Instructional Space Optimization Feasibility Study
UW-Madison College of Engineering

Final Report & Recommendations

Administrative Process Redesign:
Alice Gustafson
Nevin Olson

FP&M Space Management Office:
Doug Rose

Office of the Registrar:
Beth Warner
Ed McGlinn

College of Engineering:
John Booske
Jeff Linderoth
Jim Luedtke
Hyeongmin Han

Office of Sustainability:
Craig H. Benson
Angela Pakes Ahlman

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Executive Summary

A feasibility study was conducted to determine whether use of instructional space (classrooms and labs) can be improved through the use of optimization techniques for instructional space scheduling. A systems-engineering optimization model was developed and used to evaluate strategies for deploying instructional space. The study used College of Engineering (CoE) class scheduling and instructional space for the evaluation. Data were obtained from previous class schedules and by interviewing of scheduling personnel in CoE. Outcomes of the study were evaluated in terms of the number and percentage of instructional spaces used as well as metrics related to campus sustainability.

The study showed that using optimization techniques for scheduling can result in improved utilization of instructional space and has potential to reduce the overall number of rooms required to deploy the curriculum in the CoE. In addition, imposing scheduling flexibility on offering times for class sections and exploiting this flexibility within a scheduling model can achieve a significant reduction in the number of instructional rooms required to deploy the curriculum. These savings can be achieved with only a small change in the frequency of assigning instruction in locations outside home building assignments for faculty and or at times that differ from times preferred by faculty. Reducing the number of rooms used for scheduled instruction in the CoE could result in significant energy and custodial service cost savings associated with delivering curriculum to students and allow repurposing of unused instructional rooms for other CoE activities.

Based on these findings, the following is recommended:

- Pilot the optimization of the Spring 2015 schedule of classes for CoE in coordination with the Office of the Registrar. This may lead to strategies to optimize scheduling for all UW-Madison classes campus-wide.
- Elevate scheduling responsibilities from department to the college level to obtain greater utilization of instructional space.
- Develop a change management plan to encourage faculty and staff to accept the findings and conclusions of this and previous studies and adopt the flexibility and process changes necessary to allow improvements for campus through optimization.

In light of the need for all of campus to benefit from the lessons learned in this and previous instructional space studies, we do not recommend replicating the CoE optimization feasibility study in other schools or colleges.

Acknowledgement

The project was jointly sponsored by Provost Paul DeLuca, Vice Chancellor Darrell Bazzell, and Dean of Engineering Ian Robertson of the University of Wisconsin-Madison. Financial support for the study was provided through the Administrative Excellence Program and the Office of Sustainability. The following persons contributed to the study: Steven Cramer, John Booske, Jeff Linderoth, Jim Luedtke, and Hyeongmin Han of the College of Engineering; Craig Benson, Amy Duwell Brockdorf, and Angela Pakes Ahlman of the Office of Sustainability; Alice Gustafson, Nevin Olson, and Tim Wiora of Administrative Process Redesign; Bill Elvey and Doug Rose of Facilities Planning & Management; Chris Olsen of Educational Innovation; and Scott Owczarek, Beth Warner, and Ed McGlinn of the Office of the Registrar.

Introduction

Conversation throughout higher education has indicated that improved utilization of space saves money and improves sustainability metrics at universities. Using space wisely allows existing space to be repurposed or decommissioned, reduces capital expenditures and maintenance costs associated with construction of new space, and reduces the environmental and economic footprint incurred by delivering the mission of higher education. There is significant interest at UW-Madison to use space more effectively. Administrative Excellence (AE), Facilities Planning and Management, the College of Engineering (CoE) Space Committee, and Educational Innovation all have examined space utilization on campus, albeit with different goals and focus. UW-System and the State of Wisconsin have also indicated they are reluctant to build new space if existing space is underutilized.

An AE study conducted in 2012-2013 indicated that instructional space utilization at UW-Madison currently is 42%, whereas many universities have successfully improved utilization to 65%. Current UW-Madison policy also stipulates a minimum utilization rate of 67% for classroom space (varies for other spaces on campus). Past studies at UW-Madison on instructional space utilization have drawn the following conclusions:

- **Utilization of instructional space across campus is below campus standards.** The average campus-wide classroom utilization is 42.6%, whereas the target utilization in campus policy is 67%

- **Utilization of general assignment classrooms is higher than utilization of department classrooms.** The average general assignment (GA) room utilization is 53.5%, whereas the average department classroom utilization is 31.7%, suggesting that centralized campus assignment of instructional space results in greater utilization.

- **Campus currently has more supply than demand for instructional space.** Only 10% of rooms scheduled for instruction met the classroom target utilization of 67% (88 of 887 rooms scheduled 2011-2012).

- **Non-compliance with scheduling policies is more prevalent in scheduling of department classrooms.** Campus policy provides 14 standard daily class start times and 14 standard meeting patterns, whereas 72 unique daily start times and 47 unique meeting patterns used are used across campus. However, 90% of scheduled sections comply with standard start times and 82% of scheduled sections comply with standard meeting patterns. This affects up to 7% of GA classrooms and 47% of department classrooms. As an example, start times or meeting patterns that are out-of-compliance leads to approximately 225 variations in start time, end time, and class length on Monday mornings between 7:30 am and 12:00 noon. The combined effect of non-compliance with policy is 22% of scheduled sections are out-of-compliance with either standard start time and/or standard meeting pattern.

Thus, an opportunity exists to use instructional space more efficiently on campus. Craig Benson, Co-Director of the Office of Sustainability and Alice Gustafson , Director of Administrative Process Redesign (APR) for campus, proposed a feasibility study to evaluate if a more efficient academic scheduling process could result in greater instructional space utilization at UW-Madison, thereby improving the sustainability metrics associated with delivering education. They chose the College of Engineering (CoE) as a test case on campus.

