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MODIFICATION OF UNIVERSITY EXAMINATION SCHEDULING MODEL: ELEVATING TIMETABLING COMMUNITIES' SATISFACTION

(*Pengubahsuaian Model Penjadualan Peperiksaan Universiti: Meningkatkan Kepuasan Komuniti Penjadualan*)

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ABSTRACT

The examination scheduling problem involves assigning exams, invigilators, and students to specific venues and time slots. It is a challenging task for all institutions even in its original form, especially when handling a huge number of examinations. The complexity increases when it requires adhering to various requirements. Many attempts have been made to solve the problem. However, they do not encounter user satisfaction. Models are constructed primarily based on the basic requirements of the respective university, and an attempt has been made to address these matters. Nevertheless, it took a considerable amount of computational time to reach 87.61% optimality. Factors causing the long computation time were identified, and an improved model was developed, emphasizing user considerations by including requirements for the full utilization of the main venues. In the new model, all possible causes were addressed. Exam assignments were optimized to match resources, schedule more exams in earlier time slots, and indirectly maximize venue usage. The objective function is reformulated to reduce the computational time while improving the optimality gap. The model was constructed using Mixed-Integer Linear Programming (MILP) and solved with the Advanced Interactive Multidimensional Modelling System (AIMMS) software, utilizing the CPLEX 20.1 solver on a Core i7 computer (3.40 GHz, 16GB RAM). Validation using a real examination problem, achieved 98.1% optimality, while further enhancing user satisfaction. A detailed analysis and comparison are discussed. This mathematical model will benefit most educational institutions by satisfying the majority of community preferences in producing better examination schedules in the future.

Keywords: scheduling; exact method; management

ABSTRAK

Masalah penjadualan peperiksaan melibatkan pengagihan peperiksaan, pengawas, dan pelajar ke tempat dan slot masa tertentu. Ia merupakan satu tugas yang mencabar bagi semua institusi, bahkan dalam bentuk asalnya, terutamanya apabila berdepan dengan jumlah peperiksaan yang besar. Kerumitan semakin meningkat apabila ia perlu mematuhi pelbagai keperluan. Banyak usaha telah dijalankan untuk menyelesaikan masalah ini. Namun begitu, ia tidak mencapai tahap kepuasan pengguna. Model-model yang dibangunkan adalah berasaskan kepada keperluan asas universiti masing-masing, dan percubaan telah dibuat untuk menangani perkara tersebut. Walau bagaimanapun, ia mengambil masa pengiraan yang agak lama untuk mencapai 87.61% tahap keoptimuman. Faktor yang menyebabkan masa pengiraan panjang telah dikenal pasti, dan sebuah model yang dipertingkatkan telah dibangunkan, dengan memberi penekanan kepada pertimbangan pengguna melalui pengambilan kira keperluan penggunaan penuh bagi tempat utama. Dalam model baharu ini, semua kemungkinan punca telah ditangani. Penugasan peperiksaan telah dioptimumkan supaya bersesuaian dengan sumber, menjadualkan lebih banyak peperiksaan pada slot masa awal, dan secara tidak langsung memaksimumkan penggunaan tempat. Fungsi objektif telah dirumus semula bagi mengurangkan masa pengiraan serta meningkatkan jurang keoptimuman. Model ini dibina menggunakan Pengaturcaraan Linear Integer Bercampur (MILP) dan diselesaikan dengan perisian Sistem Pemodelan

Multidimensi Interaktif Lanjutan (AIMMS), menggunakan penyelesai CPLEX 20.1 pada komputer Core i7 (3.40 GHz, 16GB RAM). Pengesahan menggunakan masalah peperiksaan sebenar telah mencapai 98.1% tahap keoptimuman, di samping meningkatkan lagi kepuasan pengguna. Analisis dan perbandingan terperinci turut dibincangkan. Model matematik ini akan memberi manfaat kepada kebanyakan institusi pendidikan dengan memenuhi sebahagian besar keutamaan komuniti dalam menghasilkan jadual peperiksaan yang lebih baik pada masa hadapan.

