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A Mixed Integer Linear Programming for Exam-Invigilator Assignment Problem: a Case Study at Universiti Pertahanan Nasional Malaysia

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***Abstract*—The assignment of invigilators for examinations is a complex and challenging task, particularly when faced with numerous factors that must be carefully considered. Critical elements are essential in this process, including staff availability, room capacity, and time constraints, requiring thorough evaluation and coordination. This paper focuses on improving the allocation of invigilators for examinations at Universiti Pertahanan Nasional Malaysia (UPNM). The issue arises when academic staff members responsible for teaching the subject are also assigned as exam invigilators, which conflicts with their primary role of assisting students in addressing their queries during examinations. It is essential to reconsider the distribution of invigilator roles, ensuring that academic staff members can focus solely on providing educational support. In contrast, qualified non-academic staff handle invigilation duties effectively. A mixed-integer linear programming (MILP) model is formulated using the existing examination timetable to solve this problem. The model is solved using a simple algorithm implemented in the XPress MP programming language, resulting in an improved solution that requires less computational effort than the conventional method. This approach offers an alternative and better solution for scheduling examination invigilators at UPNM, ensuring the efficient and effective management of exam procedures while maximizing the utilization of available resources. It can serve as a starting point for future investigations into UPNM's scheduling procedures.**

***Keywords*—Mixed integer programming; assignment problem; invigilator; examination; university.**

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I. INTRODUCTION

The examination timetabling problem is a complex combinatorial problem that belongs to the class of NP-complete sub-problems [1]–[3]. This indicates that the problem is unlikely to be solvable within polynomial time. The examination timetabling problem comprises three primary components. The initial element involves developing an examination schedule. Next, the process involves assigning classrooms for the examinations, followed by assigning university staff members to serve as invigilators during the examinations.

The primary objective of this paper is to address the problem of allocating invigilators to examinations. This issue has received attention from operations research as researchers aim to develop effective and equitable solutions for allocating invigilators to specific exams. To assign the invigilator, the process begins by first establishing the examination timetable, which includes carefully scheduling each exam's dates, times, and locations. This crucial step ensures that all courses and levels are adequately covered and that no overlapping exams or conflicts could affect the smooth conduct of the assessments.

Invigilators must be present during examinations at educational institutions to uphold fairness, maintain the integrity of exams, and prevent any form of misconduct. However, the invigilator selection process can pose challenges and consume a considerable amount of time. These challenges encompass numerous factors, such as the invigilators' preferences, qualifications, and experience and each exam's specific requirements.

Numerous methodologies have been suggested to tackle the exam-invigilator assignment problem, such as mathematical programming techniques, with a particular emphasis on exact methods and heuristic algorithms to identify the optimal assignment based on predetermined criteria and constraints. In this paper, an accurate method is known as Mixed Integer Linear Programming (MILP) is utilized to solve the exam-invigilator assignment problem at the Universiti Pertahanan Nasional Malaysia (UPNM). This method is favored over others because it can produce a better optimal solution. According to Kantor et al.'s research, MILP is used for system analysis and optimization because it is flexible and powerful when dealing with complex problems [4].

Solving complex scenarios that involve multiple courses, invigilators, and timeslots using exact methods presents significant computational complexity and poses a substantial challenge. In cases where the number of courses, invigilators, and timeslots is limited, the same methods can offer precise and optimal solutions. Koide [5] proposed a MILP model of examination proctor/invigilator assignment problems for faculty and academic staff. However, the proposed model could not find the global optimal solution in an acceptable time for system users using practical data. This study was further revised by Koide [6] by constructing a system based on the use of electronic spreadsheets to derive the optimal proctor assignments. The results showed that the resulting assignments were deemed satisfactory for practical settings.