The goal of the feasibility study was to understand the reduced need for instructional space that could be accomplished by assigning space for instruction more optimally. To achieve this goal, a systems-engineering optimization model was developed and used to evaluate strategies for deploying instructional space in CoE. Outcomes of the study were evaluated in terms of metrics related to campus sustainability. The study did not engage in actual space scheduling or space repurposing, assess research space, evaluate methods to report space utilization in real time, or explore methods to measure or track success in optimal space use. This report describes the methods and outcomes of the study, and provides recommendations for future initiatives to use instructional space more optimally on campus.

Methodology

A Working Team met biweekly over a nine-month period to define and analyze the space optimization modeling for the CoE courses to be scheduled in instructional space on the CoE campus. The Working Team defined and implemented data gathering exercises, developed modeling approaches and strategies, and created measures to articulate the outcomes of the study. Input from a Steering Committee and the study Sponsors was gathered along the way to confirm and refine the method.

Data Gathering and Reconciliation

The study required an extensive amount of data regarding class schedules, room requirements, and course conflicts. CoE departmental curricular representatives were interviewed to understand and document the planning and scheduling processes. The Working Team followed processes described by CoE departments in developing semester instruction plans to determine the course conflicts. Additionally, CoE departmental curricular representatives provided information about meeting patterns that must be assigned to a specific room. All data were reviewed for completeness and consistent definition for collection and use in scheduling.

Modeling Approach

An optimization model was developed to assign instructional space to meet a specific objective given a fixed set of rooms and a set of scheduling constraints. Optimization is a modeling paradigm where a mathematical model is applied to decision problems. Solutions to the decision problem are evaluated according *objectives* and optimization algorithms seek solutions that perform well with respect to these objectives while additionally obeying a set of given restrictions. Formally, an optimization model is characterized by a set of *decision variables* and a set of *constraints*.

The optimization model was developed to simulate CoE class scheduling in CoE instructional space based on the assumption that the time and room of course meeting patterns are chosen centrally. The decision variables in the optimization model indicate whether or not a given meeting pattern should be scheduled in a specific offering time and in a specific room. Constraints ensure that the schedule does not contain overlaps and that scheduled rooms are of sufficient capacity.

Assumptions and Limitations

1. The class schedule data used is from Fall 2012 and Spring 2013. Results are reported for the Fall 2012 scenario. Similar results were obtained using Spring 2013 data.

2. CoE class scheduling meeting patterns and the CoE weekly instruction schedule were used in the model to represent typical conditions in CoE. The Working team thoroughly reviewed CoE department scheduling procedures to incorporate rules that prevent curricular conflicts.

3. The modeling was limited to CoE courses and assumes all CoE courses are scheduled in space on the CoE campus; 136 non-CoE course sections currently taught on the CoE campus were removed from the CoE instructional space schedule for modeling.

4. All CoE instructional space (department and GA classrooms and class labs) is equally available providing a combined 96 rooms on the CoE campus for instruction.

5. The base scenario model follows campus policy for allocation of instructional space (classrooms and class labs) and uses standard start times and standard days/patterns.

6. Flexibility is built into the schedule by including a buffer of three offering times for each instructional room over the instruction week.

The following minimum requirements for input data are listed below (see the Appendix for specific or formal definition of terms):

- Set of *meeting patterns*. Each meeting pattern is a section offered within a course. Instruction may occur multiple times during the week in a meeting pattern.
- Set of *offering times*. An offering time is the set of times in which instruction may take place. For example "MWF 0800AM-0850AM" is an offering time used by the model. In the model, meeting patterns are matched directly with offering times. Each meeting pattern has an associated set of offering times in which it may be scheduled feasibly.
- Set of *rooms*. Key attributes of each room used in this study are seating capacity and categorized use.
- Set of *course conflicts*. Courses are considered “conflicting” if students are required to take these two courses in the same semester.

Constraints

The following constraints were developed for any feasible room schedule.

1. Each meeting pattern must be scheduled in a feasible room. A room is feasible for a meeting pattern if the capacity is at least as large as the class enrollment and if the categorized use of the room matches the meeting pattern. Some meeting patterns are assigned to only one room, as determined by CoE departmental curricular representatives.
2. Each meeting pattern must be scheduled in a feasible offering time. For this study, possible offering times were restricted to offering times following university policy. The model used the time the meeting pattern was taught in the actual previous schedule as a surrogate for the “ideal time” that meeting pattern would be taught, but allowed the meeting pattern to be scheduled at times different from that “ideal time,” with a restriction that the duration of the offering time must stay the same, and the start-time should be within two hours of the start time of the ideal time, or be at exactly the ideal time but on a different day (e.g., a meeting pattern offered at 4:00-5:15 p.m. on Tuesday/Thursday could be moved to the same time on Monday/Wednesday).

3. Discussion and lab sections within a course could not overlap with the lecture associated with the course (de facto meeting pattern course conflicts). Overlap of different discussion and lab sections within the same course was limited.
4. Discussion and lab sections for courses defined to be in conflict were scheduled to minimize overlaps. Specifically, the model ensures lectures of different courses do not overlap and that the majority of lab and discussion sections do not overlap.
5. If the same instructor teaches multiple courses, times of these courses cannot overlap.
6. Every room must have three unscheduled offering times during the week. This constraint is included as a buffer to allow flexibility in modifying the schedule in response to late changes in course offerings. This constraint also provides flexibility to assign non-CoE courses in CoE space.

