Running Out of Classroom Space? Maybe It's a Schedule Problem

Abigail Crocker, United States Military Academy

Abigail Crocker is an Army Engineer Officer and Assistant Professor in the Department of Systems Engineering at USMA. She graduated from USMA in 2014 with a Bachelor of Science in Civil Engineering with Honors. In 2018, she received a Master of Science in Engineering Management from Missouri University of Science and Technology. In 2024, she earned a Ph.D. in Operations Research and Industrial Engineering from the University of Texas at Austin. She is a licensed Professional Engineer and certified Project Management Professional.

Joseph Speight, United States Military Academy

Joseph Speight is an Army Engineer Officer and Instructor in the Department of Civil and Mechanical Engineering at USMA. He graduated from USMA in 2013 with a Bachelor of Science in Civil Engineering. In 2017, he received a Master of Science in Geological Engineering from the Missouri University of Science and Technology. In 2022, he earned a Master of Science in Civil and Environmental Engineering from Stanford University. He is a licensed Professional Engineer.

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Abstract

As universities across the country deal with space limitations, managing resources and maximizing classroom utilization becomes a critical conversation. Optimizing class frequency and duration within engineering accreditation constraints may enable programs to achieve a higher level of learning in the classroom while providing for more efficient time management. This optimization may also lead to a more effective utilization of available space.

The objective of this paper is to assess the effects of various schedules constructed by varying the frequency and duration of course offerings on not only classroom space utilization, but also surrounding considerations such as schedule simplicity, flexibility, and robustness. This analysis is limited to the undergraduate curriculum at a small engineering university. The study compares the current schedule to several proposed alternatives, with a focus on the course and laboratory requirements of the civil engineering curriculum. Each schedule is assessed using a value model to determine the highest scoring schedules based on established criteria and weights. The analysis additionally provides a methodology for assessing various university schedules which can be extended for use at other universities to assess proposed schedule modifications.

Introduction

Most growing universities look for opportunities to continually update and modernize academic spaces as resources allow. Amid modernization, it is not uncommon to undergo changes in the academic structure of the departments to meet the changing criteria of accreditation agencies and to better align with the priorities of university leadership. Such is the case at a small engineering school where this study takes place. While the long-term benefits of such an endeavor will significantly assist in modernization, one of the short-term effects can be a significant strain placed on available classroom space. Various research efforts have begun to look at potential actions that can be taken to aid university planners in scheduling classroom space during the next decade of development. One such measure is a detailed look at the efficiency of the university's overall schedule to see if changes could increase classroom utilization rates without decreasing the high level of engineering education provided.

The lengthening of certain classes provides an opportunity for both greater depth and application of learning in the classroom as well as increased schedule flexibility. Conversely, the effect of each missed class is amplified with longer class meetings. Mixing courses with varied durations within a university also results in unique scheduling challenges for both classroom space and individual students. An initial analysis of course offerings within the civil engineering curriculum showed that of 15 courses required by the major and taught by the department in fulfillment of a civil engineering degree, 9 of those courses are taught as 75-minute classes with 30 class meetings and 6 are taught as 55-minute classes with 40 class meetings. In order to enunciate potential impacts of additional proposed shifts in class durations, we analyze the University's schedule as a

whole, taking into account not only the need for efficient use of classroom space but also additional objective measures capturing University-wide benefits of each considered schedule.

The primary contributions of our article are as follows:

- We propose five university schedules for analysis using value modeling.
- We develop or adapt five objective measures to quantify relative benefits of each schedule, as well as proposing relative weighting for each measure.
- We systematically score each schedule on each objective measure, obtaining an overall score for each, and enunciate additional considerations for each identified schedule.

Literature Review

There are extensive research efforts within the classroom use and utilization space. In a 2002 Facilities Manager article, the author concluded that "[w]hen a campus that is experiencing growth has a shortage of classroom space [...] a careful look at the utilization and scheduling of existing classrooms becomes important [1]." The author went on to discuss some of the greatest factors affecting classroom utilization efficiency noting that "[w]hen class starting or ending times differ from standard meeting times, the result is a classroom schedule as a matter of accommodation rather than optimization [1]." The author further outlines the consequences of a lack of uniformity in university schedules, stating that "[t]he effect of excessive non-uniform class start or end times throughout the week means that one class is continuing to use a room, thereby preventing another class from being scheduled at a regular start time, leading to lower utilization [1]." While the author's proposed solution of enforcing uniform class start and end times has significant merit, it is simple on paper, and does succeed in "gaining additional classroom space without the need to add classrooms," it does not significantly address pedagogical concerns about transforming course structures to accommodate space constraints [1].

