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Optimizing Classroom Space in a Constrained Environment

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Abstract: This paper discusses the complexities of space allocation to classroom resources and class sections in a campus learning environment. The authors investigated how the United States Military Academy (USMA) can continue its academic program when Thayer Hall becomes inactive due to renovations and construction. The group conducted extensive background research and stakeholder analysis and concluded that the stakeholders have three main objectives: stewardship of classroom resources, effective use of cadet time, and maintaining faculty preferences. The data collection process resulted in an in-depth inventory of all available classroom spaces around campus. The group then formulated courses of action that could be feasible, given the feedback received from our key stakeholders. The three COAs formulated are the 3-2 Model, Academic Day Expansion, and Expanded Sections Model. The group uploaded the COAs into a software platform, GAMS (General Algebraic Modeling System), and saw how it would affect scheduling and classroom allocation.

Keywords: Space Utilization, Space Allocation, GAMS, Scheduling

1. Introduction

The United States Military Academy (USMA) is known for its rigorous academic schedule, which emphasizes adult learning through the Thayer Method. A key aspect of this method is maintaining small class sizes—typically up to 18 cadets per class—to facilitate engaging discussions and enhance learning. Various academic buildings support these educational activities. Following the Academic Building Upgrade Plan (ABUP), USMA plans to renovate Thayer Hall, rendering 130 classrooms inoperable. In response, the Academy will rely on available classrooms and labs in the new Cyber & Engineering Academic Center (CEAC), Building 606, Mahan Hall, Washington Hall, and other facilities to continue the Academic Program. Based on a space estimate of 28 square feet per cadet, by the current scheduling matrix, a standard classroom consists of 18 desks and chairs, along with essential resources such as chalkboards and display screens. Standard labs, which include spaces equipped with heavy machinery such as chemistry and automotive labs, are classified as special-use classrooms. These rooms are restricted from scheduling non-designated courses due to departmental constraints. The loss of 130 classrooms from Thayer Hall presents a significant challenge for the USMA Academic Program, both in terms of classroom allocation and space utilization.

Our capstone project partnered with the Dean's Staff of Resources to assess the feasibility of maintaining the Academic Program at the United States Military Academy (USMA) while Thayer Hall is under construction. The core problem we investigated was whether USMA could continue its academic operations at a similar capacity during this period. Before engaging with key stakeholders, our group familiarized itself with the problem at hand. Our literature review helped us narrow our focus on space utilization, which is critical during the construction phase. Some key findings from the literature review include examining how cadet scheduling and time management impact student learning and optimizing the cadet development system. We also explored how classrooms could be equipped to serve multiple departments, enhancing their utility, by utilizing student-focused learning techniques (Park and Choi, 2014). Not to mention, how the physical layout of classrooms should be considered when looking into how the students being taught will be affected by physical classroom aspects (Crumly et al., 2014). Doing this we were able to analyze the affects and structure of the Thayer method and determined whether classes with increased sections sizes would affect this process (Radhika and Van Dann, 2019). Additionally, we considered the use of scheduling software (GAMS) to optimize space and time management, and we analyzed the effects of classroom size, exploring

potential solutions to accommodate needs during construction. These findings guide our approach to ensuring the continuity of the Academic Program at USMA during the construction of Thayer Hall.

