DSO 570 Final Project
Optimizing Course Scheduling at Marshall
Final Report

Group 9

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Executive Summary

The purpose of the report is to find bottlenecks in the current Marshall course scheduling process and apply optimization accordingly to the areas needed improvements. Course scheduling can always be a challenging task for the administration office as it involves many parties at the same time. There are many aspects should be taken into consideration, such as limited classroom resources, new classes planned, students and faculty's preferences, and department arrangements, etc.

In this project, our group aims to maximize the overall Marshall classroom utilization rate and the courses offered during prime time (10am – 4pm). We extracted related data from the readily available historical data as the optimization inputs, which included the duration of the course, previously registered students of the course, size of each classroom, number of time slots needed and available for scheduling. The optimization is subjected to several constraints such as that the number of the registered students for each course can be no more than the size of the classroom assigned, and that each classroom in each period of the week can only be assigned to one course. **After performing the entire optimization analysis, the final outputs include summary of performance, optimal solutions, and the formatted schedule table - what day, time slots, and classroom that a course is assigned to**.

As soon as the deadline for adding/dropping courses has passed in each semester, Shannon's team can perform this optimization to figure out next year's schedule. **By implementing this optimization model, Shannon's team will be able to:**

1. Utilizing classroom resource more efficiently by increasing the current overall Marshall classroom seat utilization rate **from 0.67 to 0.86**.
2. Assigning classes primarily during prime-time by increasing the percentage of students taking classes during prime time **from 0.59 to 0.92**.
3. Monitor and evaluate the Marshall course schedules and classrooms in a term basis.
4. Output a feasible schedule on time using limited administrative effort.

With all these benefits that our model can bring, there still exist limitations. We were not able to accurately quantify the preferences and needs of lectures, departments, and students at this stage. Although some small surveys are readily available, we still had to make some assumptions to cater these preferences. Hence, conducting additional surveys are necessary so that our model can offer more potential benefits to all stakeholders.

Problems

The scheduling of courses and classrooms at USC Marshall is a complicated systematic procedure with lots of constraints. Under this situation, **the tradeoff between requirements of different parties involved and limited resources of classrooms during the prime-time can be a conundrum**.

Based on the analysis of historical data, we found that the usage of classrooms has a rather polarized distribution. In some departments such as ACCT, classes with low seat utilization rate indicating limited large classroom resources were not well used. However, in other departments, their courses with such high seat utilization rates denoted that classrooms were almost fully occupied and failed to provide students with a good learning experience. **The severe imbalanced classroom usage clearly reflected the inefficiencies in the current Marshall course scheduling process which therefore required further improvemen**t.

Hence, our group would like to apply optimization to this case in order to help the Marshall administration office generate a satisfying course schedule so that for each Marshall class, the final number of enrolled students will be as close to the size of the classroom as possible. The objective of the optimization is to maximize the average seat utilization rate of all the courses offered by Marshall and the course arranged during prime-time (10am – 4pm) at the same time. **Shannon's team can carry out this optimization before phase I of the classroom scheduling process and allocate each department coordinator a set of classroom-time slots based on the optimized course schedule output**.

Methodology

Assumption

Before the analysis, we made **five main assumptions to shrink the scope and simplify our model**. The five assumptions are as follows:

- The analysis is only limited to courses within Marshall
- One course can only require two days per week at most
- The time slot is 2 hours (to save computational power)
- The registration count for each course is similar to last year
- Seat utilization rate and prime time utilization rate are two metrics that valued equally

Before applying our model, we suggest considering these assumptions again and make some adjustments if needed. Some of the assumptions can be altered based on the scenario such as the unit time slot and equal weight assumptions. As for the time slot assumption, it is possible to change the time slot unit into 30 minutes and add the consecutive constraint to make sure the course longer than 2 hours will be assigned to the same classroom consecutively. By this way, the result will be more realistic to the business case. However, it is extremely computational heavy. Hence, we simplified our model by excluding the consecutive constraint and adding this assumption to accord with the original data and our computational power. The equal weight assumption can be adjusted freely according to how Shannon's team values these two rates as long as the sum of the weight equal to 1. The weights only serve as a tradeoff adjustment parameter.

