DSO 570: USC Marshall Classroom Scheduling Optimization

3.1 Project Report

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1. Executive Summary

The Academic Administration team at USC Marshall School of Business is looking to improve their current system for scheduling classes. Hal Warning and Shannon Faris, who lead the classroom scheduling process, mentioned a number of goals they have in mind when creating the schedule, when they first introduced this problem. Our team has chosen to focus on one of these goals in particular: increasing the school's tuition revenue by creating an allocation that satisfies the different sizes and capabilities of the classrooms. Our team found the biggest opportunity for improvement was not necessarily enhancing the current department allocation strategy, but rather using those allocations to add a new layer of specificity to the process by assigning exact classrooms for each department's courses.

Currently, departments are provided their allocated rooms and time slots, but are left to assign the individual courses themselves. Our optimization tool is meant to be used by the departments, and utilizes the allocations provided by Shannon and Hal's team to assign individual classes to rooms that would minimize the number of empty seats in the room. In other words, classes are being assigned to rooms with a number of seats that most closely matches the size of the class itself. The potential gain from this optimization is that the reduction of empty seats results in higher tuition revenue for the school. After optimization, classes that are capable of having more registered students are being placed in larger classrooms, allowing for more seats to be filled in the class. The number of seats filled directly correlates to the tuition revenue for the school because each empty seat represents a lost opportunity for the school to gain tuition from a student registered for those extra units in the course.

There are a few crucial assumptions and simplifications we have made in order to implement this tool:

1. The tool focuses on Undergraduate level courses, as the department allocations for Graduate level courses follow a different format.
2. Departments are allocated enough time slots and rooms to fulfill the number of classes they are offering the following year.
3. Seats offered for a class can be used in lieu of the registered count, as the registered count is not known prior to the start of the semester.
4. Departments know the list of classes they are offering by the time forms are submitted to SIS.
5. Departments will consider faculty preferences themselves when assigning individual classrooms.

Our recommendation is for the departments within Marshall to utilize this tool to optimally assign their classes to the best-fitting classrooms. This will result in less empty seats per class, which leads to more tuition revenue for the school as a whole.

2. Opportunity for Improvement:

The major opportunity for improvement our group has identified in Marshall's current class scheduling process is that the current process does not assign specific rooms to each department's courses based on class size. Therefore, we have chosen to build a tool that will fill this gap and improve upon the current process. To illustrate this weakness, we can take a look at some examples for the DSO department. The table below shows how the room assignments from the current process resulted in higher numbers of empty seats, compared to the optimal room choice as determined by our tool.

Section	Seats Offered	Optimal Room	Optimal Room Capacity	Empty Seats (Optimal Room)	Old Room	Old Room Capacity	Empty Seats (old)
14882	140	JFF105	150	10	HOH EDI	269	129
14896	140	EDI	269	129	HOH EDI	269	129
14921	140	JFF105	150	10	HOH EDI	269	129
14917	140	JFF105	150	10	HOH EDI	269	129
14912	140	JFF105	150	10	HOH EDI	269	129
14927	34	ACC205	36	2	HOH2	73	39
16236	46	JFF103	48	2	JFF236	60	14
16230	37	JFF103	48	11	JFF LL103	48	11
16222	32	ACC205	36	4	BRI202A	34	2

Figure 1: Empty Seats from Current Scheduling Process

In the following sections, our team will explain the methodology, details, and results of our optimization tool which aims to solve the aforementioned weakness in the current classroom scheduling methodology.

3. Optimization Methodology

The primary goal of our optimization tool is to help the Office of Finance and Administration at USC Marshall automate and streamline the classroom scheduling process, which involved a large amount of manual work in past years. Our approach aims to achieve this by minimizing the empty space in all the classrooms assigned to **undergraduate level classes** at Marshall, assuming the Office has already allocated enough classrooms to each department within the school. To illustrate our methodology, we start by defining our input data:

(i) Input Data

- **Base Schedule**: This data set is derived from the course schedule dataset for 2015 to 2019. For the sake of simplicity, since our approach is focusing on optimizing the undergraduate course schedule for Fall 2020, we kept the most recent undergraduate schedule available (Fall 2018) as our reference to minimize possible curriculum changes in the past years. For modeling purposes, we dropped extraneous information and only kept the columns relevant to our optimization formulation, which include: Term, Type of classes, Registration counts, Department, Classroom Capacity, Course Code, Section, Level (=UG), Seats offered, Number of credits, Wait count, Total tuition units, Remaining seats, Session, Days of classes, Class begin and end time, Class begin and end dates, and Demand.