2. Stakeholder Analysis

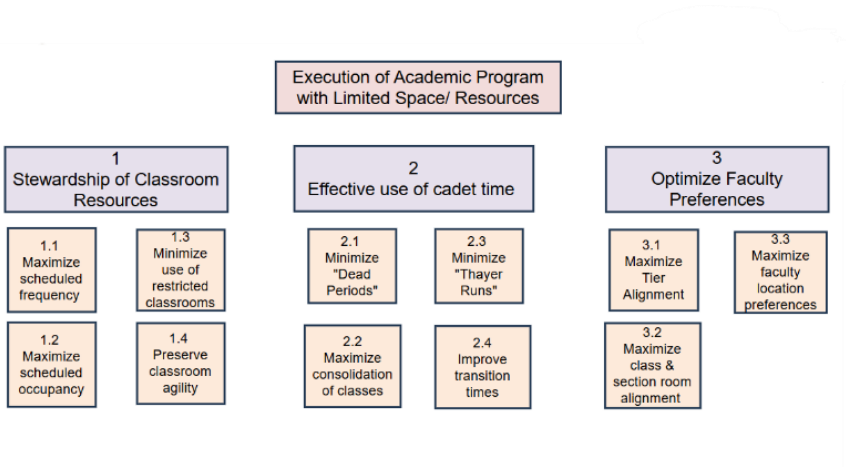

Figure 1. Optimizing Classroom Space Value Hierarchy

Utilizing a qualitative value model as seen in Figure 1, we establish the fundamental objective of the project as the execution of the academic program with limited space and resources. To achieve the fundamental objective, three functions were established upon meeting with stakeholders. These three functions consist of the stewardship of classroom resources, effective use of cadet time, and the optimization of faculty preferences.

The stewardship of classroom resources is defined as the proper usage of a classroom and its resources. To meet each function, objectives were established. In the case of the stewardship of classroom resources, it was determined the following objectives would uphold the proper usage of the classroom space: the maximization of scheduled frequency, maximization of scheduled occupancy, minimized use of restricted classrooms, and the preservation of a classroom's agility. When looking at the maximization of scheduled frequency, the goal is to ensure that a classroom is scheduled during each hour of the day and spaces are not going unused. The maximization of scheduled occupancy then refers to the number of cadets scheduled for a specific section. To ensure the maximum usage of classroom resources it is the goal to meet the set 18 cadets per class standard, especially for core curriculum courses. It also aims to minimize the use of restricted classrooms. This ensures that West Point is not using spaces such as labs or areas that are dedicated to other academic endeavors to conduct class.

Next, looking at the function of the effective use of cadet time, we focus on efficient scheduling between classes. This can be complete through meeting objectives of minimizing dead periods, maximizing the consolidation of classes, minimizing Thayer runs, and improving transitions times. The goal of the minimization of dead periods is to decrease the amount of time cadets have in which they have little ability to conduct meaningful work. In this context, a dead period is defined as a window less than thirty minutes in which a cadet must transition from one duty to another. The next value measure of the maximization of the consolidation of classes is the scheduling of a cadet's classes sequentially. We also seek to minimize the number of "Thayer runs." A Thayer run is defined as the 10-to-15-minute window in which a cadet must exit class, change uniforms, and reach their next class period. Finally, we investigated improving transitioning times. Transition times are the time gaps between classes, and we were tasked with trying to find a way to organize class periods more efficiently to allow for more productive schedules.

The final function is the optimization of faculty preferences. Although the bulk of West Point's stress is on the performance and livelihoods of cadets, faculty is a valuable resource which must be accounted for. The first objective is the maximization of tier alignment, meaning that classes are aligned with the intended classroom space of the course. The next objective is the maximization of faculty location preferences. Traditionally, departments stake claim to certain buildings, classrooms, and hallways for their own department teachings. For this objective, we are going to attempt to maximize the department preferences for their teaching locations as best as possible. Finally, we will attempt to maximize class and section room alignment. This objective is similar to maximizing faculty location preferences, we will attempt to keep the same sections in the same classrooms they have historically been taught in semester to semester. Because the actual classroom location a class

is taught in is not of utmost importance, this will not be a value measure we are concerned with, but it is something to keep in the backs of our minds.

3. COA Development

For the project to be successful, our team first needed to grasp an understanding of potential solutions to our problem. As discussed earlier, our stakeholder analysis was pivotal in our understanding of the scope of the problem and what precisely we were to do that would aid the registrar department in tackling the space-constraint problems. However, finding solutions to the space-constraint problem was a challenge that required ideas generated from stakeholders, instructors, and cadets alike.

In order to think of and formulate potential solutions, our group relied on the concept of "unstructured brain writing." In this process, everyone at the meeting (stakeholders, instructors, registrar members, and the capstone team) were given a stack of sticky notes and a pen. After the team briefly explained the problem statement and value model associated with the project in order to prime the group, the people present were given free rein to come up with as many potential solutions to the problem as possible, with no limitations and no legal/feasibility considerations.

