Contents

1 Introduction

Navigating the course requirements for an undergraduate degree at McGill University is a complex and challenging task, particularly for freshmen who are new to academic planning. With a typical degree requiring the completion of 120 credits over four years, students must carefully balance prerequisites, electives, major and minor requirements, and time constraints across semesters. In addition to meeting these requirements, students often aim to optimize their academic experience by selecting high-quality courses, minimizing course difficulty, and choosing professors with strong teaching ratings. This project aims to assist McGill undergraduate students in optimizing their course selection over a four-year study plan. For analysis purposes, we demonstrate our model using a student pursuing a Joint Major in Mathematics and Computer Science with a Minor in Management. The goal is to design an optimal four-year course schedule that satisfies all academic requirements while balancing workload and aligning with the student's academic and career objectives. The primary objective is to ensure the student fulfills all program requirements while achieving academic excellence and personal growth. By strategically selecting courses, the student can maximize academic performance, acquire deeper knowledge in key areas of study, and enhance their preparedness for future opportunities, such as graduate studies. Prioritizing high-quality courses and experienced professors allows the student to extract maximum value from their educational investment. Using decision analytics, this project frames course scheduling as an optimization problem and applies binary linear programming to incorporate constraints such as credit limits, prerequisite sequencing, and term-specific course offerings. The report outlines the problem formulation, data collection, implementation, and results, providing actionable insights into optimizing course scheduling for undergraduate students.

2 Problem Description and Formulation

2.1 Problem Description

The optimization model for this project draws inspiration from the Knapsack problem, a well-known challenge in operations research and computer science. The Knapsack problem involves selecting a subset of items, each with a weight and value, to maximize the total value while staying within the weight capacity of the knapsack. Similarly, in this project, each course section represents an item with attributes such as value and weight. The value of a course is determined by factors like course quality, professor rating, and difficulty, with appropriate weights assigned to each factor. The weight corresponds to constraints such as the course's credit load and time availability. The knapsack, in this context, is the student's schedule for a specific semester, constrained by total credit limits, time conflicts, course availability, and prerequisite requirements.

This scheduling problem is extended over eight semesters spanning four years, transforming it into a multi-period knapsack problem. Each semester serves as an individual knapsack, with binary decision variables indicating whether a course is included in the schedule for that semester. Additionally, the model incorporates time-series dependencies, requiring prerequisite courses to be completed in earlier semesters, adding a sequential dimension to the problem. This approach seamlessly integrates the structure of the knapsack problem with time-series considerations, providing a systematic and efficient solution to the inherently complex task of course scheduling.

2.2 Model formulation

The undergraduate degree at McGill University requires students to complete 120 credits in 8 semesters over four years. This academic journey presents multiple challenges, including prerequisite requirements, program requirements, and scheduling constraints.

Indices	
i	Index for course sections.
j	Index for semesters ($j \in \{1, 2, \ldots, 8\}$).
k	Index for prerequisite courses for course i.
j'	Index for semesters before j (i.e., semesters in which prerequisites may be completed).
i_1, i_2	Indices for course sections that overlap in time or have restrictions.

Parameters	
Credits_i	Number of credits for course i.
$\text{Prereq}(i)$	Set of prerequisite courses for course i.
RestrictedPairs	Set of all course section pairs that cannot be taken in the same semester due to restrictions (e.g., overlapping content).
OverlapPairs	Set of all course section pairs that overlap in schedule (e.g., same day and time).
$\text{Sections}(c)$	Set of all sections for a given course c.
RequiredCourses	Set of all required course sections that must be completed during the program.
Quality_i	Quality score for course i.
ProfessorRating_i	Professor rating for course i.
Difficulty_i	Difficulty score for course i.

Decision Variables	
$\text{Take}_{i,j}$	Binary decision variable indicating whether course i is taken in semester j.

Objective Function:

To maximize the overall benefit to the student, this benefit is a weighted combination of the following factors: ***i)*** **Course Quality:** Prioritizes courses that provide academic value and relevance to the student's program. ***ii)*** **Professor Rating:** Gives importance to courses taught by highly-rated professors to enhance the learning experience. ***iii)*** **Course Difficulty:** Minimizes courses with higher difficulty levels to balance workload across semesters. The weights assigned to these factors reflect their relative importance, ensuring a balanced trade-off between academic performance and workload management. It also allows personal preferences to be reflected through optimal weighting.

$$\text{Maximize: } \sum_{i,j} \text{Take}_{i,j} \cdot \left(\text{Weight}_q \cdot \text{Quality}_i + \text{Weight}_r \cdot \text{ProfessorRating}_i - \text{Weight}_d \cdot \text{Difficulty}_i\right)$$