Matci and Ilgın [7] proposed a MILP model for Anadolu University's examination timetabling problem to minimize the invigilator's score. This study assumed that previous test invigilators should not be assigned to the current test. The assignment's success criterion reduced the invigilator's scores. Aizam and Sithamparam [8] proposed an integer programming model approach for the examination timetabling problem at the Malaysia University of Terengganu to minimize the preference cost of assigning courses, nurses/invigilators/lecturers, and exam timeslots. The findings showed that adding randomly generated data to the model for validation purposes was also successful.

In a recent study, Mokhtar et al. [9] aimed to delve deeper into the survey previously conducted by Kahar and Kendall [10]. They proposed a mathematical programming model as a solution to the problem of exam-invigilator assignment at Universiti Teknologi Mara (UiTM) Pahang, Raub Campus. Their goal was to evenly distribute the responsibilities of the invigilator, chief invigilator, and standby invigilator among the academic staff members. Unlike Kahar and Kendall's study, new constraints were considered in their model, such as the chief invigilator of a large room should be a senior lecturer, and a lecturer can only hold the position of chief invigilator of a room once. The experiment showed that the proposed model can produce a feasible and optimal timetable that satisfies all constraints faster than the manual assignment procedure.

In contrast, it is impractical to find the best solution using exact methods due to computational complexity in large-scale scenarios where the number of courses, invigilators, and timeslots is significantly higher. In such cases, heuristic methods can speed up the procedure of finding a suitable solution, yet they may not guarantee the optimal solution.

Kahar and Kendall [10] developed a heuristic method for the exam-invigilator assignment problem at the University Malaysia Pahang (UMP). They demonstrated a constructive algorithm that produces high-quality solutions better than the university's existing applications. Unlike their existing software, the proposed technique can produce high-quality solutions while meeting all hard and soft limitations.

Lourenco et al. [11] used a multi-objective integer programming model to assign exam invigilators. The weighted objective function combined a workload-fairness function with a preference function. A scatter search-based method solved the model using real data from a university in Spain. Erden et al. [1] employed a genetic algorithm to solve the exam-invigilator assignment problem, considering the invigilators' preferences and preventing exam overlap. Turkish public university data was utilized in this case study. Results show that the genetic algorithm model fulfills constraints to assign invigilators to time slots.

Pokudom et al. [12] introduced ant colony system exam proctor schedules for educational institutions. Their research aimed to minimize the amount of time staff members spend proctoring exams, ensure an equitable distribution of workload, and eliminate the need for exam proctoring on weekends. The findings indicate that implementing the ant colony system yielded favorable outcomes. Huynh et al. [13] solved the proctor assignment problem using a genetic algorithm and integer programming. They compared the results of both methods and found that integer programming, i.e., zero min loss, outperformed the genetic algorithm regarding fitness score. Sagir et al. [14] used the Analytic Network Process approach to prioritize the objectives of the invigilator-exam assignment problem.

Several studies developed web-based application systems for exam-invigilator [15]–[17], online proctoring systems using computer vision and machine learning [18], and automatic assigning invigilator timetable scheduling systems using shuffling algorithms [19]. As for online examinations, Colonna [20] conducted a study on the legal implications of using artificial intelligence (AI) as an exam invigilator. Besides, several previous studies employed heuristics/metaheuristics [2], [21]–[23], developed a multi-objective examination model [24], fuzzy integer linear programming model [25] and decision support systems [26]–[29] to solve exam timetabling problems.

This paper is structured as follows: Section 2 presents the problem description and model assumptions and outlines the methodology employed in this study. Section 3 presents the findings and engages in a thorough analysis. Lastly, the concluding remarks are shown in the conclusion section, summarizing the key points and implications of the study.

II. Materials and Method

This section provides a detailed description of the problem and the model's underlying assumptions. The National Defense University of Malaysia (UPNM) was founded on 1 June 1995 as the Malaysian Military Academy (ATMA) to provide bachelor-level study programs and military training for Malaysian Army Cadet Officers (ATM). On November 10, 2006, ATMA was expanded into the UPNM [30].

