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A Multi-Objective Optimization Model for Clinical Rotation Scheduling of Medical Students in a Multi-Campus Medical School

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Abstract

Medical student scheduling plays an important role in medical education. Ineffective schedules can lead to workload imbalance and inequitable learning conditions for students. The problem becomes more severe in multi-campus medical schools, where clinical wards are located in multiple locations. To address this challenge, this article develops a multi-objective mixed integer programming model for medical student scheduling problems with a multi-campus scenario. The model incorporates three objectives: 1) maximizing workload alternation, 2) minimizing inter-group deviation, and 3) minimizing inter-campus travel. The model is solved using IBM ILOG CPLEX with a lexicographic goal programming approach to handle trade-offs among multiple objectives. Computational results demonstrate that prioritizing workload alternation produces a schedule that varies workload levels while maintaining fairness across student groups and acceptable levels of campus travel. The results also highlight the importance of objective prioritization in multi-objective clinical rotation scheduling and illustrate the model's potential as a decision support tool for medical education schedulers.

Keywords
Medical student scheduling, Mixed integer programming, Workload balancing, Fairness, Multi-campus scheduling.

1. Introduction
Medical education requires students to rotate across multiple clinical wards during their clinical training years. Each ward differs in complexity, clinical intensity, and expected workload. In addition, at the case study medical school, clinical training is delivered across several campuses, and each ward is offered only at specific campuses. As a result, students are required to travel between campuses to complete their training. An inefficient rotation schedule may

therefore create workload imbalances, produce inequitable learning conditions, and make unnecessary travel among student groups. Hence, designing a schedule that balances academic workload, ensures fairness, and minimizes inter-campus traveling is an important and challenging task.

In practice, clinical rotation schedules are often created manually based on the scheduler's experience and simple rules. However, manual scheduling often struggles to incorporate the curriculum and logistical requirements. An example of a requirement is that students must complete all mandatory wards to meet curriculum requirements. In addition, to support learning outcomes, rotations should alternate workload levels across periods, as research shows that balancing high- and low-workload enhances the educational experience and reduces burnout (Ruotsalainen et al., 2015). Importantly, students also expect fairness in the schedule in terms of the distribution of workloads. In addition, because of multi-campus setting, excessive travel between campuses increases the burden on students. These challenges highlight the need for a systematic approach to produce effective clinical rotation schedules.

Current research in medical personnel scheduling and/or nurse rostering has focused on reducing costs, time, or other resources. However, relatively few studies examine medical student scheduling, especially in workload balancing, fairness, and inter-campus transportation. To address research gap, this study develops a multi-objective mixed integer program (MIP) to construct schedules for medical students in a multi-campus setting. In the model, three objectives are considered: 1) maximizing workload alternation, 2) minimizing inter-group deviation, and 3) minimizing inter-campus travel. In addition, system constraints, such as requirements from students and the medical school, are incorporated into the model.

The remainder of this article is structured as follows. Section 2 provides literature review of related research. Section 3 presents the methodology. Experiments and results are reported in Section 4. Finally, Section 5 provides the conclusion of the research.

2. Literature Review

In healthcare operations, scheduling plays a critical role by affecting service quality, staff well-being, operational costs, and overall system efficiency. Schedules that are well-designed can improve operation efficiency and reduce costs, and, ultimately, improve quality of patient care (Weaver et al., 2023). On the other hand, studies also show that ineffective schedules can lead to higher costs and/or unnecessary work assignments (Legrain et al., 2015), and link to fatigue and burnout of healthcare personnel, a problem observed at all levels of medical workforce (National Academies of Sciences Engineering and Medicine, 2019). These findings highlight the need for systematic, data-driven approaches to develop effective scheduling for healthcare professionals.

Current research has focused on scheduling healthcare professionals, especially physicians and nurses. Optimization techniques have been widely applied to solve scheduling problems, with the objective to, for example, reduce cost and/or improve operational efficiency. In addition, the complex and unique requirements of the health system are also considered in the model. For example, Beaulieu et al. (2000) used MIP to develop physician schedules for emergency room. The model considers working hours, preferences, and seniority of physicians. Fügener et al. (2015) applied MIP to balance anesthesiology shifts in network of hospitals in Germany. The study demonstrates that optimization methods improve overall workload equity to physicians. Bard & Purnomo (2005) used mathematical programming to create schedules that accommodate preferences, but still maintain the maximum level of patient benefit. These examples demonstrate that the optimization models can effectively and successfully address complex clinical scheduling problems.