Constraints:

Course Load Per Semester: Students must take exactly five courses per semester to maintain a balanced workload.

$$\sum_i \text{Take}_{i,j} = 5, \quad \forall j \in \{1, 2, \ldots, 8\}.$$

Credit Requirements: The total credits across all semesters must be between 120 and 122, meeting graduation requirements.

$$120 \le \sum_i \sum_j \text{Take}_{i,j} \cdot \text{Credits}_i \le 122.$$

Prerequisite Constraints: Courses can only be taken if their prerequisites are completed in earlier semesters. Both AND and OR conditions for prerequisites are handled.

$$\sum_{k \in \text{Prereq}(i)} \sum_{j' < j} \text{Take}_{k,j'} \ge \text{Take}_{i,j}.$$

$$\sum_{j' < j} \text{Take}_{k,j'} \ge \text{Take}_{i,j}.$$

Course Availability: Courses can only be taken in the semesters (Fall, Winter, or Both) in which they are offered.

$$\text{Take}_{i,j} = 0, \quad \text{if } i \text{ is not offered in the term of semester } j.$$

Required Courses: All mandatory courses for the student's program must be taken at least once during the four years.

$$\sum_j \text{Take}_{i,j} \geq 1, \quad \forall i \in \text{RequiredCourses}.$$

No Multiple Sections: A student can enroll in at most one section of a given course.

$$\sum_{i \in \text{Sections}(c)} \sum_j \text{Take}_{i,j} \leq 1, \quad \forall c \in \text{Courses}.$$

Course Restrictions: Some courses with overlapping or conflicting content cannot be taken in the same semester.

$$\text{Take}_{i_1,j} + \text{Take}_{i_2,j} \leq 1, \quad \forall (i_1, i_2) \in \text{RestrictedPairs}, \forall j \in \{1, 2, \ldots, 8\}.$$

No Time Conflicts: Courses scheduled at the same time in the same semester cannot be taken together.

$$\text{Take}_{i_1,j} + \text{Take}_{i_2,j} \leq 1, \quad \forall (i_1, i_2) \in \text{OverlapPairs}, \forall j \in \{1, 2, \ldots, 8\}.$$

Math Complementary Courses: Students must complete at least 12 credits from designated math complementary courses.

$$\sum_{i \in \text{MathComplementary}} \sum_j \text{Take}_{i,j} \cdot \text{Credits}_i \geq 12.$$

Computer Science Complementary Courses: Students must complete at least 9 credits from advanced computer science courses.

$$\sum_{i \in \text{CompComplementary}} \sum_j \text{Take}_{i,j} \cdot \text{Credits}_i \geq 9.$$

These constraints collectively ensure that the generated schedule meets program requirements, avoids conflicts, and aligns with the student's academic goals. By balancing workload, satisfying prerequisites, and adhering to term offerings, the model provides a practical and optimal schedule for the student.

3 Results and Discussion

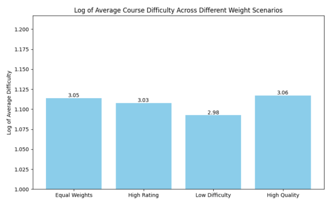
3.1 Optimal Result

The results showcase the optimized outcomes of our model. The model selects courses that best fit into each semester to maximize the objective value function, which considers program requirements, workload balance, and academic goals. Each semester includes five courses, arranged into a detailed schedule table with time slots. This table enables the student to visualize their course distribution and make adjustments based on individual preferences or specific needs. The model provides flexibility, allowing the student to tailor their schedule while adhering to their academic plan.

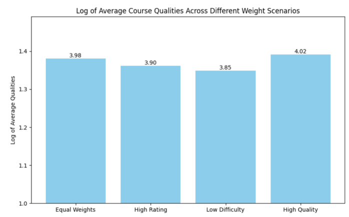
Semester 1	**Semester 2**	**Semester 3**	**Semester 4**
BIOL 111	BIOL 112	PSYC 100	ESYS 104
- MW 13:35-14:25	- MW 09:35-10:25	- TR 16:05-17:25	- TR 16:05-17:25
MATH 140	COMP 202	MATH 223	COMP 250
- MWF 09:35-10:25	- MW 11:35-12:55	- TR 11:35-12:55	- TR 14:35-15:55
MGCR 211	MATH 133	MATH 242	MATH 222
- TR 10:05-11:25	- TR 08:35-09:55	- MW 16:05-17:25	- TR 13:05-14:25
MGCR 341	MATH 141	MATH 323	MATH 324
- TR 13:05-14:25	- MWF 10:35-11:25	- TR 10:05-11:25	- MWF 09:35-10:25
MGCR 352	MATH 204	MGCR 271	MATH 447
- TR 11:35-12:55	- TR 14:35-15:55	- MW 13:05-14:25	- MWF 08:35-09:25