Metrics of performance

There are two metrics of performance in our analysis. One is to represent the benefit of the administration office and the other reflects the interest of student and professors. The average seat utilization rate is the average of seat utilization rate for each course. As this rate increases, Shannon's team is able to make the full advantage of all the resources such as professor, classroom, and other operational resources. The prime-time (10am – 4pm) utilization rate measures the percentage of students taking courses in prime time. This metric can reflect the satisfaction degree both for students and for professor since the time slots in prime time are those time that more people prefer to take. In the objective of our formulation, we combine these two metrics with equal weight and obtain an overall rate to quantify the performance of class scheduling for each semester.

Application of analysis and optimization

a. Input

To perform the optimization, nine sets of input required by our model are listed as follows:

- Days of the week **I**: from Monday to Friday
- Time slots **J**: names of minimized time slot unit
- Prime time slots **Jp**: names of the minimized time slot unit in prime time
- Classrooms **K**: names of classrooms
- Course with section **Z**: names of course and its section
- Register count **R**: the number of registered students for each course
- Days per week **N**: the number of days per week needed for each course
- Sizes of room **S**: the size of each classroom

b. Output and application

After performing optimization analysis using our model, the optimization outputs include the **summary of performance, optimal solution, and the formatted schedule table**. Shannon's team is able to monitor all the metrics performance as well as obtain a plan for scheduling denoting what day, time slots, and classroom that a course should be assigned. The optimal solution can not only provide a plan for scheduling but also help the team to check out the effectiveness of scheduling with the classroom capacity and registered count in comparison to each other. The formatted schedule table will provide a clearer understanding and visualization of the class schedule based on time and classroom as well.

The administration office can carry out this optimization before phase I of the classroom scheduling process and will be able to provide each department coordinator a suggested class scheduling based on this optimized output schedule. Even if they make some adjustments for scheduling within the department, the metrics will not change a lot. Hence, as soon as the deadline for adding/dropping courses has passed in each semester, next year's schedule and potential metrics performance can be available by performing our optimization. Shannon's team can interact with each department as soon as possible to make some adjustments according to the coordination.

c. Potential issues

Since our model is only the simplified version of class scheduling optimization, there are some potential issues Shannon's team should think about as well before conducting the result. **First is reconsidering the assumptions** that were showed above and alter some of the parameters if required. **Second, we do not take the availability of professors into consideration**. In some cases, the part-time professors can only take those slots at night. Given the result of our optimization, the department coordinators have to do some adjustments to those courses. Sometimes the problem can be solved inside the department such as exchanging courses. However, sometimes additional time slots are needed. One solution is to provide the unoccupied classrooms which do exist according to our analysis. Another solution is to conduct preference survey for each professor and add more constraints to our model. Either way will be feasible. However, the second solution will be computational heavy, and the tradeoff should be considered as well. **Third, another potential issue is some adjustments should be made if two courses offered at the same time are highly likely to be chosen by the same group of students**. For this case, the schedule may have an impact on the registration rate which is not a desirable situation.

Formulation

To formulate the model, we specify the decision as to **whether assigning course z to classroom k in j time slot of i day of the week**. Our objective is to **maximize the average seat utilization rate of all the courses offered by Marshall and maximize the percentage of students taking courses in the prime time (10am – 4pm) at the same time**. This objective has two components which represent two interest groups, the management team, and students. Considering their benefits, we assign equal weights to these two components and combine them together to **maximize the average rate**. By using this combination, we are able to scale up our metric to be between 0 and 1 providing a realistic setting as well. The higher the optimal objective is, the better the class scheduling performance is.

Several constraints are set to make sure each assignment is reasonable and maintain the major feature of class scheduling in Marshall as well. It is impossible to include all of the constraints in our model because we should make a tradeoff between the computational power and result. However, we do capture all the most important aspects. The left-out constraints and solutions were discussed in the potential issues above.