After 10 minutes of brainstorming, the team began to group similar ideas together on the white board by simply moving sticky notes around the board. But before the meeting could disband, it was pivotal that we had a clear understanding of what precisely each idea was. If there was any confusion or misperceptions of ideas, the ideas could potentially be disregarded, and this would directly violate our goal of keeping as many possible solutions as possible. To navigate this problem, we quickly clarified all ideas on the board by asking the member who wrote it to clarify their thoughts so that the entire group had a clear understanding of the ideas.

Brainstorming solutions resulted in the Zwicky's Morphology Table shown in figure 3, which enabled the creation of the four unique COAs.

Design Parameters				
Non-Academic Structure	**Length of Day**	**Academic Day Structure**	**Unorthadox Classrooms**	**Adjust Course Reqs**
Status Quo	Status Quo	Status Quo	Status Quo	Status Quo
Two Lunch	CMDT/Dean/WPR Period to morning	**M/W/F->55 min T/TH->75 min**	Collab rooms	Reduce # of low enrollment courses
Open Meals	Remove ESP for have Class	Spread class time offerings	**Non-Traditional Spaces**	Validation of courses
	Remove ESP for CMDT/Dean	4 Days with Lab on 5th day	**Remote Teaching**	**Increased Section Size**
	Extend class day		Fully Remote (in person WPR)	

Figure 3. Zwicky's Morphology Table

Our four main COAs are grouped by color in Figure 3, and highlighted below:

1. **3-2 Model** (M,W,F 55 min classes, T/TH 75 min classes)
2. **Double Up Model** (2 sections scheduled for every classroom per hour, one in person and the other virtual)
3. **Academic Day Expansion** (Add one teaching hour during each day of instruction)
4. **Expand Sections** (Ensure a minimum of 18 cadets per section, and utilize unorthodox teaching locations)

Important to note is the fact that for ease of viewing, all COAs have the "status quo" of all other parameters, except for the "Expand Sections" COA (blue) that takes adjustments from both unorthodox classrooms, as well as adjusting course requirements.

4. Methodology

4.1 Inventory Development and GAMS Implementation

To assess the magnitude of the Thayer Hall renovation, we conducted a thorough evaluation of the classroom inventory. This process began with the identification of currently used classroom spaces throughout the academy. Each room

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was then categorized based on its capacity and its functional use. These categories included general classrooms, hard labs, and soft labs. Moreover, we identified non-traditional spaces as well, such as collaboration rooms and conference rooms, that could potentially be converted into a viable classroom space. Along with the future construction of Thayer Hall, the current construction of the Cyber and Engineering Academic Center (CEAC) and the Math and Systems Engineering Center (MSEC) posed another conflict in making sure proper accountability of all teaching spaces were presented in the software inventory. Understanding that these buildings would be available before the start of construction on Thayer Hall, we collaborated with Dr. Ledlie Klosky, a key stakeholder in the development of the CEAC and MSEC. With his help, we obtained blueprints and furniture layouts for these new buildings to determine the count and capacity of future classrooms/labs. This updated inventory was then processed in the General Algebraic Modeling System (GAMS) software to more accurately depict the operational environment at the time of Thayer Hall construction. GAMS is a high-level mathematical optimization modeling system. We leveraged this existing commercial GAMS platform that has been developed and refined over the years to manipulate input files and analyze outputs efficiently. Previous research by Urbán Rivero (2020) on Integer Linear Programming (ILP) models for classroom assignments highlights how structured optimization approaches can reduce scheduling conflicts and improve space utilization efficiency. The application of ILP principles within the GAMS framework allows for the precise handling of classroom constraints, features, and optimization penalties to ensure optimal room assignments.

$$minimize \sum_{i,n} v_{i,n} p_{i,n} \tag{1}$$

The above objective function (equation 1) details the optimization methodology of GAMS where i is a classroom feature, n is a classroom, v is a binary variable of feature violation, and p is a penalty score of feature i in classroom n. GAMS utilizes this minimization function to not only minimize the number of penalties administered to various sections but also to minimize course section hours without a room. Both subject to the constraints that section size cannot exceed room capacity, each section is assigned to only one room and time slot, and that there is no "double-booking" of rooms.