Medical students are considered important resources for healthcare systems. Medical student work scheduling involves constraints fundamentally different from those of other clinical staff. For example, medical student scheduling must account for both hospital constraints (e.g., required number of students assigned to each ward) and curriculum requirements (e.g., minimum duration of training in each ward). The need to satisfy these unique constraints distinguishes medical student scheduling from other personnel scheduling problems in healthcare.

To respond to the unique characteristics of the problem, researchers have proposed several approaches. For instance, Akbarzadeh & Maenhout (2021) developed decomposition-based method that generates effective solutions for medical student scheduling problems. Moreover, Castaño & Velasco (2020) used MIP with variable neighborhood search to create schedules that can maintain both feasibility and quality of the final solutions. In addition, Dusadeerungsikul & Nof (2024) developed a systematic approach to solve medical student scheduling problem. The approach uses a mathematical model to generate an initial schedule and uses artificial intelligence to address unexpected issues in real time, addressing dynamic nature of the problem.

Although the current literature provides important insights into the student rotation scheduling problem, most studies address specific aspects of the problem individually. The integrated consideration of three dimensions explored in this work (i.e., balancing workload, ensuring fairness among student groups, and minimizing inter-campus travel) remains limited. These dimensions are important in medical schools, especially when the rotation influences both educational experience and practicality of logistics. Therefore, by building on previous research, this study develops a multi-objective optimization model that considers these aspects within unified model.

3. Methodology

3.1 Problem description

The study considers the medical student clinical rotation scheduling problem in a multi-campus medical school. Throughout their clinical training years, medical students are required to rotate through a set of clinical wards. Every ward has a specific workload level that reflects its clinical intensity and learning demand. Students are organized into groups, and, within each group, all students follow the same rotation schedule.

Clinical training is provided at multiple campuses. Note that each ward is offered at exactly one campus. Due to supervision and capacity limitations, each ward can accommodate at most one student group at a time. The assignment of wards to time slots, therefore, determines not only workload students receive but also the need for inter-campus travel. Ineffective scheduling can lead to cognitive overload and inequitable learning conditions across groups. In addition, excessive campus travel may increase students' logistical burden.

The decision is to assign wards to time slots for each student group, to create work schedule. In this study, three objectives are considered:

- Maximizing workload alternation: Consecutive assignments of high-workload wards can negatively affect student performance and well-being. Hence, the schedule should alternate between high- and low-workload wards across planning periods.
- Minimizing inter-group deviation: Different schedules may yield unequal fluctuations in workload among groups (even though, at the end, all groups need to complete all wards). The schedule should aim to deliver the overall workload alternation experienced by each group to be as similar as possible.
- Minimizing inter-campus travel: Frequent campus changes lead to additional travel burden for students. The schedule should therefore minimize unnecessary inter-campus movement.

In this research version, the focus is on the core modeling features of the problem. Additional institutional rules, such as fixed schedule placements for specific wards, pairing constraints, and/or restricted scheduling windows, are excluded. The resulting problem is a multi-objective, multi-campus clinical rotation scheduling problem that assigns wards to time slots while balancing workload alternation, fairness across student groups, and campus travel.

3.2 Mathematical Model

Sets:

S: Set of wards, indexed by $s \in \{1, \dots, |S|\}$
T: Set of time slots, indexed by $t \in \{1, \dots, |T|\}$
G: Set of student groups, indexed by $g \in \{1, \dots, |G|\}$
C: Set of campuses, indexed by $c \in \{1, \dots, |C|\}$

Parameters:

W_s = Workload level of ward s.
$a_{s,c} \in \{0,1\}$: 1 if wards s is at campus c; 0 otherwise. Note that each ward is offered at exactly one campus ($\sum_{c \in C} a_{s,c} = 1; \forall s$).

Decision Variables:

$x_{s,t,g} \in \{0,1\}$: 1 if ward s is assigned to group g at time t; 0 otherwise.
$z_{t,g}^{(1)}$ = Absolute workload difference between t and $t+1$ for group g.

$z_g^{(2)}$ = Deviation of total alternation for group g from the average value.
$z_{t,g}^{(3)} \in \{0, 1\}$: 1 if group g changes campus between t and $t+1$; 0 otherwise.