- **Department Allocations:** This data comprises a sample undergraduate classroom allocation plan by department as of Fall 2019; this is the allocations sheet that Hal and Shannon typically send to the departments. For this problem, we kept information about the classroom capacities and classroom distribution by time block and department. We assume that the classroom assignment by department will follow a similar format in Fall 2020, and that the departments are being allocated enough time slots and rooms to fulfill the number of classes they are offering (i.e., the total number of rooms and times is enough for the department to schedule all of its classes).

(ii) Optimization Output

We created the optimization tool using Jupyter Notebook, and utilized two sets of data. The first dataset contains scheduling information from 2015 to 2019 which we used to create a ‘base_schedule’ as shown in Figure 1, and the other is related to the department allocation information in 2020 titled ‘department_allocations_20201.xlsx’, as shown in Figure 2.

section	department	course	level	seats_offered	first_days	first_begin_time	first_end_time
14010	ACCT	ACCT-380	UG	25	TH	12:00:00	13:50:00
14012	ACCT	ACCT-385	UG	20	H	18:00:00	21:30:00
14025	ACCT	ACCT-370	UG	38	MW	8:00:00	9:50:00
14026	ACCT	ACCT-370	UG	39	MW	10:00:00	11:50:00
14027	ACCT	ACCT-370	UG	39	MW	12:00:00	13:50:00
14029	ACCT	ACCT-370	UG	109	F	10:00:00	11:50:00
14040	ACCT	ACCT-371	UG	39	TH	12:00:00	13:50:00
14041	ACCT	ACCT-371	UG	39	TH	14:00:00	15:50:00
14042	ACCT	ACCT-371	UG	37	TH	16:00:00	17:50:00
14050	ACCT	ACCT-372	UG	46	TH	12:00:00	13:50:00
14051	ACCT	ACCT-372	UG	46	TH	14:00:00	15:50:00
14052	ACCT	ACCT-372	UG	46	TH	16:00:00	17:50:00
14055	ACCT	ACCT-373	UG	43	MW	8:00:00	9:50:00
14056	ACCT	ACCT-373	UG	46	MW	10:00:00	11:50:00
14057	ACCT	ACCT-373	UG	44	MW	12:00:00	13:50:00

Figure 2: Subset of Undergraduate Allocation Data, ‘base_schedule.csv’

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		ACC201	ACC205	ACC236	ACC303	ACC310	BRI5	BRI8	HOH1	HOH2	EDI	JFF105	JFF125
2		48	36	39	46	54	42	36	73	73	269	150	101
3	MW												
4	8:00	ACCT	BUCO		ACCT	ACCT	ACCT	ACCT	FBE	DSO	FBE	DSO	FBE
5	10:00	ACCT	BUCO		ACCT	ACCT	ACCT	ACCT	FBE	DSO	FBE	FBE	FBE
6	12:00	ACCT	BUCO	ACCT	ACCT	ACCT	ACCT	BUCO	FBE	DSO	MKT	FBE	FBE
7	2:00	ACCT	BUCO	ACCT	ACCT	FBE	ACCT		FBE	DSO	FBE	DSO	FBE
8	4:00	ACCT	BUCO	ACCT	ACCT	FBE	ACCT		FBE	DSO	FBE	DSO	FBE
9	6:00	ACCT	BUCO	ACCT					FBE	DSO	FBE	FBE	FBE
10	8:00	ACCT		ACCT					FBE				
11	TH												
12	8:00	ACCT	DSO		ACCT	ACCT	ACCT	ACCT	FBE	DSO	FBE	FBE	FBE
13	10:00	ACCT	DSO		ACCT	ACCT	ACCT	ACCT	FBE	DSO	DSO	FBE	FBE
14	12:00	ACCT	DSO	ACCT	ACCT	ACCT	BUCO		FBE	DSO	FBE	FBE	FBE
15	2:00	ACCT	DSO	ACCT	ACCT	FBE	BUCO		FBE	DSO	MKT	FBE	FBE
16	4:00	ACCT	DSO	ACCT	ACCT	FBE			FBE	DSO	DSO	FBE	FBE
17	6:00	ACCT	DSO	ACCT					FBE	DSO	FBE	FBE	FBE
18	8:00	ACCT	DSO	ACCT									
19	F												
20	8:00												
21	10:00												
22	12:00												
23	2:00												

Figure 3: Subset of ‘department_allocations_20201.xlsx’

From the dataset ‘schedule_2015_to_2019.csv’, we created a new dataset, ‘base_schedule.csv’, using the information in the UG_Master_Distribute sheet. This aligns with our assumption that we will only focus on undergraduate level courses. The list below shows the features that were extracted from the dataset ‘schedule_2015_to_2019.csv’.