UPNM has established four faculties to provide a comprehensive educational framework that supports various aspects of defense science, technology, engineering, management, and healthcare. These faculties are the Faculty of Defense Science and Technology, Faculty of Engineering, Faculty of Defense Studies and Management, and Faculty of

Defense Medical and Health. There are 18 undergraduate programs available at UPNM.

A. Problem Description

At the end of each academic semester, students must take part in a series of examinations that typically span over a few weeks. To facilitate this process, the Examination Unit Committee of the Academic Management Division at the UPNM campus prepares an examination timetable. When evaluating the suitability of a room/invigilator for examination purposes, several factors are considered. These factors include the room's capacity, the examination's timing, and the specific requirements that must be met to facilitate a fair and efficient examination process. Once the exam timetable is finalized, the committee manually assigns exam rooms, time slots, and invigilators for each exam. Note that this manual approach can be time-consuming and prone to human error.

B. Model Assumptions

The following assumptions are used to develop a mathematical programming model for the exam-invigilator assignment problem.

- The examination timetable is already available.
- Two different time slots are available each day, one in the morning and one in the afternoon.
- There are examination rooms available, each with sufficient capacity and a similar size.
- The maximum number of invigilators assigned in each exam room is fixed.
- Invigilators are assigned to one room per timeslot.
- Each invigilator is assigned to several examination time slots throughout the week of the examination period.
- Only non-academic staff are scheduled as invigilators for exam rooms and time slots, as academic staff are designated to assist students with questions during exams.
- The model does not include the assignment of the chief invigilator.
- There is an equal number of students in each examination room.

C. The Proposed Mathematical Model

This section details the integer programming model for the exam-invigilator assignment problem. The mathematical model in this study is based on Kahar and Kendall [7], with some modifications due to study requirements. All notations, parameters, and decision variables used in the development of the exam-invigilator assignment model are as follows:

1) Notations:

i 1 ... N, where N is the number of examinations
l 1 ... L, where L is the number of non-academic staff
r 1 ... R, where R is the number of rooms
t 1 ... T, where T is the number of timeslots

2) Parameters:

l_r The number of invigilators required in each room r
x_{it} 1 if examination i is scheduled on a time slot t, 0 otherwise
y_{it} 1 if examination i is assigned to room r, 0 otherwise
z_{rt} 1 if room r is assigned to a time slot t, 0 otherwise
S The maximum number of examinations assigned to an invigilator

3) Decision variables:

v_{lrt} 1 if non-academic staff s is assigned to invigilate at time slot t in room r, 0 otherwise

4) *Objective function:* The objective function F of the model is formulated to determine a schedule that achieves equitable distribution of invigilation duties among the non-academic staff, thereby ensuring that each time slot receives an equal allocation of invigilators.

$$\min F = \sum_{l=1}^{L} \sum_{r=1}^{R} \sum_{t=1}^{T} v_{lrt} \qquad (1)$$

5) Constraints:

- Non-academic staff are not assigned to multiple invigilation duties at a time.

$$\sum_{r=1}^{R} v_{lrt} \leq 1 \quad \forall l \in \{1, \dots, L\}, \forall t \in \{1, \dots, T\} \quad (2)$$

- *All non-academic staff must invigilate a maximum of S examinations within the exam period.*

$$\sum_{t=1}^{T} \sum_{r=1}^{R} v_{lrt} \leq S \quad \forall l \in \{1, \dots, L\} \qquad (3)$$

- The total number of invigilators assigned to each room r in timeslot t must equal the number required for each room.

$$\sum_{l=1}^{L} v_{lrt} = z_{rt} l_r \quad \forall r \in \{1, \dots, R\}, \forall t \in \{1, \dots, T\} (4)$$

III. Results and Discussion

This section details the implementation of the model in a case study focused on the scheduling of exam invigilators at Universiti Pertahanan Nasional Malaysia (UPNM). The primary dataset for this study is the short semester examination, academic session of 2021/2022. The data about this examination is acquired from the Examination Unit in the UPNM Academic Management Division.