Our reasonable assignment constraints include **classroom capacity constraint** ensuring the classroom assigned is big enough to contain all the enrolled student, **classroom availability constraint** avoiding assigning more than one course together, and **course duration constraint** guaranteeing the duration of each course is fulfilled. To maintain **some traditions**, we set up one more constraint to keep the two days a week course occupies same classroom and time of a day in the two days as well as follow the ‘Monday and Wednesday’ or ‘Tuesday and Thursday’ pattern. It is possible to add the consecutiveness constraint if we relax the time slot unit assumption discussed above. The consecutiveness constraint will make sure the same course that takes one time a week will be finished consecutively both for the time and for the classroom. Considering our computational power, we neglect this constraint for now.

Above is the overview of our formulation, all the mathematical details can be found in the technical appendix attached which will offer a more concrete understanding of the model.

Proposal evaluation

In order to conduct our analysis and get an optimized metrics with the decision, course and enrollment information as well as room capacity data are needed. The details are as follows:

- Course and enrollment information
  - The duration of the course
  - Previously registered count of the course
  - The requirement of days per week for each course
- Room capacity
  - Size of each classroom

To evaluate our proposal, **we used readily available historical data (excel files) including Marshall_Course_Enrollment_1516_1617 and Marshall_Room_Capacity_Chart as our data inputs. We exclude those courses that are outside of Marshall or longer than 2 hours to save the computational time and narrow the scope of the problem**. Also, **we chose Spring 2017** as our historical data for the course and enrollment information which can serve as a reference for class scheduling of Spring 2018. This process is a mimic of class scheduling as discussed before which is what Shannon's team will conduct in the future. With these two datasets, required inputs for the model can be directly or indirectly derived and will be ready for conducting optimization. The result of our evaluation will be mentioned in the following parts of the report.

Results

We started to perform our optimization analysis using MIP from a small dataset as the input and with a simple model. After verifying our metrics and the accuracy of optimization outputs, we ran our optimization model into larger dataset (here we used Spring 2017 course enrollment schedules as the dataset). **Our optimization output is actionable, logically coherent from the input data and has plausible assumptions to back it up**.

1. Actionable

Using our optimization outputs, Shannon's team **will be able to get the potential gains** as listed below:

- **Improve the current average seat utilization rate of Marshall courses** from **0.67** to **0.86** (see the code attachment for details). It means by implementing our optimization model, the team will be able to arrange classrooms more efficiently subject to the number registered of students by around **28%** than arranging courses manually.
- **Increase the percentage of students taking the Marshall courses in prime time** from **0.59** to **0.92** (see the code attachment for details). By using our optimization model, the team will be able to fulfill the preferences and needs of students around **59%** more than the current courses schedule.
- **Monitor and evaluate** the Marshall course schedules and classrooms **from one term to another term** more efficiently than the manual procedure. The results would be beneficial for not only the team but also for other stakeholders, such as faculties and students.
- **Efficiently utilize** the available space to schedule all courses and **output a feasible schedule on time**, well before registration starts. It is very useful to cater future circumstances.
- **Satisfy the preferences of faculty** by prioritizing courses taught in two days will be held at the same time. It is important to match the times with faculty preferences, so as to improve the work environment for faculty and help Marshall to recruit and retain the best.

By looking at **the output (Table 1)**, they will be able to assign each course based on the days, the time (either prime time or not) and the classrooms without worrying about crash courses and courses which take considerably more than classroom's capacity or occupy too large classes than needed.

Our optimization model will also **allow the team to deal with future circumstances** like a large-scale renovation building. If efficiency does not rise through optimization, then Marshall may be forced to increasingly schedule classes during early morning or late evening hours, which may be unpopular to the majority of students and faculty.

Furthermore, our optimization model is **adaptable to the changing needs of the students and faculty**, as the set of courses and the demand for each course changes from one year to the next, and there may be changes in the composition of students as well as turnover among faculty.

