1. Student-Level Scheduling Optimization Problem

The problem formulation presented in Moallemi & Patange (2023) aims to schedule students' in-person attendance while adhering to social distancing guidelines and minimising excess occupancy in classrooms, based on the following assumptions:

1) Each student is assigned to one of M groups, where M is predetermined. For each day of the term, one group is assigned to attend classes in person, rotating daily.

2) The social distance capacity of the classroom is fixed and known in advance.

3) Some classes will still exceed the social distancing capacity, requiring students to attend online in a separate room with finite capacity.

4) Each class follows a weekly schedule.

5) The ideal uniform fractional student assignment is adopted to ensure each student has an equal chance to attend each class in person an equal number of times.

1.2 Key Elements of the Formulation

1.2.1 Parameters:

S: Set of students; C: Set of classes; T: Set of hours in a week;

c_t: The set of classes scheduled at time t; d: Each day of the term;

T_d: The set of hours on day d; E: The capacity of the excess room;

A_k: Set of students enrolled in class k; c_k : Social distancing capacity of class k.

M: Number of groups;

1.2.2 Decision Variables:

The decision variable is π_{ij}, a binary variable representing student i's assignment to group j.

e_{jk}, δ_{jk}, s_j^t , and s are auxiliary variables introduced for the linear formulation of the problem.

1.2.3 Objective Function: minimise $\sum_{k\in c}\sum_{j=1}^{M}\mathrm{e}_{jk}+\lambda\sum_{k\in c}\sum_{j=1}^{M}\delta_{jk}+\mu s$

The objective function is a linear combination of the following three metrics, with λ and μ to be non-negative weights that determine the importance of each metric in the optimisation process.

1) Total Excess (TE): $\mathrm{TE} \triangleq \sum_{1\le j\le M}\sum_{k\in c}(\sum_{i\in A_k}\pi_{ij}-c_k)^+$

At the optimum, the first term of the objective function is set to the sum of excesses from each class when each of the groups is scheduled to attend classes in person.

2) Total Deviation (TD): $\mathrm{TD} \triangleq \sum_{1\le j\le M}\sum_{k\in c}\left|\sum_{i\in A_k}\pi_{ij}-\frac{|A_k|}{M}\right|$

At the optimum, the second term of the objective function is set to the product of λ and the total deviation from the uniform fractional student assignment.

3) Surplus Simultaneous Excess (SSE): $\mathrm{SSE} \triangleq \left(\max_{1\le t\le T, 1\le j\le M} s_j^t - E\right)^+$

At the optimum, s is corresponding to how much maximum number of students assigned to the excess room exceeds the excess-room capacity.

1.2.4 Constraints

The formulation of this section can be seen in appendix A.2.

1) **Single Group Assignment Constraint-** Each student can be assigned to only one group, ensuring fair scheduling across all students.
2) **Excess Constraint-** Assigns lower bound to auxiliary variable e_{jk} representing the surplus of students in a specific class and a group.
3) **Deviation Constraint-** Assigns a lower bound to auxiliary variable δ_{jk} representing the absolute difference between an assignment and the uniform fractional student assignment.
4) **Excess Student Calculation-** The auxiliary variable s_j^t has summation of auxiliary variable e_{jk} as its lower bound. When minimised, s_j^t will be set to simultaneous excess at a specific time and group. s has the difference between s_j^t and the excess room capacity as its lower bound, ensuring only the maximum value of ($s_j^t - E$) acts as a binding constraint, rendering all other constraints with s redundant.
5) **Binary Constraint-** The decision variable π_{ij} is a binary variable.
6) **Non-negativity Constraints-** This equation ensures that the auxiliary variables e_{jk}, δ_{jk}, and s, are non-negative since the excess in the class, the contribution to the total deviation by the class, and the surplus simultaneous excess must be non-negative.

2. Hybrid Timetable Scheduling for MSBA

For the MSBA program at WBS, we are tasked with developing a hybrid timetable scheduling for a single term.

2.1 Assumptions

For ease of computation, some more assumptions were made to run the model:

1) All online classes are converted to in-person classes and take place at 0.004. The analysis focused only on MSBA students across six main modules.
2) The social distancing capacity of a room is the total capacity of the room divided by the social distancing parameter and rounded up.
3) The excess capacity room for MSBA students is WBS room 0.001 with a total capacity of 96.
4) The classes scheduled to commence at half past the hour are rescheduled to start on the hour (30 minutes later) for ease of computation.

5) Lecturer availability, room availability, and allocation of students to distinct groups for a module without any simultaneous lectures are all considered in the given data.
6) Students having a gap in between lectures have enough space to reside on campus.
7) All students are assumed to be capable and willing to commute to the campus.
8) 1-hour lectures and 2-hour workshops have same weightage in the calculation of TE and TD.