- section : the section code of the course (to identify unique course sections)
- department: the department of the course in question
- course: the course name - necessary for
- level : the level (UG for undergraduate and G for graduate)
- seats_offered: The number of seats offered in this section of the course
- first_days: the days on which the course is offered, for example MW or TH
- first_begin_time: the start time of the course (can be the same as past years)
- first_end_time: the end time of the course (can be the same as past years)

We first converted the ‘start time’ and ‘end time’ fields to a time format in units of minutes. Records with ‘TBA’ in these fields were removed prior to this.

```
base_schedule['first_begin_time'].apply(lambda x: to_minutes(x))
```

Then, we subtracted the ‘start time’ variable from the ‘end time’ variable to calculate the total length of time (in minutes) for each class, and converted it into a time-period variable with 30 minutes per period.

The final output of our optimization tool is an excel spreadsheet containing classroom assignment sheets corresponding to the departments at Marshall School of Business, with each sheet detailing the class section and optimal classroom it should be assigned to, as well as the average empty seats per class calculated. For a concrete example of the output, see Section 4 of this report.

(iii) Formulation Description

In our optimization approach, we are focusing on whether we should assign a class in a room so as to minimize the total empty space of the classrooms, where the empty space in each room is defined as the difference between the capacity of the room and the number of seats offered in that class.

The main task of this approach is to answer the question of whether a class should ever be assigned to a room, regardless of the time slots it is fitted into, because we want to give the Office some flexibility to adjust the schedule at their discretion. Concretely, the decision variable we created for our objective function is a binary variable X_{ij}, denoting whether to assign Class *i* in Room *j*. Our objective is then set to find the optimal solution that, for each department, iterates through all combinations of classes and rooms and looks for one that minimizes the total empty space.

This objective is subject to three constraints. The first is what we call availability of classrooms, since each department has access to a certain classroom only for a limited number of time blocks, if we were to assign a class to this room, then the time the class takes up cannot exceed this amount. The second constraint is the classroom size limit, that is, a class cannot be fitted into a room that has fewer seats than the number predesignated. Truthfully one might argue that there can be a discrepancy between the number of offered seats and students actually attending the class, however since we don't know how many students will be attending a class in the upcoming Fall, we deem the preassigned number of seats to be a reasonable reflection of the actual registered amount. Lastly, our third constraint requires that each class has to be assigned precisely once, no classes can be left out or take place multiple times. For the precise mathematical formulation, please refer to the Technical Appendix.

(iv) Command Execution and User Interaction

The end user of this optimization tool can be any authorized staff involved in the classroom scheduling process for each of the departments at Marshall, but may be especially useful for Hal in altering his allocations and assigning rooms to specific classes when he allocates classrooms to departments. For a foolproof guide to running the program, please follow the following steps or refer to the documentation.

- Make sure the optimize.py file is in the same directory as the input file (input.xlsx).
- If you are operating on a Windows platform, open an Anaconda Command Prompt. If you are using a Mac, simply click on ‘Terminal’ in the Utilities folder.
- Make sure to change to the directory path where the files are located, for example, if your current directory is C:\\Users\\USC, and the files are located in C:\\Users\\USC\\Downloads, simply type ‘cd Downloads’.
- Enter ‘ipython optimize.py input.xlsx output.xlsx’ to generate the output spreadsheet in the current directory.
- If the program returns ‘File {Filename} not Found’, make sure all the files are named exactly as in the command line above.

Once the output.xlsx file is generated, one can open it to access the optimized classroom results for each department. He or she may assign each class section to its optimal classroom in the time slot they see fit.

4. Optimization Results

The output of our team’s optimization tool is an Excel document with a separate sheet for each of the departments in Marshall. The individual sheets contain the optimal room assignments for each of that department’s classes, based on class size, in order to minimize the number of empty seats in the class. In other words, the tool assigns course sections to the classroom that would best fit the number of students in the class.