Finally, we have noticed that there are some institutional limitations. The department coordinators are currently overtaxed in general, so any cutting-edge solution that requires additional time and effort from them has a low chance of being adopted. To deal with this issue, when building our optimization model, **we pay high attention to build a solution that would save them significant time and efforts and would minimize the risk of disrupting normal operations**. Our model can run well for the large dataset (one term course schedule: **Spring 2017 with 432 different courses**) in around **4 minutes 28 seconds** subject to data cleaning and format requirements.

Room	ACC 306B	ACC201	ACC205	ACC236	ACC303	ACC306B	ACC310	ACC312	BRI202	BRI202A	...	JFF416	JFF417	JKP102	JKP104	JKP110	JKP112
M 8			FBE-529 15403					WRIT-340 66785		BUAD-302 14681	...						
M 10	ACCT-582 14289	BAEP-451 14378	BUAD-302 14662	MKT-599 16564	BUAD-281 14524	ACCT-574 14202	BUAD-281 14520	WRIT-340 66789	ACCT-373 14057	BUAD-304 14728	...	BUAD-497 15104	BUAD-306 14786	ACCT-470 14116	BAEP-451 14375	ECON-351 26358	ECON-352 26367
M 12	GSBA-612 16111	BUAD-497 15108	BUAD-302 14654	ACCT-473 14136	BUAD-497 15110		ACCT-473 14137	WRIT-340 66734	ACCT-373 14056	BUAD-310 14892	...	MKT-556 16537	BUAD-302 14650	DSO-547 16280	ACCT-470 14115	MOR-588 16720	FBE-421 15324
M 14		BUAD-281 14530	BAEP-554 14448	ACCT-581 14277	MKT-450 16496		ACCT-372 14051	WRIT-340 66769	FBE-554 15425	BUAD-310 14897	...	BUAD-307 14848	BAEP-551 14446	BUAD-280 14509	BUAD-280 14507	FBE-421 15325	ECON-352 26368
M 16			DSO-582 16289					ACCT-574 14203		BUAD-302 14677	...		ACCT-581 14276				
T 12		BAEP-451 14379	ACCT-530 14207	MOR-431 16671	BUAD-281 14528		ACCT-528 14242	BUAD-305 14766	ACCT-410 14003	BUAD-304 14755	...	MKT-405 16469	MOR-469 16680	DSO-570 16298	ECON-351 26349	ECON-351 26348	FBE-458 15367
T 14		DSO-424 16218	BUAD-201 14486	ACCT-410 14004	ACCT-370 14026		ACCT-528 14228	WRIT-340 66791	MKT-530 16525	BUAD-310 14923	...	MKT-405 16471	BUAD-302T 14701	ACCT-374 14061	ECON-351 26350	BUAD-306 14780	BUAD-306 14783
T 16								WRIT-340 66728		BUAD-302 14646	...		MKT-525 16518				
T 18			DSO-433 16227					WRIT-340 66715		FBE-470 15380	...						
T 20			BAEP-491 14397					WRIT-340 66746		BUAD-311 14914	...						
W 8			FBE-529 15403					WRIT-340 66785		BUAD-302 14681	...						
W 18			ACCT-580T 14273					WRIT-340 66779		BUAD-302T 14704	...		MOR-598 16730				
W 20			BUAD-305 14768					WRIT-340 66716		MKT-445 16493	...		FBE-558 15440				
H 8			ACCT-430 14146					WRIT-340 66781		BUAD-302 14683	...		ACCT-372 14052				
H 10	BUAD-304 14740	BUAD-281 14521	ACCT-371 14042	BUAD-306 14787	FBE-557 15436		ACCT-474 14140	WRIT-340 66719	MOR-463 16673	BUAD-304 14745	...	BUAD-497 15092	ACCT-416 14105	MKT-533 16530	DSO-510 16302	ECON-352 26365	BUAD-311 14912
H 12		BAEP-451 14379	ACCT-530 14207	MOR-431 16671	BUAD-281 14528		ACCT-528 14242	BUAD-305 14766	ACCT-410 14003	BUAD-304 14731	...	MKT-405 16469	MOR-469 16680	DSO-570 16298	ECON-351 26349	ECON-351 26348	FBE-458 15367
H 14		DSO-424 16218	BUAD-201 14486	ACCT-410 14004	ACCT-370 14026		ACCT-528 14228	WRIT-340 66791	MKT-530 16525	BAEP-599 14425	...	MKT-405 16471	BUAD-302T 14701	ACCT-374 14061	ECON-351 26350	BUAD-306 14780	BUAD-306 14783
F 10		BUAD-425 15005	BUAD-310 14888	BUAD-307 14802	BUAD-304 14732	ACCT-526 14233	BUAD-302T 14708	BUAD-304 14743	BUAD-307 14834	BUAD-304 14727	...	BUAD-307 14820	BUAD-304 14737	BUAD-304 14739	ACCT-570T 14257		BUAD-304 14723
F 12		BUAD-425 15008	DSO-401 16215	BUAD-425 15003	BUAD-425 15016	MOR-331 16682	BUAD-252 14591		BUAD-307 14804	BUAD-304 14725	...	BUAD-304 14722	BUAD-307 14808	BUAD-304 14748	BAEP-499 14401		
F 14		BUAD-304 14752	BUAD-304 14736	BAEP-465 14392	BUAD-425 15013		BAEP-465 14393		BUAD-307 14846	BUAD-310 14899	...	BUAD-302T 14705	BUAD-310 14895	BUAD-302T 14707	BUCO-450 15198	BUAD-304 14747	
F 16											...						

