because the program served a vital function at the university. An OUS program of non-competition did not allow departments at PSU to have their own PhD programs if such a program existed at another OUS school. System Science worked with outside departments to confer PhDs on their students through the departmental PhD option. About fifteen years ago this non-competition program was eliminated and five years ago departments began conferring PhDs directly to their own students. Due to this change, System Science saw its number of degree seeking students halved, and found its budget and expenses under greater scrutiny.

The cuts in education funding in 2009 and 2010 [1], [11] put further pressure on programs like System Science to be revenue positive. 18.4% of the total education budget afforded by OUS - about $373 million of the total $2.03 billion budget – was spent on instructor, graduate assistant and adjunct instructor benefits, but could not justify spending more without clearly assessing the effectiveness of the professors' time [7].

To this end, university officials decided not to replace a tenured faculty member who retired at the end of the 2010-2011 school year. This presents the System Science program director with difficult choices. Either courses must be eliminated, or the remaining two tenured faculty members and two half-time contracted faculty members must absorb the load. Failing that, the program may need to hire adjuncts to make up the difference in this increasingly restrictive budgetary environment.

1.3 Problem Statement

Currently, System Science is reassigning classes on an ad hoc basis. This may compromise students' ability to complete their degrees in a timely way or to take their most preferred classes. The program director needs a decision support tool that can help establish a course schedule and assign classes while balancing several conflicting objectives that are subject to tight constraints. The objectives under consideration are *cost*, *student credit hours* (a well-established surrogate for income in universities), *professor preference*, *student interest*, and *ease of degree completion.* Constraints include limits on per quarter teaching loads, on yearly teaching loads, on number of classes taught by adjuncts, and on professors' abilities to teach certain classes; as well as strong preferences of senior faculty to teach specific classes in specific terms.

2 METHODOLOGY

To address the needs of the System Science Department for a decision support tool, we worked closely with the program director to develop a linear programming model based on the program's specific characteristics.

2.1 Data Gathering

In order to understand the problem as well as to define objectives and constraints, data were gathered about the program through various means. Multiple interviews were conducted with the program director to define the costs of instruction based on faculty appointment type, the constraints on per quarter and per year teaching load limits, the weights to place on professor preference based on seniority, and hard constraints on course frequency, timing and instructor assignment. Student credit hours for the 10 previous years were obtained by querying the registration database.

Professor preference was assessed by survey. Each professor was asked to indicate his preference for teaching each class on a four point scale with a 3 indicating high interest, a 2 moderate interest, a 1 low interest, and a 0 indicating inability or unwillingness to teach a class. Data on student interest and degree progress were obtained by a similar survey of students and alumni. Students and alumni were asked to indicate the classes that they either had taken or likely would take to complete their degrees. They were also asked to rate their interest in all classes with the same four point scale above.

2.2 Modeling Method

The modeling team originally chose to use a spreadsheet model and the simplex solver for ease of communication with the stakeholder. As the scope of the problem was small with only five available professors (including a to-be-hired adjunct) and few course offerings, this appeared to be a well suited method to follow in creating our decision support tool. However, upon formulating the problem mathematically, the small problem turned out to have over six hundred decision variables, far exceeding the 200 variable limit set by Microsoft Excel. We then decided to use GLPK (GNU Linear Programing Kit), a linear programming software package which does not limit the number of decision variables.

2.3 Mathematical Formulation

2.3.1 Decision Variables and Objective Functions

The primary decision variable in the model is a four dimensional binary variable, x_{cpty} , where the subscript *c* represents the 21 systems science courses, *p* represents the five professors, *t* represents the three terms in the academic year (summer term being excluded for practicality purposes and inconsistent availability of professors and classes offered), and *y* represents the two years over which all classes may be taught. b_c is a secondary variable based on student credit hours linked to x_{cpty} .

$$x_{cpty} = \begin{cases} 1 \text{ when course } c \text{ is taught by professor } p \text{ in term } t \text{ in year } y \\ 0 \text{ otherwise} \end{cases} \tag{1}$$

$$b_c = \begin{cases} 1 \text{ when more than } 10 \text{ students attend a class given once a year} \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

To optimize the system, the following five objective functions were considered.