Semester 5	**Semester 6**	**Semester 7**	**Semester 8**
MATH 235	COMP 206	COMP 360	COMP 302
- MWF 10:35-11:25	- MW 14:35-15:55	- MW 16:35-17:55	- TR 14:35-15:55
MATH 423	COMP 251	MATH 317	COMP 330
- TR 11:35-12:55	- TR 11:35-12:55	- WF 11:35-12:55	- TR 16:05-17:25
MGCR 222	COMP 273	MATH 350	MATH 236
- MW 14:35-15:55	- MW 13:05-14:25	- TR 16:05-17:25	- MWF 11:35-12:25
MGCR 331	MATH 340	COMP 424	MATH 314
- TR 13:05-14:25	- TR 13:05-14:25	- TR 08:35-09:55	- TR 08:35-09:55
MGCR 372	COMP 551	COMP 462	MATH 527
- TR 14:35-15:55	- TR 10:05-11:25	- TR 11:35-12:55	- TR 13:05-14:25

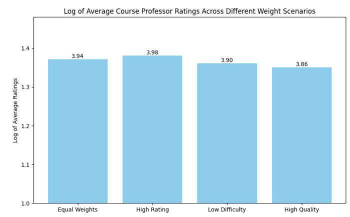
3.2 Scenarios Validation



(a) Weight scenarios of course difficulty.



(b) Weight scenarios of qualities.



(c) Weight scenarios of rate prof.

The scenarios validation section demonstrates how varying the weights assigned to different factors—course quality, professor ratings, and course difficulty—impacts the objective value, thereby testing the model's effectiveness. The bar charts illustrate the logarithm of average values for each factor under four distinct weight configurations: equal weights for all factors, a higher weight assigned to professor ratings, a higher priority on low course difficulty, and a higher weight on course quality. By adjusting the weights to prioritize specific factors, these scenarios provide insights into how different preferences influence the optimization outcomes. The subsequent charts exhibit similar trends, confirming the model's responsiveness to varying weight priorities. When specific factors such as course quality or professor ratings are prioritized, the model effectively adjusts the schedule to emphasize those attributes, demonstrating its ability to align course selections with different academic goals. This consistent pattern across all charts highlights the model's adaptability and effectiveness in optimizing schedules based on distinct priorities.

3.3 Sensitivity Report

Sensitivity analysis is crucial as it evaluates how changes in inputs impact model outcomes, ensuring robustness and reliability. After obtaining the final result for our optimal model, we conducted a case analysis to better understand its behavior and implications. Specifically, we modified the objective function to minimize the outcome, identifying the worst possible course scheduling scenario. This approach allowed us to explore the extremes of decision-making within the constraints of the model. By running the model for the worst-case scenario, we observed that many courses appeared in both the best and worst results but were associated with different sections. This raised an intriguing question about the significance of selecting the same course but with different professors and how these choices might impact overall performance, including metrics like quality, difficulty, and professor ratings. To test this further, we set equal weights of 0.333 for quality, difficulty, and professor ratings. This balanced weighting enabled us to analyze how selecting different sections for the same course could influence a student's experience with respect to these three objectives. The resulting objective function value for the best-case model was 65.70, while for the worst-case model it was 50.30, with a significant difference of 15.40. Notably, a difference of 9.69 in professor ratings accounted for over 60% of the total disparity in objective values.

Optimized Model Section	**Alternative Section**	**Optimized Model Professor**	**Alternative Professor**
MGCR 331-1	MGCR 331-2	Matthew Goodman	Sol Tanguay
MGCR 352-7	MGCR 352-5	Simon Blanchette	Fabienne Cyrius
MGCR 211-2	MGCR 211-8	Dongyoung Lee	Yin Zhu
MATH 140-2	MATH 140-1	Artem Kalmykov, Sidney Trudeau	Marcin Sabok, Sidney Trudeau
MGCR 271-2	MGCR 271-1	Robert Glew	Gabriel Frieden
MATH 141-4	MATH 141-3	Bartosz Syroka, Sidney Trudeau	Sidney Trudeau
MATH 323-2	MATH 323-3	Alia Sajjad	Tharshanna Nadarajah
MATH 223-2	MATH 223-3	Shereen Elaidi, Hugues Bellemare	Jeremy Macdonald
COMP 273-2	COMP 273-1	Paul Kry	Mona E Elsaadawy
COMP 250-2	COMP 250-1	Giulia Alberini	Giulia Alberini
MGCR 372-4	MGCR 372-2	Maxime Cohen	Yichuan Daniel Ding
COMP 206-2	COMP 206-1	Joseph P Vybhial, Max Kopinsky	Jacob T Errington
COMP 302-2	COMP 302-1	Jacob T Errington	Brigitte Pientka
COMP 360-1	COMP 360-2	Robert Robere	Hamed Hatami