This study aims to develop a mathematical model for the exam-invigilator schedule, aiming to offer an alternative solution for the UPNM Examination Unit Committee in their task of assigning exam-invigilators. The model can allocate an appropriate number of invigilators and prevent them from working consecutive time slots.

TABLE I
EXAMINATION-TIME SLOTS AND INVIGILATORS

Time Slot, t	Examination Room, r	
	Dewan Lestari Level 3, $r = 1$	**Dewan Lestari Level 4, $r = 2$**
1	Monday, 9 AM (14)	Monday, 9 AM (12)
2	Monday, 2 PM (10)	-
3	Tuesday, 9 AM (9)	Tuesday, 9 AM (8)
4	Tuesday, 2 PM (6)	-
5	Wednesday, 9 AM (12)	Wednesday, 9 AM (8)
6	Wednesday, 2 PM (3)	-
7	Thursday, 9AM (12)	Thursday, 9AM (11)
8	Friday, 9AM (8)	Friday, 9AM (11)

Note: ( ) indicates the number of invigilators assigned in each room

This facilitates the invigilator to obtain sufficient rest before administering subsequent examinations, making it a practical and efficient method for assigning exam invigilation tasks compared to the existing schedule.

Table I lists the examination rooms and invigilators assigned during the allotted time for exams. The examination timetable comprises 52 examinations, which are conducted over five days. Due to the limited availability of examination facilities, only two rooms with similar capacities are utilized.

TABLE II
EXAM-INVIGILATOR ASSIGNMENT, CASE 1 ($S = 2$)

Time Slot, t	$l_r = 3$ (Optimal = 39; Invigilator = 20)		$l_r = 6$ (Optimal = 78; Invigilator = 39)		$l_r = 8$(Optimal = 104; Invigilator = 52)	
	Dewan Lestari Level 3, $r = 1$	**Dewan Lestari Level 4, $r = 2$**	**Dewan Lestari Level 3, $r = 1$**	**Dewan Lestari Level 4, $r = 2$**	**Dewan Lestari Level 3, $r = 1$**	**Dewan Lestari Level 4, $r = 2$**
1	5, 7, 17	4, 10, 18	5, 7, 16, 23, 28, 35	4, 10, 17, 21, 29, 38	5, 7, 16, 23, 28, 37, 45, 51	4, 10, 17, 21, 29, 36, 44, 50
2	6, 12, 17	-	6, 12, 19, 25, 32, 33	-	6, 12, 19, 25, 32, 39, 40, 49	-
3	4, 12, 18	2, 11, 14	4, 12, 14, 22, 30, 35	2, 11, 19, 24, 33, 34	4, 12, 14, 22, 30, 35, 42, 49	2, 11, 19, 24, 33, 34, 41, 48
4	5, 13, 19	-	5, 13, 18, 26, 31, 36	-	5, 13, 18, 26, 31, 39, 40, 48	-
5	3, 8, 14	6, 13, 15	3, 8, 14, 22, 30, 38	6, 13, 15, 23, 31, 39	3, 8, 14, 22, 30, 33 , 41, 51	6, 13, 15, 23, 31, 38, 42, 52
6	3, 11, 20	-	3, 11, 20, 21, 29, 34	-	3, 11, 20, 21, 29, 37, 46, 47	-
7	7, 8, 19	1, 9, 16	7, 8, 15, 24, 32, 37	1, 9, 16, 25, 27, 39	7, 8, 15, 24, 32, 38, 45, 52	1, 9, 16, 25, 27, 35, 43, 46
8	2, 10, 16	1, 9, 15	2, 10, 17, 26, 28, 36	1, 9, 18, 20, 27, 37	2, 10, 17, 26, 28, 36, 43, 50	1, 9, 18, 20, 27, 34, 44, 47

TABLE III
EXAM-INVIGILATOR ASSIGNMENT , CASE 2 ($S = 3$)