The tool runs on the assumption that there are enough time slots and large enough classrooms assigned to each of the departments in the initial department allocations that are used as an input to the tool. With the sample input of department allocations that we utilized, our tool was able to optimize classroom assignments for the DSO, BUCO, and BAEP departments as they met our key assumptions. While the overall objective value of the tool was to find the minimum number of empty seats across all classes for each department, our team divided the objective value by the number of classes in that department, in order to arrive at an average number of empty seats per class, which allows for better interpretability. An overview of these values is found in the table below:

Department	Average Empty Seats (new)	Average Empty Seats (old)
ACCT	1.37	2.81
BAEP	2.3	0.7
FBE	36.71	32.16
BUCO	0.95	1.45
MOR	0	0.05
MKT	1.42	2.16
DSO	8.38	29.67

Figure 4: Average Objective Values

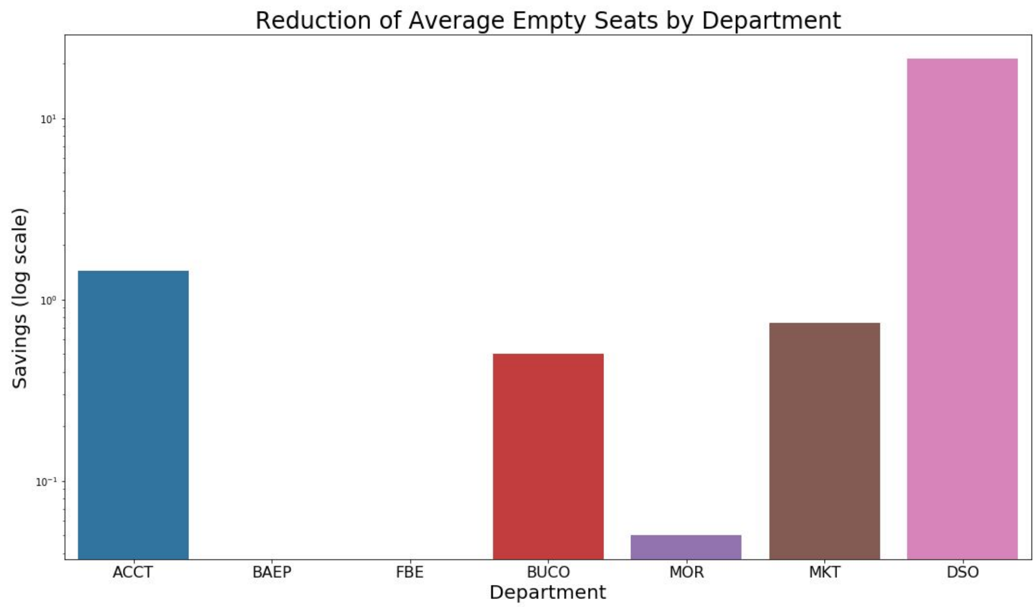

Figure 5: Reduction of Average Empty Seats

Here is an example for the DSO department, to illustrate the format of the individual sheets:

Class_Section	Room	Course	Students	Capacity	Average Empty Seats per Class
14010	BRI8	ACCT-380	25	36	1.37
14025	ACC236	ACCT-370	38	39	
14026	ACC236	ACCT-370	39	39	
14027	ACC236	ACCT-370	39	39	
14040	ACC236	ACCT-371	39	39	
14041	ACC236	ACCT-371	39	39	
14042	ACC236	ACCT-371	37	39	
14050	ACC303	ACCT-372	46	46	
14051	ACC201	ACCT-372	46	48	
14052	ACC201	ACCT-372	46	48	
14055	ACC201	ACCT-373	43	48	
14056	JFF239	ACCT-373	46	48	

Figure 6: Output Format Example

Our optimization tool provides a solution that fills in a gap in the current process: a lack of specific classroom assignments for each of the department's courses. Without a more specific room assignment, departments are left to choose rooms themselves and may not be considering the size of the room compared to the size of the class itself. This can result in inefficient use of classrooms, such as assigning a 50-student class to a room with 100+ seats.

Ultimately, the minimization of empty seats is correlated to the tuition units Marshall is receiving from the classes being full. Although typically tuition units are calculated based on the registered count of the class, the number of registered students is not known prior to classes being scheduled. Therefore, we have used the seats offered for the class as the basis for this calculation and are considering the empty seats as the difference between the classroom size and seats offered for the course. To quantify the gains from our tool, we can look at a specific example. Section 14882 in the DSO department offers 144 seats for students. In the most recent semesters, this course was assigned to room HOH EDI which has a capacity of 269, meaning there were 125 empty seats in the room that would not be filled by students. In this case, the room assignment resulted in a lost opportunity for Marshall or the DSO department to fill the room with a larger course, which would have resulted in more tuition revenue. Our optimization tool assigns this course to room JFF105 instead, which has a capacity of 150, resulting in only 6 empty seats compared to the 125 previously. These numbers can be quantified in terms of tuition revenue by multiplying the number of lost tuition units by the tuition cost per unit:

	Department	**Class Section**
	DSO	14882
	Initial Room Assignment	**Optimal Room Assignment**
Capacity	269	150
- Seats Offered	144	144
= Empty Seats	125	6
* Units	4	4
= Total Lost Tuition Units	500	24
* Tuition Cost per Unit	$1,928	$1,928
= Lost Tuition Revenue from Empty Seats	**$964,000**	**$46,272**

Figure 7: Sample Calculation for Tuition Revenue Lost

In this example, use of the optimization tool would have resulted in an increase of up to $917,728 in tuition revenue by reducing the number of empty seats and opening the larger room to be filled by a larger class with more students.

5. Discussion

The objective of our optimization tool is to minimize the total number of empty seats for the classrooms assigned to the departments in Marshall. There are three constraints required in order for our tool to arrive at a proper solution. First, the length of class time cannot exceed the availability of classrooms assigned to that department. There are a few assumptions regarding this, first, that the classroom is available during the necessary amount of time. Second, the class can only be assigned to a classroom that is not currently occupied by that department or another department.

The second constraint is that the classroom capacity exceeds class sizes (the number of seats offered), and is based on the assumption that current class size is a reasonable reflection of the actual registered amount for the upcoming year. This is important because we don't want any class sizes beyond what the classroom could hold, and we want to make sure the classroom is capable of holding a certain number of class sizes. In order to validate this assumption and interpret this constraint into actual formulation, we defined that the size of the current occupied class (defined as S_iY_{ijt} in our technical formulation) is less than the assigned classroom size (F_j).

Third, each class can only be assigned once. This prevents some of the classes from being left out or assigned multiple times. In order to provide optimal solutions to the Office of Finance and Administration, we want to make sure this tool considers all classes and achieves the maximum effort on scheduling at Phase I, so any additional modifications on scheduling were considered an extra cost. In technical terms, we translated this constraint as a defined binary variable X, where if a class starts at a certain time period, the variable equals one.

This optimization tool provides the best suitable case for assigning classes to specific classrooms based on department, classroom capacity, level, seats offered, number of credits, remaining seats, days of classes, class begin and end time, class begin and end dates, and demand. We used classroom capacity and seats offered to determine the number of empty seats, which is our objective function we want to minimize. Using level and department, we made valid assumptions to ensure the assigned classes are undergraduate level and from departments that were allocated a sufficient number of time slots. We also assume classes fall within five types of group days, Monday/Wednesday, Tuesday/Thursday, and individual Monday/Wednesday/Friday. This assumption also becomes one of our constraints. We used the terms to simplify our analysis to classes in the Fall 2018 semester, and we used class begin and end time to determine the number of 30-minute time periods needed for each class. Our results delivered on average roughly 1 empty seat for each ACCT class, 3 empty seats for each BAEP class, 37 empty seats for each FBE class, 1 empty seat for each BUCO class, 0 empty seats for each MOR class, 1 empty seat for each MKT class, and 8 empty seats for each DSO class. As Figure 4 has shown, all departments have improved the number of empty seats except for two departments, BAEP and FBE. The reason is because BAEP has been allotted more spots than the department needs, and the rooms allotted are larger than the class sizes. For FBE, the department was allocated much larger classrooms resulting in a higher number of empty seats.

We used the number of units and tuition cost per unit to calculate tuition revenue saved by reducing the number of empty seats. This tool provides a better solution than manually assigning classes, and helps avoid additional manual modifications in Phase II.

There are several suggestions we want to provide to Shannon and Hal on utilizing our tool. First, the tool performs best when all assumptions that we have mentioned are met, most significantly that departments are allocated a sufficient amount of time slots as needed (based on historical numbers). Second, that class information for the next year will be similar to historical data, as we made an assumption that past class information is indicative for the next year, including class time, class size, room capacity, section, remaining seats and registration counts. Ultimately, this solution can resolve possible issues that may arise from lack of communication between departments and the Office of Finance and Administration, which led to suboptimal choices in rooms previously. Automating this process will allow for less manual alterations to the schedule, which can also result in quicker turnaround time for creating the final schedule for all of Marshall’s courses.

A1. Mathematical Formulation

Note: We assume there is enough classroom space allocated to each department and we focus only on classes with the following traits.