Measures

A set of baseline measures was established to reflect current instructional usage and provide comparison for modeling outcomes. The following measures were used:

- *Number of rooms used for instruction:* total number of rooms used by the schedule.
- *% in previous room:* Percentage of meeting patterns assigned to same room they were scheduled in the previous schedule. This measure is based on the assumption that the room assigned for the previous meeting pattern was acceptable, and hence is a “good” room. In an implementation of this model, this metric could be replaced with % in “most desired room”, where the most desired room would be specified by the department offering the course.
- *% in home building:* Percentage of meeting patterns assigned to the home building of the department offering the course. If a meeting pattern is not assigned to the previous room, then the model attempts to assign the pattern to a room in the home building of the department offering the course.
- *% at ideal time:* Percentage of meeting patterns assigned to a standard offering time as close as possible to which the meeting pattern was previously assigned.
- *% near ideal time:* Percentage of meeting patterns that were assigned to a standard offering time with the start time within 1.5 hours of the start time that was previously assigned.

Review and Refinement

The Working Team reviewed the assumptions in modeling, including removing all non-CoE courses, returning all CoE course from off CoE campus, using campus policy standard meeting patterns and start times, and moving courses out of non-instructional CoE space into classrooms and class labs. The Working Team also reviewed results of the simulations periodically to evaluate feasibility and to determine adjustments needed to establish baseline calculations. Replication of the current schedule (using CoE instructional space only) as well as following campus scheduling policies were also reviewed and discussed in detail. The best scenarios summary was reviewed and discussed along with the number of rooms, soft conflicts, home buildings, ideal time constraints, and the measures of room capacity utilization. A variety of scenarios were developed to evaluate the effects of modifying constraints to increase or restrict flexibility.

The Working Team identified measurable progress milestones for the development of a systems engineering approach to simulate optimal space utilization by outlining the sequence of steps needed to accomplish the goals of the charter. These milestones were used to guide the project and chart progress. These milestones assisted the Working Team with accomplishing the goals in the charter.

A Steering Committee reviewed and accepted the defined baseline measurements, constraints, modeling terminology and assumptions. The Steering Committee was disbanded after reviewing the modeling approach.

Input on the formulation was solicited from the Project Sponsors, along with recommendations for next steps and additional analyses. Two updates were conducted for the Project Sponsors.

Craig Benson, John Booske and Alice Gustafson joined the Working Team and Bill Elvey joined the Project Sponsors in their oversight role. The Working Team reviewed the initial model execution and identified the gaps in constraints defined.

Sustainability Analysis

Data were gathered on energy consumption, energy costs, and custodial costs for classroom and class lab spaces for use in the sustainability analysis. Data assignments were based on un-weighted energy consumption for classrooms and class labs (i.e., buildings do not have sub-metering for electrical use by space type, so all spaces are assumed to use energy equally) and un-weighted custodial costs for those same rooms. Data were not available to compute other sustainability metrics, such as greenhouse gas emissions and water use. All energy and custodial data were obtained from Facilities Planning and Management (FP&M).

The analysis included all of the CoE buildings included in the Feasibility study.

- Engineering Centers Building
- 1410 Engineering Drive
- Engineering Hall
- Engineering Research Building
- Material Science & Engineering Building
- Mechanical Engineering Building
- Water Science & Engineering Building
- Wendt Commons

Energy consumption in rooms was computed as the product of the energy consumption per unit area in the building and the area of each room. The custodial cost for instructional rooms was computed as the product of the area of each room and the custodial costs per unit area. Energy costs were computed assuming the energy cost is $.08656/kWh, which was provided by FP&M. An annual custodial cost of $2.59 per assignable ft^2 was also provided by FP&M. Sustainability metrics were normalized per student credit hour (SCH) to provide generality. For Fall 2012, the Office of the Registrar indicated that CoE provided 31,532 SCH.

Results

The preliminary model and scenario analysis centered on understanding the different tradeoffs in class schedule measures---number of rooms used, number of courses in home building, and number of classes at or near the ideal time---described in the preceding section. The result of the preliminary analysis was a proper calibration, or “weighting,” of these objectives so that the optimization model returned schedules that fared well across all metrics. The primary measure used to guide the optimization is minimizing the total number of rooms used for instruction, while location and time measures were given smaller weightings.

The performance of a representative optimized solution for the Fall 2012 is shown in the following table and compared to the actual schedule using the measures described in the preceding section.

Scenario	Rooms used (96 available)	GA rooms used	Room utilization	% in previous room	% in home building	% at ideal time	% near ideal time
Current	73	40	36.5%	100	86.2%	100	100
Best Fit	52	30	60.9%	64.7%	91.1%	81.3%	99.5%

The optimized solution is able to use 21 fewer rooms than the implemented schedule, while increasing the number of meeting patterns offered in the home building and scheduling nearly all of the meeting patterns very close to the time in which it was previously offered. This performance was representative. For nearly all scenarios investigated by the Working Team, the optimized schedule was able to create a class schedule that used significantly fewer rooms than the schedule that was used in Fall 2012 or Spring 2013.

Subsequent analysis was conducted to attempt to address the primary question of the project: To what extent does flexibility in scheduling policy and centralized scheduling impact the efficiency of space utilization for instruction? Additional analysis was performed based on feedback from the stakeholders to assess the impact of increased enrollment on scheduling efficiency.

Impact of Flexibility

The Working Team undertook an analysis to understand the extent of the gains in efficiency that were tied to the ability to completely determine the offering time for all of the meeting patterns. Specifically, in a "real" implementation of a centralized scheduling approach, the Working Team anticipated that complete flexibility does not exist when setting the offering times for all meeting patterns. To simulate this behavior, the optimization model was run with a given percentage of the meeting patterns having a fixed offering time. In the simulation, the meeting patterns for which the offering time was to be fixed were chosen randomly, and the remaining meeting patterns were scheduled so as to accommodate these fixed offering times.