Auxiliary Variables:
$W_{t,g}$ = Workload at time t of group g.
U_g = Total workload alternation for group g.
$\overline{U}$ = Average workload alternation across all groups.
$R_{t,g,c} \in \{0, 1\}$: 1 if group g is at campus c at time t.

Objective Functions:

Objective 1 – Maximizing workload alternation.

$$F_1\colon \max \sum_{g \in G} \sum_{t=1}^{|T|-1} z_{t,g}^{(1)} \tag{1}$$

The first objective focuses on alternation between high- and low-workload across consecutive periods.

Objective 2 – Minimizing inter-group deviation.

$$F_2\colon \min \sum_{g \in G} z_g^{(2)} \tag{2}$$

The second objective ensures fairness by minimizing the differences in total workload alternation levels across student groups.

Objective 3 – Minimizing inter-campus travel.

$$F_3\colon \min \sum_{g \in G} \sum_{t=1}^{|T|-1} z_{t,g}^{(3)} \tag{3}$$

The third objective reduces unnecessary inter-campus travel.

Constraints:
Workload alternation measurement: Equations (4) – (6) linearize the absolute difference between consecutive workloads:

$$z_{t,g}^{(1)} \geq W_{t,g} - W_{t+1,g} \qquad ; \forall t \leq |T| - 1, g \tag{4}$$
$$z_{t,g}^{(1)} \geq W_{t+1,g} - W_{t,g} \qquad ; \forall t \leq |T| - 1, g \tag{5}$$
$$W_{t,g} = \sum_{s \in S} w_s x_{s,t,g} \qquad ; \forall g, t \tag{6}$$

Fairness across groups: Equations (7) – (10) calculate the deviation from the average workload alternation:

$$z_g^{(2)} \geq U_g - \overline{U} \qquad ; \forall g \tag{7}$$
$$z_g^{(2)} \geq \overline{U} - U_g \qquad ; \forall g \tag{8}$$
$$U_g = \sum_{t=1}^{|T|-1} z_{t,g}^{(1)} \qquad ; \forall g \tag{9}$$

$$|G|\,\bar{U} = \sum_{g \in G} U_g \tag{10}$$

Campus transition identification: Campus change occurs when two consecutive time slots involve different campuses, which is calculated by Equations (11) – (12):

$$R_{t,g,c_1} + R_{t+1,g,c_2} \leq 1 + z_{t,g}^{(3)} \qquad ; \forall t \leq |T| - 1, g, c_1 \neq c_2 \tag{11}$$

$$R_{t,g,c} = \sum_{s \in S} a_{s,c} x_{s,t,g} \qquad ; \forall g, t, c \tag{12}$$

Assignment constraint: Each ward is assigned exactly once per group, and each group attends exactly one ward in each time slot (Equations (13) – (14)):

$$\sum_{t \in T} x_{s,t,g} = 1 \qquad ; \forall s, g \tag{13}$$

$$\sum_{s \in S} x_{s,t,g} = 1 \qquad ; \forall t, g \tag{14}$$

Ward capacity: Each ward can be assigned to at most one student group in each time period (Equations (15)):

$$\sum_{g \in G} x_{s,t,g} \leq 1 \qquad ; \forall s, t \tag{15}$$

Variable domains (Equations (16) – (17)):

$$x_{s,t,g}, R_{t,g,c}, z_{t,g}^{(3)} \in \{0,1\} \qquad ; \forall s, t, g, c \tag{16}$$

$$z_{t,g}^{(1)}, z_g^{(2)} \geq 0 \qquad ; \forall t, g \tag{17}$$

4. Experiments and Results

4.1 Experimental Setting

The proposed model was evaluated using a case study from a multi-campus medical school. The model was implemented and solved using IBM ILOG CPLEX. A lexicographic goal programming approach was used to handle the three objectives introduced in Section 3. In the experiment, F_1 was given the highest priority, followed by F_2 and F_3. This priority reflects the objective of balancing cognitive load while considering equity and logistical feasibility. The main parameters used in the experiment are summarized in Table 1.