As an example of extremely efficient classroom scheduling, a 2010 United States Naval Academy (USNA) Classroom Utilization Study found that the Naval Academy performed above the national average in its utilization of its classrooms with an average utilization rate of 74% [2]. This analysis was commissioned because of an increase in the demand on Naval Academy facilities due to sustained growth in the Academy's academic programs. One of the recommendations of the analysis was to "reclaim a seventh daily period of instruction by shortening the noon meal period and beginning the afternoon class sessions earlier [2]." Researchers found that this action could provide additional academic space, specifically a 14% increase, at no financial cost and without displacement of any other Academy requirements or constraints [2]. Other recommendations by this study were to create a centralized process of classroom scheduling and more productively use individual classrooms by decreasing the cushion maintained within each departmental level schedule.

From a pedagogical standpoint, a 2008 study by Reardon et al. sought to determine if longer face-to-face classroom meeting durations led to a more effective learning experience. Examining

1-hour, $1\frac{1}{2}$-hour, and 3-hour formats for a 3-credit course, the authors determined that "[s]tudents find the moderate class format significantly more appealing than either of the other two formats based both on the attitude toward the class formats and students' preference for the class formats," though there was only a marginal impact on student grades [3]. Interestingly, the researchers also found that "teaching a moderate class format may potentially boost instructor evaluations significantly higher than if the same instructor taught a short or intensive class format [3]." By way of explanation, the authors hypothesized that "[p]edagogical variety may be obtained in any class format but may well be easier to obtain in lengthier class formats [3]."

A 2007 paper examined the relationship between course scheduling and student achievement using student grades as a measure of performance [4]. The study observed 12,866 students an average of 8.2 times for a total of 105,428 grades in a class with the entire sample population coming from Clemson University over the course of two semesters. Researchers limited their sample to courses that meet at standard class times on Monday-Wednesday-Friday (MWF), Tuesday-Thursday (TTh), or Monday-Wednesday (MW) which made up 77.4% of the full sample. The authors concluded that students performed best in late afternoon classes when scheduled two days a week while they performed best in morning classes when scheduled three days a week. However, while the analysis showed that students did perform slightly better in a class that meets more often during the week, student grades were affected more strongly by the time of day, with those in afternoon classes demonstrating higher performance.

In contrast, a 2016 paper found that there was no statistical difference between student learning in courses meeting two days a week versus three days a week [5]. This paper looked at a small, highly selective liberal arts college where – like similar institutions – they were facing constraints of classroom scheduling. The researchers' data set is from an anonymous college and spans a decade of student grade records, with $n \approx 125,000$. the authors found that there was no statistical difference between students' grades in two days a week and three days a week courses. The authors did note potential pedagogical advantages for courses which meet two days a week, rather than three, such as increased flexibility within class meetings to balance lectures and class activities, as well as allow for longer in-class exams.

Similar results were shown in a 2019 paper where researchers examined the effects of transitioning an undergraduate engineering course from shorter and more frequent class periods to longer and fewer in-class sessions [6]. The authors examined four different courses which underwent similar transitions within a single academic year going from forty 55-minute classes in the fall semester to thirty 75-minute classes in the spring semester. The authors concluded that there was no meaningful change in assessment performance with the marginal change falling within the previous decade's standard deviation. However, the authors noted some challenges with students' ability to remain engaged during the longer sessions and also that the heightened consequences of each class absence merit closer attention.

Methods

In this study, we compare schedules with 55-, 75-, and 90-minute classes, as well as schedules which combine 55- and 75-minute classes. All schedules include a minimum of ten-minute

passing periods. The University currently operates on a schedule with alternating day 1s and 2s, both of which have overlapping 55- and 75-minute class periods. A key set of constraints in this study is that the class day is currently 8.5 hours long, including a designated lunch hour during which classes may not be held, and no evening or weekend classes are offered. Currently, the morning academic period is approximately four hours long, and a classroom can hold either four 55-minute classes, three 75-minute classes, or some less efficient combination of the two. There is a 75-minute exam/lecture period each day 1 after lunch. Up to two 55-minute classes or one 75-minute class can be held in a classroom on day 1 afternoons and up to two 55-minute classes or two 75-minute classes can be held in a classroom on day 2 afternoons. Each proposed schedule maintains at least two exam/lecture periods per week, though in the two schedules which combine 55- and 75-minute classes, the exam/lecture period is only 55 minutes in duration. In order to schedule a full 75-minute exam/lecture period for these schedules, either the class day would extend by 20 minutes, or it would replace a class hour on day 1 or day 2.

