# Dynamic Course Scheduling for Strategic University Scaling via Mathematical Optimization

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## 1 Introduction

In the competitive academic markets with evolving enrollment trends, universities need optimized operations to manage resources effectively and advance their missions. Universities often use a combination of commercial software or ad hoc custom solutions together with manual adjustments for adapting year-over-year course schedules. As universities grow and scheduling demands intensify with faculty preferences and enrollment trends change, manual modifications (even with commercial software) become time-consuming and increasingly challenging to manage, yielding results that may be far from optimal [4, 2]. In contrast, optimization-driven approaches offer optimal or best near-optimal solutions to these challenges, allowing for rapid and efficient adjustments to schedules via a wide range of constraints and objective functions.

Optimization-driven approaches can reveal the organizational capacity of universities and enable long-term strategic decision-making. However, the adoption of these techniques is limited. One of the main challenges is presenting $\mathbf{x}^*$ (the optimal solution) to stakeholders in an intuitive and interactive manner. This project aims to demonstrate how mathematical optimization can enhance long-term decision-making at universities, specifically using Worcester Polytechnic Institute as a case study. Through a series of visualizations, stakeholders will be able to compare the differences between actual and optimized space utilization. Additionally, the trade-offs between accommodating additional students and course sections over the years will be illustrated through various scenarios.

## 2 One-sentence description

This project aims to demonstrate how mathematical optimization can enhance strategic decision-making at universities, specifically by using visualizations to compare actual versus optimized space utilization and illustrating trade-offs in accommodating students and course sections at Worcester Polytechnic Institute.

## 3 Project Type

Scrollytelling visualization.

## 4 Audience

> *Who is the audience for this project? How does it meet their needs? What happens if their needs remain unmet?*

This project primarily targets university administrators and decision-makers, showcasing the significant benefits of adopting mathematical optimization in academic operations. By demonstrating how optimization can streamline course scheduling, maximize space utilization, and efficiently allocate resources, the project aims to persuade universities to invest in these technologies. The visualizations and scenario comparisons provided will make the advantages tangible, helping stakeholders see the potential for cost savings and improved operational efficiency.

To ensure the optimization tool remains effective and relevant as conditions change, the system can be designed to accommodate additional visualizations for different datasets or scenarios. This flexibility allows continuously adapt to new challenges and opportunities as they arise, thereby providing enduring value to the university's strategic decision-making process.

# 5 Approach

## 5.1 Details

*What is your approach?*

My approach is centered around developing a user-friendly interface that is designed for both technical and non-technical users, emphasizing the practical impact of optimization through interactive visualizations rather than complex mathematical expressions. Recognizing that the potential of operations research tools often goes unrealized in academic settings, I aim to bridge this gap by implementing cutting-edge analytical tools in an intuitive manner. Instead of relying on traditional methods like spreadsheets and emails, our web-based platform will offer a self-explanatory and engaging tool that simplifies data interpretation and decision-making processes. This will enable users to not only understand but also interact with the data, exploring various scenarios and their outcomes to fully grasp the benefits and implications of optimization in university operations.

## 5.2 Evidence for Success

*Why do you think it will work?*

This approach is grounded in a proven need for optimized course scheduling at WPI, evidenced by the enthusiastic response from key stakeholders such as the registrar, provost, and board of trustees when initially presented with interactive visualizations. The marked shift in engagement when stakeholders were shown an interactive treemap—highlighting their heightened interest and inquisitive reactions—underscores the potential impact of this tool. By expanding beyond treemaps to include a variety of visualizations, the webpage will cater directly to the evolving questions and needs of the users, such as exploring the capacity to add more students. This tailored, interactive approach not only addresses specific institutional challenges but also significantly enhances stakeholder understanding and decision-making capabilities. The positive feedback and interest already generated suggest that the full implementation of this project will meet, if not exceed, the expectations of WPI's decision-makers, making it a valuable asset in their strategic toolkit.