2.2 Data Preparation and Modeling

To address the complex scheduling optimization problem described, several steps were undertaken, combining data preparation and model formulation.

2.2.1 Data Preparation

The class schedule was converted to Excel as a binary time slot matrix. Each available hourly timeslot (T) was represented as a number starting from 0 at 9 am on Monday to 44 at 6 pm on Friday (Appendix A.4). Data for class schedules (including room capacity) and student-class assignments were provided in an Excel format (Appendix A.3). Using Python's Pandas library, the data was read into data frames and then converted to NumPy arrays.

2.2.2 Model Formulation

1) Objective Function: Aimed to simultaneously minimize student conflicts, maximize course satisfaction, and optimize room utilization.
2) Constraints: Constraints were formulated as discussed in Moallemi & Patange (2023).
3) Decision Variable: Represented as model.x, a binary variable.
4) Auxiliary Variables: Represented by TE, TD, s and s_j^t, as Non-Negative Reals.
5) Parameters:

Description	Value(s)	Type
Number of Groups (M)	2 - 6	Varying
Available Time (T)	0 - 44	Fixed
Room Capacity (E)	—	Varying
Excess Room capacity	96	Fixed
Social Distance parameter (F)	2 - 4	Varying
Importance Weighting TD (λ)	0.25	Fixed
Importance Weighting SSE (μ)	10	Fixed

Table 2.1 The parameters for scheduling

3. Results and Improvements

3.1 Mixed-Integer Programming (MIP) Approach Results

The preliminary outcomes obtained in line with the operational methodologies outlined in the research paper by Moallemi, C., and Patange, U. (2023), closely resemble the findings of the paper. A notable observation from the algorithm's output is the detailed scheduling recommendations tailored for different social distancing protocols and number of groups where we observe that TE and SSE decrease with increasing number of groups (M), whereas TD increases with the increasing number of groups (2024, Appendix A.1).

After analysing various outcomes, the recommended solution is to set the number of groups at 2 and implement a social distancing capacity equal to half of the total capacity, resulting in a minimized objective value of 2.

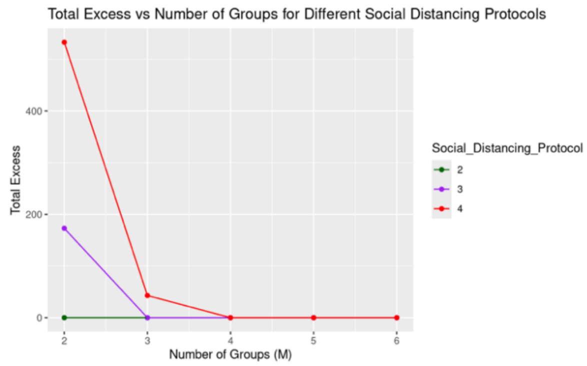

Figure 3.1 Effect of increase in the number of groups on total excess for different social-distancing protocols

3.2 Limitations and Recommendations

1) **Simplification:** The model assumes simplified assignments, potentially missing real-world scheduling scenarios complexities.
2) **Fixed Schedule**: The static schedule might not reflect real-world variations. The formulation should be modelled to be dynamic and could adapt to changes like optional classes.
3) **Practicality for students:** The model prioritizes efficiency but neglects student preferences by disregarding gaps between classes and transportation issues. Introducing weights for these gaps and allowing dynamic student groups for interaction could improve student satisfaction.

4. Conclusion

In conclusion, the application of Mixed-Integer Programming for hybrid scheduling, as demonstrated by the Python code results, reflects a pioneering step towards optimising academic operations amidst public health concerns. The insights garnered from this analysis not only corroborate the findings of Moallemi and Patange but also presented a scalable and adaptable solution for WBS. Such innovations pave the way for a more resilient and responsive approach to scheduling challenges, leveraging mathematical sophistication to ensure continuity, safety, and efficiency in academic settings.

APPENDIX

A.1 Experimental Results of Hybrid Scheduling

Social Distancing Parameter	M	TD	SSE	TE	Objective value
2	2	8	0	0	2
2	3	25.3	0	0	6.3
2	4	32	0	0	8
2	5	36.8	0	0	9.2
2	6	46.6	0	0	11.6
3	2	8	0	173	175
3	3	25.3	0	0	6.3
3	4	32	0	0	8
3	5	36.8	0	0	9.2
3	6	46.6	0	0	11.6
4	2	8	18	533	715
4	3	25.3	0	43	49.3
4	4	32	0	0	8
4	5	36.8	0	0	9.2
4	6	46.6	0	0	11.6

Table 1 Summary of experimental results of hybrid scheduling with different values of M, and different social distancing policies.