Another key feature of the University's current schedule which we assume must be maintained is the existence of two different two-hour lab blocks. Currently, labs are scheduled primarily on day 2 afternoons, and conflict with one 75-minute period and one 55-minute period. Alternately, labs can be scheduled for the first two 55-minute periods on day 2 (which also overlaps the first two 75-minute periods). Only ten labs can be scheduled per course per semester, so each lab block has three designators such that a student could theoretically have three courses with labs that meet in the same time block, but different days throughout the semester.

The primary driver in exploring alternate scheduling formats is constrained classroom space, which incentivizes efficient use of that classroom space. However, there are additional significant considerations for any proposed schedule such as ease of implementation, daily schedule simplicity, class schedule flexibility, and overall schedule robustness. For this reason, we use a value model to assess each proposed option. We select an additive value model with five objective measures, each of which is linearly scaled from zero to ten based on a low and high value. Weights are assigned by assessing the relative importance of a one unit shift on each scale.

In order to evaluate classroom efficiency, we calculate the number of available class minutes per room per day and multiply by the number of class days in the year for the proposed schedule. For instance, with an alternating day 1/day 2 40-class meeting semester-based schedule, if six 55-minute classes can be held in a classroom on each day, then there are 55 minutes $\times$ 6 classes $\times$ 40 classes $\times$ 2 days $\times$ 2 semesters $=$ 52,800 class minutes available per classroom per year. Based on the range of feasible values among the proposed schedules, that value would be converted to a score between zero and ten for classroom efficiency. This measure only captures regular class use of classrooms, not lab use of regular classrooms or designated exam/lecture hours within the schedule.

Ease of implementation captures the additional workload and risks associated with converting courses to fit a different class duration than currently offered. The assessment of this value measure, therefore, is particular to our University's current schedule, but could be reassessed given a different starting point for use at other universities. A ten for ease of implementation would indicate that no courses are required to change duration, while a six would indicate that

40% of courses are changing duration, and a zero would indicate that every course changes duration.

For students as well as instructors, there is value in having a consistent, simple daily schedule. In order to measure schedule simplicity, we use the number of unique class transition (start and/or end) times. For a schedule with six non-overlapping course periods each day and no exam/lecture or lab periods, for example, the simplest schedule would have identical class times and transition times each day of the week, leading to 12 unique class transition times. As long as they use start and end times common to the standard course periods, this metric will not penalize for multi-period courses (e.g. a 120-minute lab period which covers two 55-minute class periods and the ten-minute passing period between them, or a similarly structured 185-minute capstone period over three 55-minute class periods).

Class schedule flexibility captures the ease or difficulty of aligning all students against their required classes for a given year, measured by the number of available non-overlapping class slots, with a penalty for schedules which only offer certain class lengths on certain days or at certain times as this will further complicate scheduling. In order to account for the effect of lab periods on a schedule, we assume a student must have room in their schedule for two lab periods each year. For example, if six 55-minute classes can be held in a classroom on each day of the semester, and a lab period covers two regular class periods, there would be $24 - 4 = 20$ available class slots for the year.

Finally, schedule robustness uses the number of class days required per year to quantify the robustness of the schedule to disruptions, either planned or unplanned. An unplanned disruption may be a weather day, and a shorter semester would allow one or more flex days to be included into the calendar (days when class will only occur if a previous class day is lost, for example due to snow or icy conditions). A planned disruption might be a finals study day, or other no-class day added into the semester in addition to class days. Because fewer required class days leads to a more robust schedule in this sense, the highest feasible number of class days will correspond to a score of zero and the lowest feasible number of class days will correspond to a score of ten, again using a linear scale between the two end points.