Once the GAMS inventory was finalized, we utilized GAMS to simulate scheduling scenarios. The first step in this process was to establish a baseline mode, which operated with the updated inventory and current scheduling parameters. This model allowed our team to assess the extent of the classroom shortfall and identify what parameters needed to be adjusted. To explore potential solutions, we developed and tested four primary Courses of Action (COAs) within GAMS: the 3-2 Model, the Double Up Model, Academic Day Expansion, and Expanded Sections. Each of these COAs was tested individually to identify its impact on the number of classroom scheduling conflicts. Additionally, we explored the feasibility of combining parts of different COAs to determine an optimal solution that would maximize efficiency while providing the most value aligned to our value hierarchy.

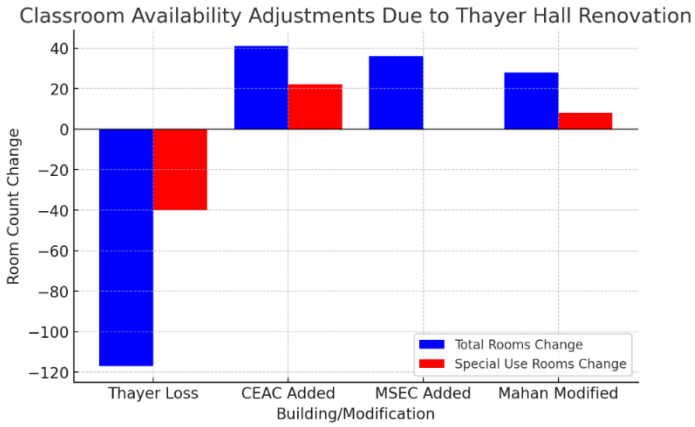

Figure 2. Inventory Classroom Adjustments

4.2 Validation

To validate our methodology, we engaged in continuous iterative feedback meetings with key stakeholders including the Registrar's Office, USMA G3 of Resources, and members of the Dean's staff. These meetings provided critical insights

that allowed our team to refine our value model, COAs, and assumptions to validate the feasibility of our proposed solutions. Through this iterative testing of COAs and stakeholder engagements, we ensured that our final recommendations aligned with the Academy's priorities and operational capabilities. By utilizing this data-driven approach, we developed a scheduling framework capable of mitigating the space constraints inflicted by the Thayer Hall renovations. The application of GAMS allowed our team to analyze various COAs effectively, ensuring that USMA can maintain its academic program while being flexible in a forever-changing environment.

5. Results

After building our baseline model in GAMS by adding the inventories of the CEAC and MSEC into the Excel data files, and also adding 11 "soft" labs (rooms classified as "labs" but that do not have any lab equipment impeding the learning environment) from Bartlett Hall and 17 additional classroom spaces that are currently used for storage and other miscellaneous uses, we came to the conclusion that approximately 103 sections would be unassigned to a classroom. Change needed to occur, and so we began to formulate our COAs into GAMS by manipulating the Excel data input files.

5.1 Feasibility

Like discussed above, once ideas were grouped into the Zwicky bins, we had to filter through the potential ideas and cut out any and all ideas we deemed infeasible. If an idea was too vague, unattainable, too disruptive, or if it directly contradicted our value model, it was cut from our table. Similar to the actual ideas generated and the parameters constructed, we also had to filter through potential COAs for feasibility once our Zwicky's table was completed.

After discussing with our stakeholders, we determined that three out of the four COAs originally brainstormed could be a potential feasible solution in the future, and all four COAs could be programmed into GAMS if needed to. The three feasible COAs are as follows:

1. **3-2 Model**
2. **Academic Day Expansion**
3. **Expand Sections**

The reason that the "Virtual Opportunities" COA was deemed infeasible was simply because it would be a "hard sell" to the academic decision makers at the institution. Although still possible to program into GAMS, the COA would not be an attractive solution to the academy even if the results were promising. As a result, the three COAs listed above are the three main COAs that our team was tasked with investigating.