Table 1. Experimental parameters

Parameters	Value
Number of wards	19
Number of time periods	19
Number of student groups	8
Number of campuses	3

4.2 Experimental Results

The experimental results are reported in Table 2. The resulting schedule alternates high- and low-workload wards and yields F_1 = 502, which promotes student well-being. The fairness across groups (F_2) is 2, which can be considered a small value. The small value of F_2 indicates that each group receives similar workload alternation, even though fairness is given secondary priority. Note that the deviations occur because of campus and ward constraints. Lastly, the number of campus transitions (F_3) is 91. Because F_3 (minimization of campus travel) is assigned the lowest priority in experiment, the resulting schedule reflects trade-off in system. Students need to travel more to achieve better workload alternation and fairness across groups.

In addition, Figure 1 illustrates the resulting schedule for all groups across planning horizon. Each cell represents the ward assigned to a student group each time period and campus. For example, “15-02” denotes Ward 15 located at Campus 2.

The experimental results indicate that prioritizing workload alternation yields schedules that support student well-being. The schedule still maintains an acceptable level of fairness across student groups. Although campus travel is not at the minimum under given priority order, the traveling requirement is feasible within the context of the case study. Lastly, these findings highlight the importance of objective prioritization in multi-objective clinical rotation scheduling. In practice, decision-makers need to explore trade-offs and select priorities of objectives that align with institutional and educational goals (Table 2, Figure 1).

Table 2. Experimental results

Objective priority	**F_1 value**	**F_2 value**	**F_3 value**
F_1, F_2, F_3	502	2	91

Time slot	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
1	14-02	01-02	03-01	04-02	05-01	02-01	06-01	12-02
2	11-03	08-02	02-01	09-02	16-01	05-01	03-01	06-01
3	06-01	04-02	05-01	17-01	07-02	19-03	16-01	14-02
4	09-02	10-01	11-03	12-02	04-02	06-01	08-02	16-01
5	18-03	06-01	15-02	13-02	02-01	10-01	11-03	08-02
6	01-02	12-02	09-02	02-01	15-02	18-03	17-01	19-03
7	15-02	05-01	06-01	07-02	10-01	16-01	01-02	17-01
8	12-02	14-02	01-02	03-01	13-02	15-02	04-02	09-02
9	05-01	02-01	07-02	16-01	12-02	01-02	18-03	04-02
10	02-01	15-02	16-01	08-02	06-01	03-01	19-03	18-03
11	08-02	09-02	18-03	11-03	03-01	13-02	15-02	10-01
12	19-03	07-02	12-02	06-01	14-02	09-02	10-01	13-02
13	07-02	11-03	08-02	10-01	19-03	17-01	13-02	01-02
14	16-01	17-01	19-03	15-02	18-03	11-03	09-02	05-01
15	13-02	19-03	17-01	14-02	11-03	08-02	07-02	03-01
16	04-02	13-02	10-01	19-03	17-01	12-02	14-02	07-02
17	10-01	03-01	14-02	18-03	09-02	07-02	02-01	11-03
18	17-01	16-01	13-02	01-02	08-02	04-02	05-01	15-02
19	03-01	18-03	04-02	05-01	01-02	14-02	12-02	02-01

Figure 1. Resulting schedule from experiment

5. Conclusion

This research examined the medical student clinical rotation scheduling problem in a multi-campus medical school. The schedules aim to balance student well-being, educational, and logistical factors. A multi-objective MIP was developed to generate schedules that account for workload alternation, fairness across student groups, and inter-campus travel.

To evaluate the model, in this study, IBM ILOG CPLEX with lexicographic goal programming was used. The results indicate that the model successfully generates a feasible schedule for medical student scheduling problem. Moreover, the resulting schedule alternates wards between high- and low-workload, as workload alternation was given priority. This workload alternation supports student well-being and learning. In addition, the schedule maintains an acceptable level of fairness among student groups. While campus travel is not at minimum, it remains feasible in the context of this study. Overall, the results show trade-offs in clinical rotation scheduling in multi-campus medical school. Importantly, the proposed model offers decision-makers a structured yet flexible tool for developing clinical rotation schedules in complex, multi-campus settings.

Researchers can further explore following directions.

1. Incorporating additional constraints: The model can be extended by incorporating constraints (such as fixed ward placements, capacity variations, prerequisite requirements) to better reflect practical limitations.
2. Conducting sensitivity analysis: Different priority orders may yield different trade-offs in the model. Investigating these trade-offs will provide better insights for decision-makers.
3. Enhancing scalability: Researcher may investigate metaheuristic approaches that can solve larger problem instances to improve scalability and provide practical solution techniques for large medical schools.

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