A.2 Functions in Paper of Moallemi and Patange

$$\text{minimize} \quad \sum_{k\in C}\sum_{j=1}^{M} e_{jk} + \lambda \sum_{k\in C}\sum_{j=1}^{M} \delta_{jk} + \mu s \tag{6}$$

$$\text{subject to} \quad \sum_{j=1}^{M} \pi_{ij} = 1 \qquad \forall i \in \mathcal{S} \tag{7}$$

$$\sum_{i\in\mathcal{A}_k} \pi_{ij} - c_k \le e_{jk} \qquad 1 \le j \le M,\ \forall k \in \mathcal{C} \tag{8}$$

$$-\delta_{jk} \le \sum_{i\in\mathcal{A}_k} \pi_{ij} - \frac{|\mathcal{A}_k|}{M} \le \delta_{jk} \qquad 1 \le j \le M,\ \forall k \in \mathcal{C} \tag{9}$$

$$s \ge s_j^t - E \qquad 0 \le t \le T,\ 1 \le j \le M \tag{10}$$

$$s_j^t \ge \sum_{k\in\mathcal{C}_t} e_{jk} \qquad 0 \le t \le T,\ 1 \le j \le M \tag{11}$$

$$\pi_{ij} \in \{0,1\} \qquad \forall i \in \mathcal{S},\ 1 \le j \le M \tag{12}$$

$$\delta_{jk},\ e_{jk},\ s \ge 0 \qquad 1 \le j \le M,\ \forall k \in \mathcal{C} \tag{13}$$

A.3 Data preparation for student class assignments

ID	Course	IB98D0 - ADA	IB9190 - AAMA	IB9HP0 - DM	IB9MJ0 - FA (Elective) L	IB98E0 - F (Elective) L	IB9BS0-SCA (Elective) L	IB9190 - AAMA G1	IB9190 - AAMA G2	IB9190 - AAMA G3
1	MSBA	1	1	1	1	0	0	1	0	0
2	MSBA	1	1	1	0	0	1	0	1	0
3	MSBA	1	1	1	1	0	0	0	0	1
4	MSBA	1	1	1	1	0	0	0	0	0
5	MSBA	1	1	1	1	0	0	1	0	0
6	MSBA	1	1	1	0	1	0	0	1	0
7	MSBA	1	1	1	0	1	0	0	0	1
8	MSBA	1	1	1	0	1	0	0	0	0
9	MSBA	1	1	1	0	1	0	1	0	0
10	MSBA	1	1	1	1	0	0	0	0	1
11	MSBA	1	1	1	1	0	0	0	0	0
12	MSBA	1	1	1	0	0	1	1	0	0
13	MSBA	1	1	1	0	1	0	0	1	0
14	MSBA	1	1	1	1	0	0	0	0	1
15	MSBA	1	1	1	0	1	0	0	0	0

A.4 Data preparation for class schedules

		T	IB98D0 - ADA	IB9190 - AAMA	IB9HP0 - DM	IB9MJ0 FA	IB98E0 - F	IB9BS0- SCA	IB9190 - AAMA G1	IB9190 - AAMA G2	IB9190 - AAMA G3	IB9190 - AAMA G4
			2	5	7	3	27	6	14	16	9	11
									15	17	10	12
	Classroom		0.004	0.004	0.004	0.004	2.004	2.004	M2	M2	M2	M2
	Capacity		292	292	292	292	120	120	73	73	73	73
Monday	9.00 - 10.00	0	0	0	0	0	0	1	0	0	0	0
	10.00 - 11.00	1	0	0	0	0	0	0	0	0	0	0
	11.00 - 12.00	2	1	0	0	0	0	0	0	0	0	0
	12.00 - 13.00	3	0	0	0	1	0	0	0	0	0	0
	13.00 - 14.00	4	0	0	0	0	0	0	0	0	0	0
	14.00 - 15.00	5	0	1	0	0	0	0	0	0	0	0
	15.00 - 16.00	6	0	0	0	0	0	0	0	0	0	0
	16.00 - 17.00	7	0	0	1	0	0	0	0	0	0	0
	17.00 - 18.00	8	0	0	0	0	0	0	0	0	0	0
Tuesday	9.00 - 10.00	9	0	0	0	0	0	0	0	0	1	0
	10.00 - 11.00	10	0	0	0	0	0	0	0	0	1	0
	11.00 - 12.00	11	0	0	0	0	0	0	0	0	0	1
	12.00 - 13.00	12	0	0	0	0	0	0	0	0	0	1
	13.00 - 14.00	13	0	0	0	0	0	0	0	0	0	0