The following table gives a summary of the results of this experiment:

Percentage Fixed	Rooms	Home Building	Near Ideal Time
10%	+1	-1.4%	+5.4%
40%	+3	-4.0%	+2.8%
80%	+3	-6.0%	+8.7%

The table shows the difference in schedule measures compared to an optimized scenario run without fixing any offering times. For example, the third line indicates that fixing the offering times for 80% of the meeting patterns results in the use of 3 more rooms for instruction, a 6% decrease in the number of meeting patterns offered in the same building, and an 8.7% increase in the number of meetings patterns offered at or near their ideal offering time. The experiment gives evidence that with a centrally-optimized schedule, inducing only a modest amount of flexibility into the schedule may result in significant improvements in room use efficiency, while maintaining a desirable schedule from a student and instructor perspectives.

Impact of Increased Enrollment

We also conducted an experiment to investigate the effect of increasing class size on the optimized schedule where flexibility is allowed. In this experiment we fixed the number of rooms that can be used to 51, and then attempted to find a schedule that maximized the number of courses taught in their home building or at their ideal time. For simplicity in this analysis we assumed that all meeting patterns increased by the same fixed percentage, either 10% or 19%. In reality, increasing enrollment would more likely be distributed as increased class sizes for lectures, but increased number of sections for discussions and lab components of a course. We report the numbers for the Fall 2012 data set in the table below. We find that with the schedule flexibility, it was possible to increase the enrollment across the board and still obtain a feasible schedule, with a modest decrease in the measures of % in home building and % at ideal time. We ran the same experiment using the data from Spring 2013, but found that with the same number of rooms (51) it was no longer possible to schedule all the meeting patterns when the enrollments increased even by 10%. We conclude that this scheduling process has the potential to help deal with increasing enrollments, but before instructional rooms are taken offline, a more detailed study considering the expected future enrollments should be performed.

Scenario	Rooms used (96 available)	Room utilization	% in home building	% at ideal time
Current	73	36.5%	86.2%	100%
Best Fit – No increase	51	59.4%	89.9%	77.3%
Best Fit – 10% Increase	51	59.4%	86.2%	71.6%
Best Fit – 19% Increase	51	59.4%	83.7%	72.1%

Sustainability Metrics

The sustainability analysis indicated that deploying the curriculum in accordance with the optimized instructional space identified in this study could result in substantial savings in energy and janitorial costs. For example, implementing the aforementioned “best fit” instructional space assignments would result in an energy savings of 32 kWh per SCH compared to existing methods, which corresponds to and energy cost savings of $2.75 per SCH or $86,800 for the semester under consideration. Custodial savings would be $2.95 per SCH, or $92,900 for the semester under consideration. Similar savings were obtained with the modest increases in enrollment described above.

Summary of Results

1. The current number of CoE instructional spaces (classrooms and class labs) available for weekly instruction exceeds the CoE curriculum demand for instructional spaces for the actual class schedules and the scenarios that were considered.

2. Improved utilization of instructional space has the potential to reduce the overall number of rooms used for CoE curriculum instruction. The “saved” space can be used to accommodate courses from other campus schools and departments or can be repurposed into other (non-instructional) uses (e.g., graduate student and staff offices, etc.).

3. Preliminary scenarios indicate that small changes in increased enrollment in CoE may be accommodated within the college by exploiting scheduling flexibility.

4. Based on preliminary model scenarios, a significant reduction in the number of instructional rooms needed to accommodate the CoE semester curricular requirements can be achieved by allowing flexibility on what offering time is used by individual class sections, and exploiting this flexibility within a scheduling model.

5. The energy and custodial costs associated with deploying the educational mission of CoE can be reduced significantly (approximately 35% in the cases considered) by assigning instructional space more efficiently using optimization techniques.

Conclusions

1. Model scenarios demonstrate that the number of needed instructional rooms can be reduced with small percentage changes in the preference for home building assignments and preferred class start times. This reduction in rooms lowers the cost and energy consumption associated with deploying the educational mission of the College of Engineering.

2. Achieving the benefits of optimization will require that the scheduling process be centralized, and that departments will need to provide key information and student-driven constraints to the central scheduler.

3. The potential improvements in utilization identified in this study rely heavily on the assumption that flexibility is included in the process and a system is in place that can take advantage of this flexibility to produce a practical schedule for the entire CoE with the reduced number of rooms. Reducing the rooms assigned for instructional use is not recommended until such a system is in place.

Recommendations

1. Pilot the optimization of the Spring 2015 schedule of classes for CoE in parallel with the Office of the Registrar to evaluate the optimization process under more realistic conditions where an initial schedule must be constructed based on estimated needs, and the schedule must be modified as the actual requirements become known. This may lead to an optimization exercise for scheduling all university classes within the Office of the Registrar, using existing software and testing current campus policy. The availability, capability, and cost of optimization tools, including commercial software systems that can perform room assignment and scheduling when given flexibility in the course offering times, may need to be explored as a result of the proposed pilot. The Instructional Space Inventory database of room attributes for all campus instructional space (GA and department) should be used for identifying all available instructional space on campus.

2. Elevate scheduling responsibilities from department to the college level to obtain greater utilization of instructional space.

3. Develop a change management plan to encourage faculty and staff to accept the findings and conclusions of this and previous studies and adopt the flexibility and process changes necessary to allow improvements for the campus through optimization strategies. In order to successfully gain usable space on campus through better utilization of instructional space it is necessary for faculty and staff to accept the findings and conclusions of this and previous studies.