Time Slot, t	$l_r = 3$ (Optimal = 39; Invigilator = 13)		$l_r = 6$ (Optimal = 78; Invigilator = 26)		$l_r = 12$ (Optimal = 156; Invigilator = 52)	
	Dewan Lestari Level 3, $r = 1$	**Dewan Lestari Level 4, $r = 2$**	**Dewan Lestari Level 3, $r = 1$**	**Dewan Lestari Level 4, $r = 2$**	**Dewan Lestari Level 3, $r = 1$**	**Dewan Lestari Level 4, $r = 2$**
1	4, 8, 11	3, 7, 13	4, 8, 12, 17, 22, 23	3, 7, 9, 16, 21, 24	4, 8, 12, 17, 22, 23, 31, 32, 36, 42, 45, 51	3, 7, 9, 16, 21, 24, 30, 33, 37, 43, 44, 49
2	4, 9, 10	-	4, 9, 10, 15, 20, 26	-	4, 9, 10, 15, 20, 22, 27, 33, 39, 44, 45, 50	-
3	3, 5, 12	4, 6, 11	3, 5, 11, 15, 20, 25	4, 6, 12, 14, 19, 26	3, 5, 11, 15, 20, 26, 28, 34, 39, 42, 49, 50	4, 6, 12, 14, 19, 25, 27, 31, 38, 43, 48, 51
4	3, 9, 10	-	3, 9, 10, 14, 21, 26	-	3, 9, 10, 14, 21, 26, 30, 34, 35, 42, 47, 50	-
5	2, 7, 12	5, 6, 11	2, 7, 11, 16, 18, 23	5, 6, 10, 17, 19, 25	2, 7, 11, 16, 18, 25, 29, 31, 37, 41, 46, 48	5, 6, 10, 17, 19, 23, 30, 32, 38, 40, 45, 49
6	1, 7, 9	-	1, 7, 13, 18, 19, 24	-	1, 7, 13, 18, 19, 24, 29, 35, 36, 43, 47, 52	-
7	2, 8, 13	1, 5, 12	2, 8, 13, 16, 21, 24	1, 5, 11, 17, 22, 23	2, 8, 13, 16, 21, 24, 28, 33, 38, 41, 46, 52	1, 5, 11, 17, 22, 23, 29, 34, 39, 40, 44, 48
8	2, 6, 10	1, 8, 13	2, 6, 12, 15, 20, 25	1, 8, 13, 14, 18, 22	2, 6, 12, 15, 20, 25, 27, 35, 37, 41, 46, 52	1, 8, 13, 14, 18, 26, 28, 32, 36, 40, 47, 51

Exams are scheduled for two-time slots per day, morning and afternoon sessions. To be exact, eight-time slots are available during exam week. 56 non-academic staff at the university are qualified to act as exam invigilators. They are assigned only a single time slot. Approximately 67 academic staff members are also assigned as invigilators. However, this study aims to allocate exam-time slots, with a specific focus on available non-academic staff while excluding academic staff from serving as invigilators.

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The proposed mathematical model is run on a PC with CPU AMD Ryzen 5 3500U with Radeon Vega Mobile Gfx processor and 8GB RAM and implemented in FICO® Xpress-MP Optimization Suite (Mosel version 4.0.3) without any solver cuts. The computational time is set to 600 seconds (10 minutes). To ensure practicality, it is assumed that an invigilator would be responsible for a maximum of two or three examinations during the period. The maximum number of invigilators required in each room, lr, is set randomly to 3, 6, and 8 for Case 1, S = 2, and 3, 6, and 12 for Case 2, S = 3. The computational time required to solve the proposed model for both cases is less than a second. Tables II and III present the computational results of the schedule of examination invigilators for both cases, $S = 2$ and $S = 3$, respectively. It should be noted that the numerical values presented correspond to the staff list numbers. Meanwhile, Figures I and II summarize the results.