In order to establish weights for the five objective measures, we assess the relative impact of a one-unit shift in each measure's score. For example, for ease of implementation, a score of ten indicates no courses need to be converted to a different class duration. A score of nine would indicate that ninety percent of courses maintain their current duration, while ten percent have to be restructured. Since we use a linear scale, each one unit decrease in score indicates an additional ten percent of courses must shift durations. Similarly, for each other objective measure, since we use linear scales and assign a score of zero to the lowest encountered value and a score of ten to the highest encountered value, a one unit change is ten percent of the difference between the highest and lowest values. We assign weights of 1–5 to the objective measures in ascending order of importance (of a one unit shift in that measure's score), and then normalize the weights to sum to one.

Results and Discussion

Keeping in mind the requirements to accommodate an exam/lecture period at least twice a week (which does not overlap with other course periods) and primary and alternate two-hour lab blocks (which may overlap with other course periods) as well as examples of schedules used by other similar universities, we propose five schedule formats for analysis. Table 1 describes the current schedule and five proposed alternate schedules. Table 2 gives characteristics of each schedule as they relate to scheduling efficiency. Using our five objective measures outlined above (classroom efficiency, ease of implementation, daily schedule simplicity, class schedule flexibility, and schedule robustness), we assess each of the measures for the current schedule and each proposed schedule.

The schedule with solely 55-minute class meetings is the most efficient in terms of available class minutes per room per year (as shown in Table 2). When scheduling only 75-minute class meetings and moving lab periods to dedicated days within each semester (typically Wednesday of each full 5-day week), we see the lowest classroom efficiency, due to only holding a total of 120 class days over school year. Although both the current schedule and the split 75-minute morning classes and the 55-minute afternoon classes schedule utilize the maximum of 160 class days per year (the same number as the 55-minute schedule), these only provide evidence of moderate efficiency because the 75-minute courses only use 75% of the available class days.

Across the University, approximately 60% of courses are currently taught as 75-minute classes. Converting a course to a different duration and number of class meetings imposes a significant workload on faculty and introduces some pedagogical risk while instructors determine the most effective methods of presenting the course in the new format. Additionally, because there are currently two options for course durations, many faculty have self-selected their preferred format for their assigned courses. Directing all courses to shift to a single format or directing a different ratio of 55-minute to 75-minute courses would impose an additional implementation burden as some or all faculty adjust not only to the new schedule, but also to a new class format. Of note, this objective measure is ease of implementation, rather than difficulty, so that a ten remains the most desired score.

Due to using the number of unique class transition times to measure schedule simplicity, this measure slightly favors longer classes in addition to uniform transition times. Therefore, while each of the schedules with a single allowed class duration (and the schedule with designated 75-minute morning classes and 55-minute afternoon classes) scores highly due to a consistent daily schedule, only the schedule with purely 90-minute classes receives a score of ten. The current schedule, with overlapping 55-minute and 75-minute class periods, has the highest number of unique transition times throughout the day. While the MWF/TTh schedule does not have overlapping class periods on a single day, it too receives a fairly low score for this measure because the two day types have almost completely different sets of class transition times. We believe this is a fair assessment of schedule simplicity, since students and instructors would have to keep track of completely different sets of transition times on the different days of the week.

A key scheduling challenge is aligning not only classrooms and instructors to the offered courses

each semester, but assigning students to particular class meeting times that accommodate all of their courses for the semester without overlap. Class schedule flexibility rewards schedules with more available non-overlapping blocks over the course of the year. At our University, students regularly take six courses a semester and often take up to seven courses a semester (fourteen courses a year). We assume that for two terms each year, each student will have a course requiring a two-hour lab block up to ten times during that term in addition to the regularly scheduled class meeting time (based on the Civil Engineering curriculum, other majors require either fewer or more labs). Because only ten lab meetings are permitted per course per term, in a 30- or 40-class term a student could take up to three lab courses which meet at different class times but share a single lab block so that electing (or being required by another major) to take additional lab courses does not significantly further restrict scheduling. For our calculations, we assume that each student attends the primary lab block two terms a year, which conflicts with at least one afternoon class period per term in most schedules, as designated in Table 1. Therefore, while Table 2 shows that there are 24 available class slots per room per year with purely 55-minute courses, an individual student only has 22 available slots in which to schedule their up to 14 courses per year, due to conflicts with lab periods.