Appendices

Appendix A: Project Charter

Appendix B: Data Assumptions

Appendix C: Background on Sustainability Analysis

Appendix D: Current Class Scheduling Process

Appendix A: Space Utilization Pilot – College of Engineering

Phase I – Feasibility Study

Charter Document

v13 08-27-13 approved

August 27, 2013

Team Name	**Space Utilization Pilot – College of Engineering**
Executive Sponsors	Provost – Paul De Luca Vice Chancellor for Finance and Administration – Darrell Bazzell College of Engineering Dean – Ian Robertson
Steering Committee (Core Team)	College of Engineering – Steven Cramer, John Booske Office of Sustainability – Craig Benson, Angela Pakes Ahlman Facility Planning and Management – Bill Elvey, Doug Rose Administrative Excellence – Alice Gustafson, Tim Wiora Education Innovation – Chris Olsen Office of the Registrar – Scott Owczarek, Beth Warner
Participants (Working Team)	*Office of Sustainability – Angela Pakes Ahlman, Amy Duwell Brockdorf *Administrative Excellence – Tim Wiora College of Engineering Faculty – Jeffrey Linderoth, James Luedtke College of Engineering Graduate Student - TBD Office of Space Management – Doug Rose Office of the Registrar – Ed McGlinn, Michelle Young **also serve as liaison to core team*
Background	The AE Instructional Space Utilization team confirmed that, in general, we underutilize our instructional space. The next step toward space optimization requires an understanding and a rebalancing of competing priorities such as class scheduling, energy efficiency, effective use of custodial staff in cleaning, and student and faculty preferences for location and class time. A feasibility study on classroom space optimization is being proposed within the College of Engineering (CoE). Students and faculty will create a systems engineering model to evaluate the variables related to instructional space decisions and assist in determining an optimum strategy for instructional space usage within the College of Engineering. Current Campus Data: 1. About 6% of campus space is assigned as instructional space (includes classroom and class labs) 2. 967 rooms are classified as instructional space (357 as General Assignment and 610 as Departmental). Almost 100 non-instructional rooms are used for instruction 3. In Engineering, there are roughly 95 classrooms and class labs used for instruction 4. Utilization is targeted at 67% by university policy; actual use for General Assignment averages 53.5% and Departmental use averages 31.7%

Goals	This feasibility study will bring a variety of perspectives together to better understand space utilization within one school, the College of Engineering (CoE). The goal is to understand the level of optimization that could be accomplished in CoE and to develop strategies that could be implemented to achieve greater optimization. Specific goals include: • Using a graduate student project, develop a systems engineered optimization model that can be used to determine optimal strategies for deploying academic space usage in CoE • Evaluate the optimization in terms of metrics related to our campus sustainability, such as cost per student credit hour (SCH), energy use per SCH, emissions per SCH, sq. footage per SCH) • Identify data, policies, or procedures needed to enable optimal space utilization within the desired educational outcome • Develop recommendations for a pilot program
Scope	Within Scope: Developing model and conducting space optimization simulations. No actual space will be scheduled or repurposed within this feasibility study. Out of scope: Research space and activity within the College of Engineering Design of instructional scheduling software or solutions Deployable software development Methods to keep real time utilization data in view of faculty and students Measurement and tracking of success in more optimal instructional space use NOTE: Work efforts related to this initiative will not preclude the use of the instructional space data by other individuals on campus
Critical Assumptions	1. Faculty and graduate student(s) will develop code and conduct necessary optimization simulations 2. Refined scope may be needed for each deliverable as more information is known 3. The pilot will include space within the current footprint of the College of Engineering including Wendt Commons 4. Optimization will only consider re-purpose or re-use of current footprint and will not include new construction as a viable solution
Timeline	Summer 2013 Development of the expectations/parameters for the fall pilot Approvals from Dean Robertson, VCFA Bazzell and Provost DeLuca Academic alignment activities within CoE Communication materials for CoE and campus Fall 2013 Feasibility Study Begins – Development of optimization simulations Progress Report – End of Fall semester Final Report – End of Spring semester

Pilot Deliverables	1. Systems engineered model 2. Progress Report 3. Final report including pilot recommendations
Approvals	Provost DeLuca and Vice Chancellor Bazzell approved the charter 8.27.13

Appendix B: Data Assumptions for COE Space Pilot Study
Hyeongmin Han, Jeff Linderoth, Jim Luedtke

1 Terminology

- Meeting pattern
  - Course lecture, section, or lab that should be assigned to a time and instructional room. Each row in `MeetingPatterns-1.xlsx` file represents a meeting pattern.
  - ID: SubjectCode_CatalogNumber_SectionNumber_MeetingNumber. E.g: 490_313_001_1 implies ISYE 313 Lecture001-1
- Course
  - A group of meeting patterns that have same subject code and catalog number.
  - ID: SubjectCode_CatalogNumber. E.g: 490_313 implies ISYE 313
- Offering time
  - Time that meeting patterns can be assigned to
  - ID: Begintime_Endtime_MTWRFS. E.g: 08:50_09:40_YNYNYN is offered on Monday, Wednesday, and Friday from 8:50a.m. to 9:40p.m.
- Standard offering time
  - Defined by the document, `standard_class_hours.pdf`
    - Approval-needed standard offering times: standard offering times that need Provost's approval.
    - Basic standard offering times: All the standard offering times that exclude Approval-needed standard offering times.
- Instructional room
  - Instructional room that meeting patterns can be assigned to. Each row in `COE Instructional Space Attributes Report 1122-1124.xlsx` file represents an instructional room. Also, we add Wendt Commons 0410, 0410A and Engineering Hall 2211 to the list of instructional rooms. In defining the instructional rooms, we used only the rooms that have Use-Subuse codes 110(Classrooms) and 210(Class Labs). If a room has Use-Subuse code 220 (Open lab), we include it in the list of instructional roms only if it is listed as a "mandatory room" for some meeting pattern.
  - ID: BuildingNumber_RoomNumber. E.g: 0408_3024_implies Engineering Hall 3024.