$\min \sum_c \sum_p \sum_t \sum_y C_p x_{cpty}$	{Minimize the cost of teaching courses, where C_p is the how much it costs for professor p to teach a class}
$\max \sum_c \sum_p \sum_t \sum_y W_p R_{cp} x_{cpty}$	{Maximize professor preference, where R_{cp} is professor p's preference for course c, and W_p weight for each professor's preference}
$\max \sum_c 2b_c C_c + \sum_c -1.5(b_c - 1)\, C_c$	{Maximize student credit hours, where C_c is the expected number of students for class c based on historical data}
$\max \sum_c \sum_p \sum_t \sum_y I_c x_{cpty}$	{Maximize student interest, where I_c is a metric of student interest in class c based on surveys}
$\max \sum_c \sum_p \sum_t \sum_y S_c x_{cpty}$	{Maximize ease of completion, where S_c is a the proportion of students who require course c to complete their degree }

Though most professors are not paid on a class by class basis, the model assumes that professors are paid according to a tiered system, wherein tenured professors are paid the most per class, followed by contracted faculty, and then adjuncts. One would expect that in a system with no contractual constraints, minimizing cost would yield recommendations that all classes be taught by adjunct faculty.

Faculty preference is based on the weighted preference of faculty. There are four tiers to the weights. The preferences of tenured faculty have the greatest weight, followed by the current contracted professor, a proposed contracted professor, and adjuncts in turn.

Student credit hours are maximized according to the following rule: if a class has fewer than ten students, it is taught every other year. Courses taught every other year can expect to have 1.5 times the number of students that they would expect were the class taught every year. For example, a class had 8 students when taught every year would have 12 students when taught every other year. This is accomplished by using the secondary variable, b_c *(2).* When classes are sufficiently large, $b_c$is 1, so the number of students expected over two years is 2*1*C_c. When classes are small, $b_c$is 0, and $(b_c - 1)$ is -1. So the number of students over two years is C_c *(-1)*(-1.5).

Student interest was denoted by the measure, I_c. I_c was obtained by multiplying the average interest rating on the student survey by the number of students who have taken or will take the class. This method weights required classes heavily, but it also takes into consideration the tendency of students to rate classes that they have no intention of taking "highly interesting." Student interest is maximized by multiplying the interest score by each class taught in the two year period.

S_c is the proportion of students who plan to take a certain class to complete their degree. Again, this weights required classes heavily. Maximizing this quantity means classes that the most current students *want* to take are the classes that are taught most frequently. This is highly correlated with the student credit hour data and interest, as is expected.

A multiple-objective formulation minimizes the sum of percentage deviations from the optimal values found by running the linear program for each objective separately. The program director did not want any particular goal weighted more heavily than the others, so all weights are assumed to be 1. This objective function was formulated as:

$$\begin{aligned}\min: & \frac{\sum_c \sum_p \sum_t \sum_y C_p x_{cpty} - 246000}{246000} + \frac{297 - \sum_c \sum_p \sum_t \sum_y W_p R_{cp} x_{cpty}}{297} \\ & + \frac{394 - \sum_c 2b_c C_c + \sum_c -1.5(b_c - 1)\, C_c}{394} + \frac{522.158 - \sum_c \sum_p \sum_t \sum_y I_c x_{cpty}}{522.158} \\ & + \frac{13.0526 - \sum_c \sum_p \sum_t \sum_y S_c x_{cpty}}{13.0526}\end{aligned}$$

2.3.2 Constraints

There are four types of constraints in this problem: contractual teaching obligations, faculty ability and the preferences of senior faculty members, program requirements for offering core classes and for consistency, as well as constraints that define and link variables. Constraints are as follows:

$s.t. \quad PQLL \leq \sum_c x_{cpty} \leq PQUL \ \forall p, t$	{Contractual teaching obligations, per quarter upper and lower limits per professor}
$PYLL \leq \sum_c \sum_t x_{cpty} \leq PYUL \ \forall p, y$	{Per year upper and lower limits per professor}
$\sum_p \sum_t x_{cpty} \leq 1 \ \forall c, y$	{Each class will be taught at most once a year}