# 6 Best-case Impact Statement

*In the best-case scenario, what would be the impact statement (conclusion statement) for this project?*

In the best-case scenario, the success of this project will not only demonstrate the practical benefits of adopting advanced optimization techniques for course scheduling at Worcester Polytechnic Institute but will also pave the way for further institutional support and funding. Together with my advisor, Professor Andrew Trapp, we can to present our findings and the demonstrated efficiencies to the provost. This will showcase the significant improvements in resource utilization and decision-making processes, compelling the administration to broaden the scope of optimization techniques across campus operations. Such support would enable us to refine and expand our tools, potentially setting a standard for operational excellence in academic settings that could inspire similar initiatives at other universities.

# 7 Major Milestones

- Understand scrollytelling library, idyll, components
- Decide the webpage flow based on thinking how it aligns with the story
- Creating treemaps with annotations, scrollytelling steps for scenario comparisons
- Embed visualizations to the webpage

# 8 Obstacles

## 8.1 Major obstacles

- Determine the type of visualizations
- Visualizing dual-axis data, without complicating it for stakeholders
- Not having any front-end experience
- Scrollytelling library (idyll) that I use for this project has poor documentation and provided links often do not work

## 8.2 Minor obstacles

- Deciding the color of the background, width and height of the visualizations
- Learning to test interactive visualization in local server

# 9 Resources Needed

*What additional resources do you need to complete this project?*

- Idyll documentation, and youtube videos to learn how to use it
- Datasets given from WPI registrar office, and optimal results that I run
- Code to generate visualizations

# 10 5 Related Publications

*List 5 major publications that are most relevant to this project, and how they are related.*

- As stated by Lindahl et al. [3], while strategic decisions have long-term effects on university timetables, the literature has largely overlooked strategic problems.
- Petrovic and Burke [5] discuss methods to solve timetabling problems, and one of the well-known techniques is integer optimization.
- McCollum [4] discuss the gap between theory and practice in university timetabling.
- A hierarchical optimization approach, where components of the objective function are assigned different hierarchical ranks, is proposed in the studies by van den Broek et al. [6].
- de Souza Alencar et al. [1] conduct an empirical methodological study for evaluation of visualizations in the context of educational timetabling problems.

# 11 Define Success

*What is the minimum amount of work necessary for this work be publishable?*

Visualization of operations research outcomes is often overlooked in the literature. For this project to be considered publishable, essential steps include conducting visualization experiments with non-experts to assess the effectiveness and clarity of the visualizations. This would involve gathering qualitative and quantitative feedback on usability and comprehension, which can guide iterative improvements to the interface and the data presentation. Additionally, expanding the range of visualizations to cover more scenarios would be beneficial to demonstrate the robustness of the tool.

# References


[1] Wanderley de Souza Alencar, Walid Abdala Rfaei Jradi, Hugo Alexandre Dantas do Nascimento, Juliana Paula Felix, and Fabrízzio Alphonsus Alves de Melo Nunes Soares. An empirical methodological study of evaluation methods applied to educational timetabling visualizations. In *International Symposium on Visual Computing*, pages 209–223. Springer, 2020.

[2] Jill Johnes. Operational research in education. *European Journal of Operational Research*, 243 (3):683–696, 2015. ISSN 0377-2217.

[3] Michael Lindahl, Andrew J. Mason, Thomas Stidsen, and Matias Sørensen. A strategic view of university timetabling. *European Journal of Operational Research*, 266(1):35–45, 2018. ISSN 0377-2217.

[4] Barry McCollum. A perspective on bridging the gap between theory and practice in university timetabling. In Edmund K. Burke and Hana Rudová, editors, *Practice and Theory of Automated Timetabling VI*, pages 3–23, Berlin, Heidelberg, 2007. Springer Berlin Heidelberg. ISBN 978-3-540-77345-0.

[5] Sanja Petrovic and E. Burke. University timetabling. In Joseph YT Leung, editor, *Handbook of Scheduling: Algorithms, Models, and Performance Analysis*, pages 45–1. CRC press, 2004.

[6] John van den Broek, Cor Hurkens, and Gerhard Woeginger. Timetabling problems at the TU Eindhoven. *European Journal of Operational Research*, 196(3):877–885, 2009. ISSN 0377-2217.