2 Data Assumptions

1. Meeting patterns
   - A meeting pattern is not included for scheduling if the meeting pattern has no begin time.
   - Meeting patterns that do not meet for the full semester (session code is not 'A1') are treated in the following manner:
     - If the meeting pattern was offered only for one or two days, it was not included for scheduling.

        * In Fall 2012-2013, meeting patterns with session code 'AAA', 'DAA', 'FAA', and 'JCB are deleted.
        * In Spring 2012-2013, there is no meeting pattern that is offered only for one or two days.
    - Pairs are formed if they need the same room and do not overlap. The pairs are tehn considered as single meeting patterns to be scheduled.
        * In Fall 2012-2013, '320_315_001_1' and '320_315_002_1' are paired.
        * In Spring 2012-2013, '418_171_001_1' and '821_200_002_1' are paired. Also, '320_315_001_1' and '320_315_002_1' are paired. For non-engineering meeting patterns, '132_771_301_1' and '132_772_301_1' are paired.
    - The remaining meeting patterns (just a couple of them) are scheduled as a full-session meeting pattern.

- We merged meeting patterns that were scheduled at the same offering time in the same room.
    - 'Back to back' meeting patterns.
        * In Fall 2012-2013, '612_349_302_1'/'612_349_002_1', '612_349_304_1'/'612_349_004_1', '612_349_305_1'/'612_3
          '612_349_306_1'/'612_349_006_1',
          '612_349_307_1'/'612_349_007_1', and '612_351_303_1'/'612_351_003_1' were merged.
        * In Spring 2012-2013, '490_350_301_1'/'490_350_601_1', '490_350_302_1'/'490_350_602_1',
          '490_350_303_1'/'490_350_603_1', '612_349_002_1'/'612_349_302_1',
          '612_349_004_1'/'612_349_304_1', '612_349_006_1'/'612_349_306_1',
          '612_349_007_1'/'612_349_307_1', '612_351_001_1'/'612_351_301_1',
          '612_351_003_1'/'612_351_303_1', and '612_351_004_1'/'612_351_304_1', were merged.
    - 'Joint' meeting patterns.
        * In Fall 2012-2013, '636_362_001_1'/'636_803_010_1', '320_376_301_1'/'320_376_302_1', '320_376_303_1'/'320_3
          '320_376_305_1'/'320_376_306_1',
          '320_376_307_1'/'320_376_308_1', '320_376_309_1'/'320_376_310_1',
          '320_376_311_1'/'320_376_312_1', '320_377_301_1'/'320_377_302_1',
          '320_377_303_1'/'320_377_304_1', '320_377_307_1'/'320_377_308_1',
          '320_210_303_1'/'320_370_001_1', '320_210_304_1'/'320_370_002_1',
          '207_315_303_1'/'207_462_301_1', and '320_370_003_1'/'320_210_302_1' were merged.
        * In Spring 2012-2013, '320_210_303_1'/'320_370_001_1', '320_210_302_1'/'320_370_002_1',
          '612_577_301_1'/'612_577_303_1', '612_313_310_1'/'612_601_403_1',
          '320_376_301_1'/'320_376_306_1', '320_376_302_1'/'320_376_311_1',
          '320_376_303_1'/'320_376_312_1', '320_376_305_1'/'320_376_308_1',
          '320_377_302_1'/'320_377_305_1', '320_377_303_1'/'320_377_306_1', and
          '320_377_304_1'/'320_377_307_1', were merged.

- Non-engineering meeting patterns that were previously scheduled in engineering campus can optionally be added. (In our base scenario they are excluded.)

2. Offering times

- Only standard offering times are used.
    - By default, we allow basic standard offering times (approval-needed standard offering times are excluded).
    - Evening times are defined as offering times that begin later than 17:30. At most two meeting patterns can be assigned to evening time in the same room.

- Additional offering times are added for the meeting patterns that cannot be assigned to the standard offering times.
  - For example, '320_454_301_1' is offered on Tuesday and Thursday for 3:00 hours, but there is no standard offering time that the meeting pattern can be assigned to. So we add '07:45_10:45_YNYNNN', '07:45_10:45_NYNYNN', '14:25_17:25_YNYNNN', '14:25_17:25_NYNYNN' to the set of offering times.

3. Instructional rooms
   - The base set of available instructional rooms is taken from the *COE Instructional Space Attributes Report 1122-1124.xlsx* file. If a room previously had no meeting pattern is assigned to it, it is excluded.

4. Conflicts between meeting patterns

   (a) We first build a list of courses that are considered to be in conflict. The idea of a conflict pair of courses is that students may need to take these two courses in the same semester, and therefore the schedule should allow this.
   - The list of course conflicts was initially populated with data from Eagle (`http://sd3.Engr.wisc.edu/flowcharts/`), where we assumed any pair of courses that is suggested to be taught in the same semester in some program is a conflict pair of courses.
   - This set of conflicts ws then refined based on interviews with department staff.

   (b) Conflicts between meeting patterns are defined based on the conflicts between courses according to the following rules.

      i. Suppose two courses A and B are considered to be in conflict.
      - In most cases, every meeting pattern associated with course A is assumed to be in conflict with every meeting pattern associated iwth course B.
      - The exception to the previous rule is that if a course has more than three offerings of a component (lecture, lab, discussion) then only a subset of the meeting patterns are considered to be in conflict.

      ii. Conflict of meeting patterns within a course.
      - Meeting patterns are grouped by component type (lectures, labs, discussion sections). Between component types, all meeting patterns associated with a component type are assumed to be conflicts with all meeting patterns in another component type. In each component type, at most three meeting patterns are assumed to be conflict with each other.