These computational results are then compared to the timetable the UPNM Examination Unit Committee prepared. The purpose of this comparison is to assess the effectiveness of the proposed model in allocating invigilators and potentially identify any discrepancies or improvements that can be made. It is found that the existing timetable has some weaknesses. The analysis of staff allocation to exam rooms during assigned time slots reveals an unequal distribution in the actual schedule generated by the Examination Unit at UPNM. The allocation of invigilators to a given room during a specific time slot is inconsistent. This could be because of the large number of courses and students. Besides, a total of 124 invigilators, comprising academic and non-academic staff, are utilized throughout the one-week examination period.

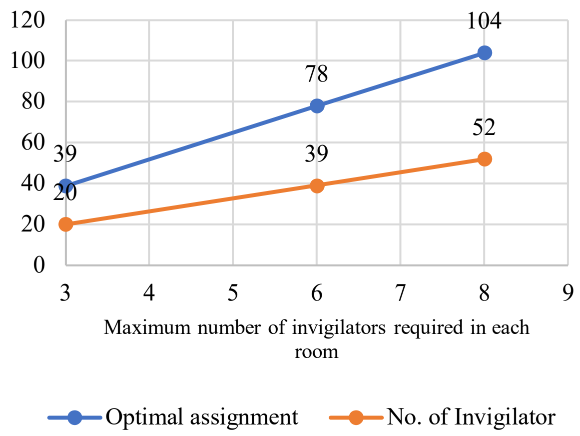

Fig. 1 Exam-invigilator assignment , case 1 (S = 2)

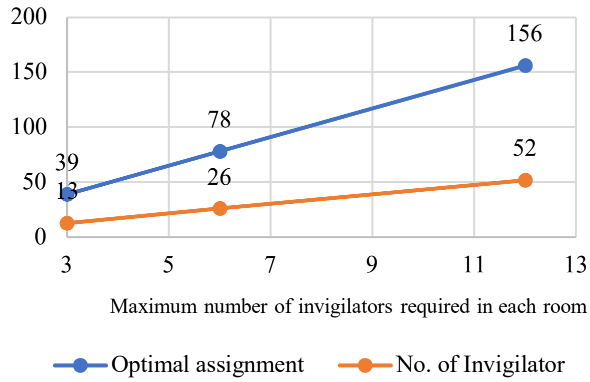

Fig. 2 Exam-invigilator assignment, case 2 (S = 3)

Based on our computational results shown in both tables and figures, the number of invigilators required is fairly distributed across eight-time slots in selected rooms to oversee no more than two or three exams per slot. The maximum number of non-academic staff assigned as invigilators is 52 for both cases, with the maximum number of invigilators required in each room being 8 or 12 individuals. The proposed mathematical model minimizes the total number of invigilators needed by at least 5%.

Furthermore, there is a positive relationship between the number of invigilators required in each room and the number of optimal assignments. However, the availability of staff will play an essential part in determining the allocation of invigilators. Regarding this case study, the maximum number of invigilators needed in each room is limited to 8 staff for Case 1 and 12 staff for Case 2. The model demonstrated a limitation in its capacity to determine the optimal solution when the number of invigilators assigned to each room exceeded the maximum. The result mentioned earlier indicates a lack of adequate staff for the assignment.

IV. Conclusion

Exam-invigilator scheduling is challenging due to factors such as the policies and regulations set by an educational institution and the need to coordinate many invigilators with a small number of available examination rooms. The findings of this study suggest that UPNM can effectively employ the proposed model for scheduling exam invigilators to enhance the existing scheduling system. This study can serve as a starting point and reference for future research on scheduling at UPNM, specifically to develop a comprehensive scheduling system for examination invigilators at UPNM. This paper successfully addresses some aspects of the problem but still falls short of providing a comprehensive solution. Improvements are deemed necessary to address the intricacies of scheduling examination invigilators and generate an enhanced timetable. In addition, it is strongly suggested that additional constraints be considered, all of which should be by the organization's unique requirements and preferences. One measure that could be considered is to assign the role of the chief invigilator in each room to either academic staff or non-academic staff.

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