Table 1. Course Schedule Optimization Outputs Overview

2. **Logically coherent from the input data**
   Since we wanted to start building our optimization model from the simple dataset and with the simple model, first, we decided to use the course enrollment data in Spring 2017 and specifically for courses offered by Marshall Undergraduate Business Administration Program (BUAD). After verifying the output accuracy, we improved our model by adding some constraints for a larger dataset. Second, we restricted classrooms that only listed in the Marshall Room Capacity Chart (45 classrooms) and made some constraints to accommodate 432 different courses in Spring 2017.

   As a result, **table 1** output implies which Marshall courses should be assigned into specific time (on Monday to Friday at 8AM to 10PM) and a specific classroom out of 45 classrooms. From the table we can see, **more courses are allocated in the prime time** (10AM to 4PM) that implies our model is able to satisfy the preferences of students.

   Furthermore, **for courses taught in two days, they will be assigned into different days but at the same time** (see the whole output for further clarification) and this feature will satisfy the preferences of faculty. All courses are assigned after considering optimal classrooms capacity, possible crash courses, courses taught in two days at the same time and the prime-time preference.

3. **Has plausible assumptions to back it up**
   We realize our optimization model still has some limitations as we built it from the simplest one and improved step by step to cater larger datasets. However, **we believe with the following assumptions, our model would work well for a larger dataset** and help Shannon's team maximize the average seat utilization rate of all the courses offered by Marshall and the percentage of students taking courses in the prime-time.

   - We excluded courses longer than two hours. In fact, these courses are around 20% of all the courses so we highly encourage the team to schedule them manually.
   - At this stage, we decided to overlook time consecutiveness. Actually, we have tried to add this constraint into our model, but it is computationally expensive to run the model (it took more than 24 hours to run the model for a large dataset).
   - We excluded online courses and courses held in offices.

Recommendations

Course scheduling is a routine task that all departments and faculties do every term. From all these advantages our model has, we believe **further analysis and optimization need to be conducted to solve the limitations so that our model can offer more potential benefits to all stakeholders**. At this stage, we have the following recommendations for Marshall to pursue as next steps.

1. **Program Pathways:** Marshall should develop sample course schedule plans for each major and for each level (undergraduate, graduate and post graduate) subject to the preferences of students, faculty and departments while considering future circumstances (such as a large-scale renovation building). The pathways will not only help students to graduate in time but also help the team to arrange scheduling courses in advance accordingly.