This finding underscores the critical role professors play in shaping a student's four-year experience at McGill, as their teaching style, expertise, and approach to the material can significantly influence the learning experience. The substantial impact of section selection highlights the importance of careful planning and decision-making when assigning courses, as the choice of professor can profoundly affect not only academic outcomes but also student satisfaction and overall engagement.

4 Problem Extensions and Model Limitation

The current model, working as a demo, assumes a fixed course load of 5 courses per semester, and it can be extended in various dimensions. Firstly, one possible extension would allow for variable course loads to account for fluctuations in student capacity (e.g., internships, part-time work, or health constraints). Secondly, our project focuses on one specific path at McGill due to data restrictions. The idea will extend the solution across the different faculties of the university, even being able to generalize the solver across different institutions. Thirdly, students may prefer certain times of the day (e.g., morning, afternoon) for courses. An extension could incorporate time preferences for scheduling decisions. This extension ensures that related courses are scheduled within the same academic year to maintain logical learning progression. Beyond student scheduling, the project's scope can extend to other scheduling needs, such as classroom allocations and faculty assignments, offering significant potential for broader institutional benefits. Ultimately, this project contributes to building a more sustainable, efficient, and equitable education ecosystem by ensuring effective resource utilization and supporting the academic and personal success of students.

Furthermore, while the current model efficiently addresses the basic scheduling requirements, it lacks the capability to adapt to unexpected changes, such as course cancellations or sudden shifts in professor availability. An extension to this model could include a dynamic adjustment feature, where the system recalibrates the schedule in real-time based on updated information from the university's course management system. This would ensure that students remain on track with their academic plans even in the face of unforeseen changes. Additionally, integrating a feedback mechanism where students can rate their satisfaction with their schedules each semester could provide data to refine and improve the model's decision-making algorithms, making it more attuned to student preferences and educational outcomes over time.

Moreover, the model currently assumes uniform academic capabilities and preferences among students, which may not reflect the true diversity of student needs. To address this, an enhancement could involve personalizing the scheduling system to accommodate varying levels of academic aptitude and learning speeds. For instance, advanced students could be offered an accelerated pathway with more challenging courses earlier in their academic career, while others might benefit from a more spread-out course load to ensure thorough understanding and retention of material. This personalized approach would not only optimize individual learning experiences but also aid in reducing the dropout rates by maintaining students' engagement and motivation throughout their university education.

In conclusion, the suggested enhancements to the scheduling model not only aim to improve its adaptability and responsiveness but also seek to personalize the academic journey for each student. By incorporating features such as real-time adjustments and a personalized learning pathway, the model can better serve the diverse needs of the student body, fostering a more supportive and effective educational environment. These developments promise to maximize both student satisfaction and academic success, ultimately contributing to the overall resilience and efficiency of the educational institution.

5 Conclusion

In summary, the deployment of an automated course scheduling system represents a significant leap forward in addressing the multifaceted challenges of academic planning at the university level. By automating the process of course selection, this system not only alleviates the administrative burden on students but also enhances their educational experience by ensuring that they can meet all academic prerequisites and graduate on time. The system's ability to analyze and recommend courses based on individual academic goals and preferences further personalizes the learning experience, thereby increasing student engagement and satisfaction.

Furthermore, by continuously monitoring course capacities and student demands, the system helps institutions optimize resource allocation, reducing instances of over or under-enrolled classes which can lead to inefficiencies in resource usage. This proactive approach to course management not only saves costs but also improves the overall educational delivery by ensuring that faculty and facilities are utilized to their fullest potential.

Additionally, the ongoing development and refinement of this system, through extensions such as real-time scheduling adjustments and personalization of academic pathways, indicate a robust framework for future enhancements. These improvements will continue to build on the foundational goals of the project, aiming to create a more adaptive, responsive, and student-centered scheduling system.

Ultimately, this project underscores the value of integrating advanced analytics and decision-making tools in educational settings. By leveraging technology to solve logistical and pedagogical challenges, institutions can significantly enhance the quality of education offered, leading to better educational outcomes and a more enriching academic environment for all stakeholders.