- Undegraduate Courses
- Classes which meet on MW, TH and MWF
- Full Semester Courses

English Description

Objective
Given the classroom allocation of a particular department, minimize the empty space in classrooms for that department.

Subject to

- (i) For each room, the classes scheduled to not exceed the total time allotted for the department.
- (ii) For each class scheduled, the number of seats does not exceed the classroom size
- (iii) Each class is scheduled exactly once.
- (iv) For each and class and each room, a class is either scheduled or not scheduled.

Mathematical Formulation

Data Variables

- I : The set of classes
- J : The set of classrooms
- A_j : The number of half hour time blocks in classroom j are available to the department
- L_i : The number of half hour time blocks required by class i
- S_i : The number of seats offered in class i
- F_j : The seating capacity of Classroom j

Decision Variables

- X_{ij}: whether to schedule class i, in room j (binary)

Note: All of the above variables are for a single department.

Objective

Minimize: $$\sum_{j \in J} \sum_{i \in I} F_j - S_i X_{ij}$$

Constraints:

$$\begin{array}{rrll}
\text{(i)} & \text{Availability of classrooms} & \displaystyle\sum_{i \in I} L_i X_{ij} \leq A_j & \forall\, j \in J \\
\text{(ii)} & \text{Room size} > \text{Class size} & S_i X_{ij} \leq F_j & \forall\, i \in I, \quad \forall\, j \in J \\
\text{(iii)} & \text{Each class is scheduled once} & \displaystyle\sum_{j \in J} X_{ij} = 1 & \forall\, i \in I \\
\text{(iv)} & \text{Binary/Non-Negativity} & X_{ij} \in \{0, 1\} & \forall\, i \in I, \quad \forall\, j \in J
\end{array}$$

A2. Discussion of Technical Details

To create this optimization tool, we have made the following assumptions

1. There is enough classroom space in Marshall buildings to accommodate all classes
2. The departments know which classes they want to offer by the time they submit their forms to SIS.
3. Departments will consider faculty preferences themselves when assigning individual classrooms.
4. Each department is allocated enough slots for all its classes being offered.
5. Seats offered for a class can be used in lieu of the registered count, as the registered count is not known prior to the start of the semester.

We believe assumption 1 is reasonable because Marshall School of Business has a history of scheduling its own courses within USC, and Marshall classrooms are sometimes used by other colleges within USC, indicating that there are enough classrooms to accommodate existing Marshall courses. This assumption is unlikely to be violated without significant over enrollment and the addition of many more courses to the Marshall curriculum.

Assumption 2 is reasonable to our best knowledge, but has a potential to be violated if there are significant changes in faculty and course scheduling in the time between scheduling and classroom assignments. We believe any course scheduling optimization would have to rely on this assumption to function effectively.

Assumption 3 depends on the directors of each department, and their relationship with the faculty in their respective departments. Because our optimization tool does not account for professor preferences and schedules, it does not assign classes to specific rooms and times. We have chosen to leave the specification of class times to the departments and their faculty, and maintain the human element of class scheduling, at least at a departmental level.

Assumption 4 is the most likely to be violated, as it can be difficult for Hal to know if his allocation to departments accommodates each department's classes effectively.

Lastly, assumption 5 is reasonable from the University's perspective, and necessary from an optimization perspective, as registration for courses varies across semesters and students have preferences for particular professors, courses, and class times, all of which affect their registration decisions. In addition, the needs and desires of faculty change with time, which can also affect their preference to teach certain courses over others. Given all the variation in faculty and student preferences, we have chosen to use seats offered as a proxy for registration count, as it at least provides an upper bound to student registration, and is based on past experience of faculty given the popularity of their courses in a typical semester and their capacity to handle student assignments.

Our optimization tool has some limitations. Firstly, it is not a full solution to the complex problem of class scheduling, and does not attempt to dictate where and when Marshall should schedule its courses. Secondly, because our solution does not allocate classrooms to departments itself, it relies on the allocation that Hal chooses being feasible in the first place, and cannot account for situations in which there is almost enough space in a classroom, or small tweaks to courses that change the number of seats offered.

Ideally, our optimization tool would be accompanied by a tool to help Hal allocate enough rooms to each department. With the addition of such a tool, our current solution would function efficiently for every department, simplifying the process of choosing a room for each of their many classes, and in turn decreasing the number of alterations Hal must make.

With more time and resources, we would like to design a tool to make Hal's job easier by efficiently allocating classrooms to departments based on the classes they will offer and their corresponding class sizes.