2. **Scheduling Summit:** The ultimate goal for our optimization model is to build a solution that would save the team significant time and efforts and would minimize the risk of disrupting normal operations. By holding a scheduling summit, all stakeholders, not only the team, will be able to assess and evaluate all course scheduling optimization models, whether the model is applicable and tractable, and decide which model gives the best solution.

3. **Preference Survey**: As we built our model, we noticed that it is challenging to quantify the preferences of lectures, departments, and students. Although, some small surveys are readily available, we still had to make some assumptions to cater these preferences. We believe that conducting comprehensive online surveys will provide us with more preferences data.

Appendix

Technical Appendix

- **Assumptions**

1. In our analysis, we used the course enrollment of 2017 spring semester to optimize the course schedule of spring semester in the future.
2. We assume the duration and number of days per week needed for each course is the same with the 2017 spring course enrollment.
3. We divide our schedule to two hours per slot, so if a course is only one hour 30 minutes long, we still treat it as a two-hour long course.
4. We only focus our analysis on the seven departments in Marshall including: Business Communication (BUCO), Data Sciences and Operations (DSO), Finance and Business Economics (FBE), Leventhal School of Accounting (ACCT), Management and Organization (MOR), Marketing (MKT), and Lloyd Greif Center for Entrepreneurial Studies (BAEP). Thus, for example, courses of MBA programs are not included in our optimization.
5. For ONLINE courses or courses held in the OFFICE, since they don't need classrooms, so we don't take them into consideration.
6. If a course has a registered count greater than the seats available in the largest classroom of Marshall, which is HOH EDI that has 269 seats, we exclude it in our analysis. We have no choice but manually assign a larger classroom outside Marshall to accommodate this large amount of student.
7. The courses in the original dataset must clearly specify the exact begin and end time of that course, otherwise we have no idea on the exact duration of that course.
8. In our analysis, we only focus on courses that are no longer than two hours. In the original dataset, 19% of courses are longer than two hours. These courses must be assigned manually.
9. In our analysis, we only focus on courses that require one or two days per week in their schedule. If a course need a schedule of three or more days per week, which is rare, further manually actions needed for that course.
10. For those courses having classes two days per week, we assign them to the same classroom at the same time on either both Monday and Wednesday or both Tuesday or Thursday. We don't assign those courses to Friday.

- **Formulation**

1. Data:

I = {"M", "T", "W", "H", "F"}: set of days of week.
J: {"8", "10", ……, "20"}: set of time slots, each with 2 hours long.
J_P: set of time slots in prime time.
K: set of classrooms.
Z: set of courses.
r_z: registered count of each course.
n_z: number of days each course requires.
s_k: size of each classroom.
C: total number of courses.
w_a, w_b: Weights of two key metrics in the objective function, $w_a + w_b = 1$.

2. Decision Variable:

x_{ijkz}: Whether course z is assigned to i_{th} day of week and j_{th} time slot in classroom k. (binary)

3. MIP:

Maximize:

$$w_a \times \frac{\sum_{i\in I, j\in J, k\in K, z\in Z} \frac{x_{ijkz}}{n_z} \times \frac{r_z}{s_k}}{C} + w_b \times \frac{\sum_{i\in I, j\in J_p, k\in K, z\in Z} \frac{x_{ijkz}}{n_z} \times r_z}{\sum_{z\in Z} r_z}$$

Subject to:

(Classroom capacity)

$$x_{ijkz} \times (s_k - r_z) \geq 0$$

For each day of week i ∈ I, each time slot j ∈ J, each classroom k ∈ K, and each course z ∈ Z.

(Classroom availability)

$$\sum_{z\in Z} x_{ijkz} \leq 1$$

For each day of week i ∈ I, each time slot j ∈ J, and each classroom k ∈ K.

(Course duration)

$$\sum_{i\in I, j\in J, k\in K} x_{ijkz} = n_z$$

For each course z ∈ Z.