$0 \leq \sum_{p}\sum_{t}\sum_{y} x_{cpty} \leq 2 \; \forall c$	{Each class will be taught 0, 1 or 2 times in two years.}
$\sum_{t} x_{cpty} \leq PA \; \forall p, c$	{Every term professors will only teach classes for which they have ability}
$\sum_{p=\neg WW}\sum_{t}\sum_{y} x_{cpty} = 0 \; for \; c = 525, 527$	{Courses 525 and 527 cannot be taught by anyone other than WW}
$\sum_{p=\neg MZ}\sum_{t}\sum_{y} x_{cpty} = 0 \; for \; c = 521, 551, 510.2$	{Courses 521, 551, and 510.2 cannot be taught by anyone other than MZ}
$\sum_{p}\sum_{t=\neg F}\sum_{y} x_{cpty} = 0 \; for \; c = 521$	{Course 521 cannot be taught in any quarter but the fall}
$\sum_{p}\sum_{t=\neg W}\sum_{y} x_{cpty} = 0 \; for \; c = 551$	{Course 551 cannot be taught in any quarter but the winter}
$\sum_{p}\sum_{t} x_{cpty} = 1 \; \forall \; c \in core$	{Core classes must be taught every year}
$\sum_{p} x_{cpt\,1} - \sum_{p} x_{cpt\,0} \leq 1 - b_c \; \forall c, t$	{If a class is taught every year, it must be taught in the same term every year}
$L_c - 10b_c \geq 0 \; \forall c$	{b_c will be 1 when L_c is greater than 10, where L_c is the total number of enrolled students, not limited to systems science registrants}
$\sum_{p}\sum_{t}\sum_{y} x_{cpty} \geq 1 + b_c \forall c$	{When b_c is 1, courses can be taught every year}

3. Results

WW schedule

F year 0	510.3	514
W year 0	511	
S year 0	510.4	525
F year 1	510.3	529
W year 1	527	
S year 1	501.4	525

JF schedule

F year 0	557
W year 0	575
S year 0	510.1
F year 1	557
W year 1	545
S year 1	513

MA schedule

F year 0	529
W year 0	553
S year 0	
F year 1	514
W year 1	575
S year 1	

MZ schedule

F year 0	521	
W year 0	551	552
S year 0	510.2	
F year 1	610	
W year 1	511	552
S year 1	510.2	

TS schedule

F year 0	610
W year 0	576
S year 0	513
F year 1	546
W year 1	576
S year 1	512

Courses by Term

F year 0	510.3	514	521	529	557	610
W year 0	511	551	552	553	575	576
S year 0	510.1	510.2	510.4	513	525	
F year 1	510.3	514	529	546	557	610
W year 1	511	527	545	552	575	576
S year 1	510.2	510.4	512	513	525	

The model was implemented in GLPK and prospective schedules produced and reviewed with the program director. Since modeling and simulation is the program director's main area of academic interest, we also were able to conduct a model walk through of the linear program itself and the data that informs it. The director pointed out several changes that the modeling team implemented and resubmitted for his review. Among the changes made due to stakeholder feedback were the addition of the constraint on teaching classes in the same quarter every year to enhance consistency, and the relaxation of the constraint on the number of adjunct positions. The output of the model (shown above) reflects these changes, and shows a possible instructor schedules over two years and the system science course schedule for that time. It should be noted that this is a best case scenario, in which the program is capable of supporting two part time contracted faculty teaching three classes a year along with two adjunct positions a year. This was effected by allowing the constraints on professors' teaching obligations to reach their maximum real values. This may not be strictly reflective of actual practice, and is an outgrowth of weighting cost evenly with all other objectives.

4. Discussion

Overall the model was well received by the primary stakeholder. Due to the setting of hard constraints on the particular preferences of faculty, many of the results were unsurprising. However, the stakeholder did find particular assignments of junior faculty members to core classes interesting, and will consider the model output when solidifying class assignments. Furthermore, the results built the stakeholder's confidence in the model recommendations of dropping classes that had seen declining enrollment. In this, the model output prompted the stakeholder to critically assess and reevaluate longstanding patters and intuition based decisions. This was a positive reassurance that, as a decision support tool, the model functioned within our project objectives. It further provided a tool that, in times pressured by funding cuts or when professors retire, could allow the stakeholder to explore many options about how to proceed.