   (c) Conflicts are divided into a set of hard conflicts and set of soft conflicts. Pairs of meeting patterns that have a hard conflict are never allowed to be scheduled at overlapping times. The model allows a very small number of the pairs of meeting patterns that have a soft conflict to be scheduled at overlapping times.

      i. Conflict between two courses A and B. Only one lecture in course A is assumed to be a hard conflict with one lecture in course B.

      ii. Conflict of meeting patterns within a course.
      - For each course, if it has multiple lectures, subgroups of meeting patterns were created which each include one lecture and roughly the same number of discussion and lab sections. The lecture and all labs or discussions in each subgroup are in hard conflict.

- Also, in each component type, at most three meeting patterns are assumed to be hard conflict with each other.

5. Overlap of offering times.

   - Two offering times are considered to overlap if they overlap on any day or the ending time of one is within 10 minutes of the begin time of the other. For example, '10:50_11:40_YNNNNN' and '11:45_12:35_YNNNNN' are in conflict because of the gap.
   - In terms of the evening time, there is no conflict between evening times on different days. Also, there is no conflict between evening time and non-evening time.

6. Possible offering times for each meeting pattern.

   - This is based on the offering time when the meeting pattern was scheduled in a previous semester. We first find the standard offering time that is closest to the historical offering time for each meeting pattern, which we define as the **ideal offering time**.
   - If ideal offering time started later than 17:30, evening times can be considered as a possible offering time. Otherwise, the meeting pattern cannot be scheduled in evening times.
   - The duration of the offering time must match the duration of the ideal offering time, with a five minute tolerance (e.g., a meeting pattern that has 55 minutes duration can be assigned to the standard offering times that have 50 minutes duration).
   - The set of possible offering times for a meeting pattern is defined by using a set of offering times that with smallest distance to the ideal offering time, where the distance between offering time x and y is defined as:

     $$d(x, y) = d_{day}(x, y) + d_{time}(x, y)$$

     Here:

     $$d_{day}(x, y) = \begin{cases} 3 & \text{If offered days of x and y are not same} \\ 0 & \text{Otherwise} \end{cases}$$

     $d_{time}(x, y)$ is defined as follows. If x and y are both non-evening times, then

     $$d_{time}(x, y) = \frac{(\text{hourly difference in begin time} + \text{hourly difference in end time})}{2}$$

     If only one of x and y is evening time, then $d_{time}(x, y) = 5$. If x and y are both evening time, then $d_{time}(x, y) = 0$.
   - Only the seven "closest" offering times to the ideal offering time will be the elements of the set of possible offering times.

7. Possible instructional rooms for each meeting pattern.

   - For meeting patterns that were previously offered 'OFF CAMPUS', we introduce a dummy room that these meeting patterns can be assigned to. An unlimited number of meeting patterns can be assigned to this room. Only meeting patterns that were previously offered 'OFF CAMPUS' can be assigned to this room.
   - We used the following procedure as a starting point for determining the set of instructional rooms a meeting pattern can be assigned to.

     (a) Capacity

- An instructional room can only be in the set of possible rooms for a meeting pattern if 'Section count' of the meeting pattern is less than or equal to 'Seat count' of the instructional room.
- If 'Section count' of a meeting pattern is less than or equal to 15, then the meeting pattern can only be assigned to instructional rooms with 'Seat count' less than or equal to 30.
- If 'Section count' of a meeting pattern is greater than 15, then the meeting pattern can only be assigned to instructional rooms with 'Seat count' less than or equal to 2.5∗(Section count).

(b) Subuse

- We defined a list of 'room categories' by merging 'Use-Subuse' attribute. Also, we added 'Blended' as a special category to list of Room categories. Wendt Commons 0405, 0410, 0410A, Mechanical Engineering Building 3121, and Engineering Hall 2317 were considered as 'Blended' rooms. The full set of room categories are below, with the set of 'Use-Subuse' attributes that were assigned to that category.
  - Classroom: Assembly - Auditorium, Class Laboratory - Instrument, Class Laboratory - Laboratory Equipment, Class Laboratory - Practice Laboratory, Class Laboratory Service - Workroom, Classroom - Classroom, Classroom - Seminar, Conference Room - Conference, and Media Production - Media Studio
  - Lecture Hall: Classroom - Lecture Hall
  - Computer Laboratory: Class Laboratory - Computer Laboratory, and Open Laboratory - Computer Laboratory
  - Wet Laboratory: Class Laboratory - Wet Laboratory, and Class Laboratory Service - Wet Laboratory
  - Dry Laboratory: Class Laboratory - Dry Laboratory, and Open Laboratory - Dry Laboratory
  - Research / Nonclass Laboratory - Dry Laboratory: Research / Nonclass Laboratory - Dry Laboratory
  - Research / Nonclass Laboratory - Wet Laboratory: Research / Nonclass Laboratory - Wet Laboratory
  - Blended: Blended
- For each meeting pattern, we first find the instructional room the meeting pattern was previously assigned to, and then find the room category for that room (based on its 'Use-Subuse' value). Any rooms that are in the same room category and meets the capacity constraint are considered a feasible instructional room for that the meeting pattern.
- We obtained a list of courses that were not previously taught in a 'Blended' room, but which should be taught in a 'Blended' room going forward. For these courses, we ignore the instructional room where they were previously scheduled, and instead require that they be scheduled in a 'Blended' room. The list of these courses are following:

'207(BME)_201_001_1'	'207(BME)_310_001_1'	'207(BME)_310_001_2'
'240(CIV ENGR)_320_001_1'	'240(CIV ENGR)_320_001_2'	'240(CIV ENGR)_330_002_1'
'320(ECE)_203_301_1'	'320(ECE)_219_001_1'	'320(ECE)_230_001_1'
'320(ECE)_230_001_2'	'320(ECE)_230_001_3'	'320(ECE)_252_003_1'
'320(ECE)_252_301_1'	'320(ECE)_252_302_1'	'320(ECE)_352_001_1'
'320(ECE)_352_001_2'	'320(ECE)_352_002_1'	'320(ECE)_352_002_2'
'320(ECE)_431_001_1'	'320(ECE)_630_001_1'	'346(EMA)_201_301_1'
'346(EMA)_201_303_1'	'346(EMA)_201_305_1'	'346(EMA)_201_306_1'
'346(EMA)_201_307_1'	'346(EMA)_201_308_1'	'348(EPD)_690_010_1'
'496(INTEREGR)_103_001_1'	'684(NE)_506_001_1'	

   - Meeting patterns scheduled in the rooms that were not in our list.
     i. If component type of the meeting pattern is lecture, discussion, or seminar, 'Subuse' of the meeting pattern is considered as 'Classroom'
     ii. If component type of the meeting pattern is laboratory, define appropriate 'Subuse' for the meeting pattern.
       * In Fall 2012-2013, '612_160_003_1' and '418_595_001_1' were considered as 'Computer Laboratory'.
       * In Spring 2012-2013, '612_160_003_1' is considered as 'Computer Laboratory'.

(c) Mandatory rooms.
   - By conducting interview with department staff, a list of meeting pattenrs that required a particular instructional room (or one of a set of instructional rooms) was identifed. For such meeting patterns, the requirements given in this list were used in place of the above procedure.
   - Each row in `Input_Mandatory rooms.csv` file represents mandatory rooms for a meeting pattern.

8. Home building of a meeting pattern.

   - We defined the home building of each program as follows:

Department	Building
BME	ECB
CBE, CEE, ECE, EMA, GLE	Engr Hall
EP	Engr Research Building
ISYE, ME, NE	ME Building
MSE	MSE Building
EPD, INTERENGR, PRO OR	No home building

   - A meeting pattern is considered to be taught in its home building if it is taught in the home building of the program that offers the meeting pattern. For programs with no home building, every meeting pattern associated with that course is considered to be taught in its home building regardless of which building it is taught in.

Appendix C: Background on Sustainability Analysis

Instructional Space Optimization Feasibility Study
UW-Madison College of Engineering

This portion of the feasibility study gathered data to analyze sustainability metrics related to operations and maintenance costs of using the classrooms spaces. For all campus engineering buildings in the study (listed below), data collection was based on the un-weighted energy consumption for classrooms and the un-weighted janitorial costs for those same classrooms. All energy and custodial data was obtained from University of Wisconsin-Madison Facilities Planning and Management (FP&M) Physical Plant.

COE Buildings Included in the Study

- Engineering Centers Building
- 1410 Engineering Drive
- Engineering Hall
- Engineering Research Building
- Material Science & Engineering Building
- Mechanical Engineering Building
- Water Science & Engineering Building
- Wendt Commons

Study Assumptions

- Average cleaning cost/ASF = $2.59 (from FPM)
- Calculations were based on Assignable Square Feet (ASF) for cleaning and electrical use.
- Average cost of energy/kWh = $.08656 (from FPM)
- The buildings do not have sub-metering for electrical use by space type, so energy use is the same regardless of room type in a given building.
- Total kWh includes ALL electricity in building (i.e. fans, pumps, outlets, lighting, etc.)
- Heating is supplied by Campus Central Steam System and Cooling is supplied by the Campus Central Chilled Water System. Per FPM, heating and cooling energy components may be as much as 2-3 times the electrical energy used in each building; this energy use was not taking into consideration as the campus is on a looped system, meaning the costs for heating and cooling the spaces in the study would be required regardless (spaces cannot be isolated).

Calculations

- **Annual Cleaning Cost per Room** = (Room Area) * (Cleaning Cost per ASF)
- **Annual Cost of Energy per Room** = (Area of Room) * (Annual Energy Cost per ASF)
- **Average kWh per ASF of Building** = (Annual kWh per ASF) / (ASF of Building)
- **Annual energy cost per ASF of room =** (Average kWh per ASF of Building) * (ASF of room) * (Average cost of energy/kWh)

Appendix D: Current Class Scheduling Process

UW-Madison uses Peoplesoft as our Student Information System, which is the repository of all of the room assignments. However, we use a product called R25 (made by Collegenet) to handle the academic room assigning for the General Assignment (GA) classrooms. All other rooms are assigned by the owning unit, via a variety of other systems.

The Schedule of Classes build process, which includes GA room assigning, goes through three phases.

Phase One: Initial Call

Departments get to start updating a Fall or Spring term about midway through the previous like term (i.e. Spring 2014 term work is begun in mid-Spring 2013, around late March). They have until about three weeks before the start of the opposite term to finish their initial data entry. The Registrar's Office then locks departments out of that term in ISIS, and begins work on the term, including room assigning, final exam code assigning, and other enrollment setup issues. At this point, we make the initial room assignments for the term (usually about 6000-6300 sections into 375 rooms). All ISIS Range 1 sections (about 2700 Lecture and Seminar sections) are examined by RO staff for quality of assignment.

Phase Two: Final Call

Departments get to review and update their offerings, including all room assignments. This work usually occurs about 6 weeks after they were last able to make changes. They get usually 8 working days to make their final changes. Then the Registrar's Office locks them out of that term in ISIS again and reviews all changes and makes re-assignments (usually 700-1000 sections). Each of these re-assignments is made manually.

Phase Three: Post-Final Call Adjustments

Around mid-term the following term's Schedule is made public via Course, Class Search, and the Student and Faculty Centers (mid-October for Spring, mid-March for Fall). After this date, departments can make daily changes to their class offerings, and the Registrar's Office checks daily for changes made that would involve GA room assignments (usually 5-10/day), up to and after the beginning of a term.