When assessing schedule robustness, we look at the number of required class and final exam days in a year. Currently, our University has 80 class days per semester, for a total of 160 class days per year. Additionally, we factor in six final exam days per term, which also reflects our current schedule. The all 75-minute and MWF/TTh schedules tied for the fewest class days (including dedicated lab days and final exam days) offering the most robustness to disruptions, whether those are unplanned weather days or planned non-class days. In contrast, the current schedule, all 55-minute schedule, and split 75-minute morning classes and 55-minute afternoon classes schedule had an equal number of required class days, demonstrating the least robustness. Uniquely, the 90-minute option adopts a trimester schedule, requiring only 150 class days across the trimesters, but additionally requiring 18 final exam days due to having three terms, rather than two, resulting in a low score for robustness.

The assessed score for each objective measure is given in columns 2–6 of Table 3. In determining the weights to use for each objective measure, we compared the effect of a one-unit change in score for each objective measure. For classroom efficiency, the difference between the high and low raw values is 12,300 available minutes per classroom per year (column 4 of Table 2). When spread over 120–160 class days per year (column 2 of Table 2, this spread corresponds to a difference of 76.9–102.5 minutes per classroom per day. However, this value is the difference between a score of ten and zero. To get the effect of a one-unit change in score, we divide by ten and conclude that a one-unit increase in score for classroom efficiency corresponds to an additional 7.69–10.25 minutes of available classroom time per room per day.

We conducted the same process for each of the other objective measures. For ease of implementation, a one-unit increase in score indicates that 10% fewer courses must undergo a change in structure. For schedule simplicity, the most complex schedule has 24 unique transition times and the simplest schedule has only 10 unique transition times. Therefore, a one-unit increase in score corresponds to 1.4 fewer unique transition times. The lowest and highest numbers for class schedule flexibility are 18 class slots and 22 class slots. Although the purely

75-minute class schedule starts out with only 18 available class slots (column 5 of Table 2), due to the dedicated lab days, no class slots are impacted by conflicting lab hours. On the other hand, for each of the other schedules, two class slots per year are unavailable due to conflicting with the primary lab hour. Due to its range (18–22 class slots), and one-unit increase in score for schedule flexibility corresponds to 0.4 additional available class slots. Finally, looking at schedule robustness and taking into account final exam days, the range of values is 152 to 172 days. Therefore, a one-unit increase in score for schedule robustness indicates two fewer required class days over the year or conversely two additional flex days to align against planned or unplanned non-class days.

Given the relative impacts of each one-unit change in score, we rank-ordered the five objective measures, assigning a value of five to the most impactful and a value of one to the least impactful, and then normalized the weights to sum to one. We determined that the most impactful single-unit changes would be having two additional flex days available followed by needing to convert 10% fewer courses. Both of these measures would have significant University-level impacts exceeding the impact of gaining 8–10 minutes of class time per room per day. We assessed schedule flexibility and schedule simplicity as the least impactful measures, especially considering the effect of only a one-unit change in score. Finally, we applied our normalized weights to reach an overall score for each alternative, given in the right-most column of Table 3.

Conclusion

Based on the described value model used to assess each proposed schedule, the MWF/TTh schedule performed the highest overall, with primary drivers being schedule robustness and ease of implementation, while this schedule scored near the bottom on daily schedule simplicity. A challenge associated with the MWF/TTh schedule is allocating and then maintaining a viable ratio of 55-minute versus 75-minute classes across the university and within academic buildings and departments for efficient classroom and faculty utilization. The 75am/55pm schedule is similarly constrained to a ratio between the classes of the two lengths, but is complicated by the need to schedule both 55-minute and 75-minute classes in every classroom every day to use space most efficiently, and receives the lowest scores on class schedule flexibility and schedule robustness.

The second highest performing schedule utilized all 75-minute classes, and scored particularly high on schedule robustness – due to requiring only 140 class and lab days combined – as well as daily schedule simplicity. This schedule would be somewhat difficult to initially implement due to converting about 40% of classes to a new instructional period. But once 75-minute classes were established, there would not be a need to continually balance the ratio of 55-minute and 75-minute classes within academic buildings and departments. Of note, the University's current schedule performed close to the average of those assessed, buoyed by the highest score for ease of implementation, since no changes would be required to current courses, but hindered by a lack of daily schedule simplicity and overall schedule robustness.