5.2 Evaluation

The first of two COAs our team was able to completely run through the GAMS software was the Expanded Sections COA. In this COA, we made the minimum amount of cadets allowed per section (in classes that had at least 18 cadets enrolled) 18. This allowed for classes like EN101 and MA103 to switch their average enrollment per section from 15 cadets to 18, and severely decreased the number of sections each class required. In doing so, we were able to free up over 50 sections that could be taught by other classes, and as a result, a total of only 55 classes were left without a classroom (a 46.6% decrease from the baseline). Thus, the expanded section COA showed a promising start to what could potentially become a viable solution. We then looked at opening as many "soft" labs as possible (17), opening classrooms currently used as storage (7), and also looked at taking "special use" constraints off of potential classrooms (13). This "least restrictive" approach enabled the team to come up with a viable solution with zero classes left without a classroom. While a solution, it is not necessarily favorable to the institution or academic departments because of high utilization rates of all classrooms available leaving little to no wiggle room for adaptability in the case a pipe breaks or classrooms come off-line for one reason or another. However, it proves that even in a worst-case scenario situation, West Point will be able to hold classes when Thayer comes off-line given the infrastructure available.

The second COA that was able to be analyzed was the 3-2 model. During this GAMS run we were able to determine that it is feasible to have a 3-2 schedule, however, given the current layout of 55 minute classes vs 75 minute classes, it is extremely inefficient to have a 3-2 model due to the imbalance between the two. However, as we will later discuss in our "way

ahead," the 3-2 model is extremely important to our stakeholders, and upon further research and changes, it can most definitely be a viable solution contingent on if a number of 75 minute classes switch to 55 minutes instead.

6. Conclusion

The availability of space, to continue our academic program here at West Point is the problem at hand. It is a unique problem that will arise from the renovation of Thayer Hall. This step of the Army Building Upgrade plan will be responsible for the deactivation of our core academic building that holds the most classrooms and offices on campus. We investigated this problem using the opinions of subject matter experts who all have a different stake in the problem. This helped drive a sequential research process where we created a problem statement, updated a data inventory of our space, and finally developed and tested our courses of actions.

The development and testing of our courses of actions is what gave this project its validity. Using the opinions and experiences of SME's as well as utilizing the GAMS optimization system, we were able to come up with feasible and relevant recommendations. While there is still much research to be had in this area of exploration, the work we have accomplished thus far will be pivotal in creating a base upon which future leaders and stakeholders can use for their own exploration.

6.1 Way Ahead

To ensure progress in future research, there are two specific courses of action we would recommend that following capstones should tackle. These models are what we call the 3/2 model and the academic day expansion model.

For the 3/2 model, we made strides in exploring the number of conflicts that would arise with this model. After manipulating the 8TAP to have the 55-minute days and the 75-minute days, we realized that this model was not currently feasible. This is because we have an excess of 75-minute classes, causing a high number of conflicts in cadet schedules in the DDS output. The next step would be to take the total number of conflicts and determine how many 75-minute classes need to be converted to 55-minute. Providing Academy leadership with this percentage will then allow them to decide which exact courses need to be changed.

As for the academic day expansion model, we did not make any data-driven progress. Instead, we gathered feedback from stakeholders that showed how invested they were in seeing the possible time and space we could buy back. For this model, we would create a new hour in GAMS, then place arbitrary classes in that hour to mimic any other existing hour. The output from that run would then be passed to Academy leadership to decide where this extra hour could go—ultimately landing in a non-traditional time of day like Commandant's Hour, Dean's Hour, the evening study period, etc.

7. References

Crumly, C. L., Crumly, C., Dietz, P., & d'Angelo, S. (2014). Designing a Student-Centered Learning Environment. In *Pedagogies for Student-Centered Learning* (pp. 73–92). 1517 Media. https://doi.org/10.2307/j.ctt9m0skc.8

Park, E. L., & Choi, B. K. (2014). Transformation of classroom spaces: Traditional versus active learning classroom in colleges. Higher Education, 68(5), 749–771.

Urban Rivero, L. E., Benitez Escarcega, M. R., & Velasco, J. (2020). An integer linear programming model for a case study in classroom assignment problem. *Computación y Sistemas, 24*(1), 97–104. Publisher: Instituto Politécnico Nacional, Centro de Investigación en Computación. http://cys.cic.ipn.mx/ojs/index.php/CyS/article/view/3388