(Two-days courses)

$$x_{"M"jkz} = x_{"W"jkz}$$

$$x_{"T"jkz} = x_{"H"jkz}$$

$$x_{"F"jkz} = 0$$

For each time slot j ∈ J, each classroom k ∈ K, and each course z that needs two days per week.

- **Format of the input and output data**

1. **Input:**

   The analysis requires two files as input:

   a. Course Enrollment:

   The content and format of each required column in this file are listed as follows:
   First Begin Time: Time of day that the class begins. (format: xx:xx:x AM/PM)
   First End Time: Time of day that the class ends. (format: xx:xx:x AM/PM)
   First Days: Day of the week that the class meets. (format: M, T, ……, F, MW, TH, ……)
   Term: Terms are identified beginning with the calendar year and then assigned a 1: spring, 2: summer, 3: fall. So, 20153= fall 2015
   Department: Department that owns this course. (format: DSO, MKT (commonly used abbreviations))
   First Room: Room that the class meets.
   Reg Count: Number enrolled. (format: integer)
   Course: Alpha numeric course name.
   Section: Section number of the course.

   b. Room Capacity:

   The content and format of each required column in this file are listed as follows:
   Room: Code defining rooms in various buildings. This column must be the first column of the file.
   Size: Seating capacity of the room. (format: integer)

2. **output:**

   The analysis will generate an excel file "output.xlsx" containing three tabs:

   a. Summary:

   This tab shows three metrics used to measure performance:
   Optimal Objective: Aggregated metric of "Average seat utilization rate" and "Percentage of students taking courses in prime time".
   Average seat utilization rate: Average seat utilization rate of all the courses offered by Marshall.
   Percentage of students taking courses in prime time: Prime time defined as 10:00-16:00.

   b. Solution:

   This tab shows the result of all the assignments. The content and format of each column in this tab are listed as follows:
   Course: Unique ID for combined course name and section of each course.
   Classroom: The assigned classroom for this course.
   Time: The day and starting time of this course, F 14 = Tuesday at 14:00.
   Reg Count: Number enrolled in the past.
   Size: Seating capacity of the room.
   Days: Number of days this course requires.

Assignment: Whether this course z is assigned to i_{th} day of week and j_{th} time slot in classroom k. We only show the output of success assignment, so the value of this column is always 1 in this tab.

c. Schedule Table:

This tab shows the schedule after the optimization:

Index: The day and starting time of this course, M 8 = Monday at 8:00.

Column: List of classrooms available in Marshall.

Cell: Course ID of the course being assigned to the corresponding time slot and classroom.

- ## Supporting Analysis

Term	20153	20161	20162	20163	20171	20172
Department						
ACCT	0.631548	0.602936	0.312500	0.673449	0.600925	0.594203
BAEP	0.735043	0.764706	NaN	0.760417	0.748188	NaN
BUCO	0.734139	0.771654	0.342105	0.796786	0.794847	0.776316
DSO	0.807345	0.723973	0.709091	0.744275	0.792160	0.705882
FBE	0.667503	0.657227	0.747525	0.632493	0.607225	0.515625
MKT	0.767059	0.672533	0.530000	0.772083	0.663931	0.333333
MOR	0.827710	0.872753	NaN	0.851108	0.767268	NaN

Table 1. Seats Utilization Rate of each Department in each Term

	Registered	Size	Utilization
Term			
20153	7700	10738.0	0.717080
20161	7148	10399.0	0.687374
20162	349	612.0	0.570261
20163	11122	15464.0	0.719219
20171	10811	16082.0	0.672242
20172	361	620.0	0.582258

Table 2. Seats Utilization Rate by Term

	Registered	Size	Utilization
Department			
ACCT	9708	15503.0	0.626201
BAEP	1390	1847.0	0.752572
BUCO	2226	2919.0	0.762590
DSO	5953	7776.0	0.765561
FBE	7471	11759.0	0.635343
MKT	5914	8276.0	0.714596
MOR	4829	5835.0	0.827592

Table 3. Seats Utilization Rate by Department