The 90-minute class schedule performed the poorest overall, particularly influenced by a lack of ease of implementation as well as low scores for class schedule flexibility and robustness. In addition, the change from semesters to trimesters would be a major undertaking and unlikely to

Table 1: Schedule descriptions

Format	Description
Current	Alternating day 1s and 2s, overlapping 55min and 75min class periods. 4 $\times$ 55min class periods in the morning, 3 $\times$ 75min class periods in the morning, 2 $\times$ 55min classes in the afternoon, 1 $\times$ 75min (2 $\times$ 75min) classes in the afternoon on day 1 (day 2). 1$\times$ 55min exam/lecture hour in the afternoon on day 1. Primary lab overlaps 1 $\times$ 55min and 1 $\times$ 75min day 2 afternoon class. 40 classes per semester (only 30 classes for 75min courses).
All 55s	Alternating day 1s and 2s. 4 $\times$ 55min classes in the morning, 2 $\times$ 55min classes in the afternoon. 1 $\times$ 55min exam/lecture hour in the afternoon on day 1. Primary lab overlaps 1 $\times$ 55min day 2 afternoon class. 40 classes per semester.
All 75s	Two day 1s and two day 2s per week, Wednesday of 5-day week is lab/study day. 3 $\times$ 75min classes in the morning, 1 $\times$ 75min (2 $\times$ 75min) classes in the afternoon on day 1 (day 2). 1 $\times$ 75min exam/lecture hour in the afternoon on day 1. Primary lab overlaps 1 $\times$ 75min day 2 afternoon class. 30 classes per semester, 10 lab days per semester.
All 90s	Alternating day 1s and 2s. 2 $\times$ 90min classes in the morning, 1 $\times$ 90min (2×90min) classes in the afternoon on day 1 (day 2). 1 $\times$ 90min exam/lecture hour in the afternoon on day 1. Primary lab overlaps 1$\times$ 90min day 2 afternoon class. 25 classes per trimester.
MWF/TTh	6 $\times$ 55min classes on MWF (40 classes per semester). 1 $\times$ 55min exam/lecture hour in the afternoon on MWF. 5 $\times$ 75min classes on T/Th (30 classes per semester). Primary lab overlaps 1$\times$ 75min T/Th afternoon class.
75am/55pm	Alternating day 1s and 2s. 3 $\times$ 75min classes in the morning, 2 $\times$ 55min classes in the afternoon. 1 $\times$ 55min exam/lecture hour in the afternoon on day 1. Primary lab overlaps 1 $\times$ 55min afternoon class. 40 classes per semester (only 30 classes for 75min courses).

Table 2: Schedule characteristics

Format	Class Days/Year	Avg Available Class Min per Room per Day	Available Class Min per Room per Year	Available Class Slots per Room per Year
Current*	160	333.75	46,650	23
All 55s	160	330	52,800	24
All 75s	120 + 20 lab	337.5	40,500	18
All 90s	150	315	47,250	21
MWF/TTh	140	352.5	48,900	22
75am/55pm	160	335	44,600	20

*Calculations for the current schedule assume that each individual room is only used for either 55-minute classes, or 75-minute classes, and there is an even split between the two.

Table 3: Schedule scores

Format	Classroom Efficiency	Ease of Implementation	Daily Schedule Simplicity	Class Schedule Flexibility	Schedule Robustness	Overall Score
Weight	0.20	0.27	0.07	0.13	0.33	1.00
Current	5.0	10.0	0.0	7.5	0.0	4.7
All 55s	10.0	4.0	7.1	10.0	0.0	4.9
All 75s	0.0	6.0	8.6	0.0	10.0	5.5
All 90s	5.5	0.0	10.0	2.5	2.0	2.8
MWF/TTh	6.8	8.5	2.1	5.0	10.0	7.8
75am/55pm	3.3	9.0	7.9	0.0	0.0	3.6

be implemented by administrators unless broader organizational factors recommended such a drastic change to the academic calendar. While ease of implementation captures the difficulty of changing to 90-minute classes, it does not fully capture externalities associated with switching from a semester to trimester paradigm.

While these particular findings are certainly of interest, the methods of this study provide an even greater contribution by outlining an analysis process that can be replicated by other universities to provide administrators with insight on relationships between schedule choice, facility utilization, and additional schedule considerations. As institutions of higher education continue to adapt and look for unique methods to achieve their modernization goals, it is critical to ensure that reliable methods are available to capture the effects of these changes on university resources, administrators, staff, faculty, and students.

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