The stakeholder suggested that the model as it stands now would best be used as a simulation-style tool where constraints can be changed and the impact of those changes on the course schedule and assignments analyzed. For example, the director could explore the results of changing the number of available adjuncts could flex from 2 to 1 to 0. The stakeholder, an instructor himself, might also choose to reduce his own teaching load from 5 to 4, since this is the norm for professors that have taken on administrative duties and have received research grants, as he has. This may seem to be a small change, but it may have a profound impact on the allocation of professors and scheduling of classes. Furthermore, this simulation approach can also allow the stakeholder to explore and prepare for worst-case scenarios. System science may undergo further shocks as educational funding continues to be tight so insight into these potential outcomes can prove valuable.

5. CONCLUSIONS

5.1 Discussion of Limitations

All models are inherently wrong to some degree. While some are useful and provide results that can be used to form effective decisions, the limitations of models must be explored and disclosed. Our model is limited because of its method of arriving at the optimal solution. Once an optimal solution is found, the program ceases its search for further optima. In the chance that multiple optima exist, only one optimal solution will be reported. It would be more useful to see a whole set of optimal options, to assess the strengths of each, and to choose among them. In our case, GLPK arrives at an optimal solution so quickly that we suspect that there exist a large number of alternate optima, which would result in different class allocations and schedules.

Another limitation of the application developed is a common limitation using models in practice. This decision support tool, while relatively easy to expand and customize from a modeling standpoint, would be difficult for the stakeholders to use when the modeling team is no longer on hand. For example, if a professor were to go on sabbatical, it would be easy for a modeler to update the model and generate a new set of schedules by changing a few numbers in the GLPK code. Stakeholders, even stakeholders who are expert users of other modeling tools, will likely not know how to modify the model to make these simple changes, or might be intimidated by command line code and choose not to use the tool at all. This limitation is common when a new tool is introduced into an organization. Unless the stakeholders are comfortable with the tool already, or they are well supported by knowledgeable users, continued use is unlikely. For this reason, spreadsheet-based linear programs might see more sustained use than a code-based implementation.

The GLPK implementation is further limited as a decision support tool for continued use by the style and formatting of its output. The output is difficult to read and requires a lot of post-processing with other tools before it can be presented to the stakeholders.

A further limitation of our methodology was in the collection of student surveys. These were collected from a small sample of students who chose to participate, drawing from an email list. A next step could be to implement a departmental exit survey based on the four point scale for student preferences. This would extend the practicality of this model year by year as resurveying professor and student preferences is required to keep the model data up to date.

To further strengthen the capacity of the model to provide useful insights, further work on the model itself needs to be done. Some additions and changes are relatively minor, and would help the model better reflect the target system. These changes include adding constraints on the ordering of classes in series, soft prerequisites (classes that make sense in a certain order, while that order is not required), and adding an objective function that places larger classes in the fall. To make the tool more useful in the long term, a spreadsheet interface or GUI should be added to address the limitation above. This would allow users to change parameters easily and experiment with tightening and loosening constraints. This enhanced model should also indicate the percentage deviation for each objective, so that stakeholders have a better sense of the impact of changing model parameters.

5.2 Generalizing the Model & Discussion of Application

As our model was custom-tailored to the needs of the System Science Program, the applicability of the model in its current state to other departments is limited. However, the general method may prove valuable to departments that will be faced with similar problems of class scheduling and professor allocation as funding cuts continue state- and nation-wide.

The methodology and logic applied in the formulation and implantation of the model, (including surveying of student interest in classes offered, professor interest and ability to effectively instruct the classes offered and assessing when and where adjunct professors are needed) can be scaled to meet the needs of a department or program to provide decision support. As adjuncts are hired in larger numbers, this can also allow senior faculty to assess what they truly want to teach.

Applied to the Systems Science program, our model has revealed potentially useful results and expandability as a decision support tool to aid the stakeholder in the allocation of professors to classes and the structuring of class schedules. Furthermore, our model has the capability to provide a simulation-style approach to exploring various changes in constraint scenarios which allows the exploration of uncertainties.

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