Kata kunci: penjadualan; kaedah tepat; pengurusan

1. Introduction

Timetables are a crucial aspect of planning and organization in various sectors, particularly in the education sector. According to the Oxford Dictionary (2010), a timetable is defined as a structured plan that schedules events or tasks to specific times, enabling individuals to manage their responsibilities effectively. In the academic field, timetables are important for organizing classes, examinations, and other university activities. The task of scheduling exams, known as the University Examination Timetabling Problem (UETP), involves assigning examinations, invigilators, and students to specific time slots and venues. This complex task requires satisfying various constraints, including room capacity, student availability, and institutional policies, while maximizing efficiency and minimizing conflicts.

Over the years, researchers have employed various optimization techniques to solve the UETP. Traditional methods, such as manual scheduling, are no longer practical due to the increasing number of exams and students. Metaheuristic algorithm, including genetic algorithms, simulated annealing, and tabu search, among others, have been employed to automate and improve the scheduling process (Jamaluddin & Aizam 2017). These methods consider both hard constraints, such as avoiding overlapping exams for students, and soft constraints, like minimizing the number of consecutive exams for students. The core challenge in UETP is managing both hard and soft constraints (Abdul Jamil *et al.* 2024). Figure 1 below illustrates the definition of both constraints.

Hard Constraint
Strict rules that must be followed without exception. Violating them makes the timetable invalid.

(a)

Soft Constraint
Flexible preferences that can be adjusted if necessary. Violating them does not invalidate the timetable.

(b)

Figure 1: Constraints definition

At Universiti Malaysia Terengganu (UMT), previous studies have focused on improving examination timetables but have faced limitations. One such study is by Chan and Aizam (2020), which introduces new objective functions to maximize venue preferences and allocate examinations within the first two weeks of the schedule. However, the model faced computational challenges, resulting in long execution times and achieving only 87.61% optimality. Moreover, the main venue, Dewan Sultan Mizan (DSM), was not fully utilized, highlighting a gap in resource optimization. This research, aims to tackle these limitations by reformulating the objective functions to reduce computational time and improve optimality. Additionally, a new objective function is introduced to maximize the utilization of the main venue, DSM, ensuring better resource allocation. Using real data from Semester II, 2018/2019, at UMT, a Mixed Integer Linear Programming (MILP) model was developed and solved using the Advanced Interactive Multidimensional Modelling System (AIMMS) software. This research aims to develop a more effective examination timetable that optimizes resource utilization and enhances satisfaction among students, lecturers, and administrators.

2. Literature Review

Research on solving the UETP has grown over the years. This growth is driven by the need to handle new constraints and changing requirements in universities. Researchers have introduced several benchmark datasets to test different solution approaches. These datasets have become the main element for researchers working to improve methods for solving educational timetabling problems. Among the most recognized datasets and their respective contributors are listed below:

Table 1: Benchmark dataset

Author	Dataset
Burke *et al.* (1996)	Nottingham
Carter *et al.* (1996)	Toronto
Merlot *et al.* (2003)	Melbourne
Ozcan and Ersoy (2005)	Yeditepe
Ayob *et al.* (2007a)	Universiti Kebangsaan Malaysia (UKM)
McCollum *et al.* (2007)	ITC2007

Real-world data has now also become the most common choice for researchers. Abdul Jamil *et al.* (2024), Muklason *et al.* (2024a), Carlsson *et al.* (2023), and Güler *et al.* (2021) are among the researchers who applied real datasets. This demonstrates the importance of applying actual problems faced by academic institutions, as this dataset offers the advantage of reflecting the actual requirements and scheduling challenges that encountered by institutions. Thus, making the results more practical and applicable. Real examination data of the Semester II session 18/19 from UMT were used in this study.

Three primary methods dominate the field: exact methods, heuristic methods, and hybrid methods. Exact methods involve mathematical models that determine the optimal solutions, adhering to all the complex rules and preferences. Tools such as CPLEX and Gurobi are often used to help solve these problems (Cavdur & Kose 2016). However, the exact methods face limitations when working with large datasets. Additionally, determining the best solution within a reasonable time can be computationally challenging.

To address this, heuristic methods are often used. These methods aim to obtain solutions more quickly, although they may not always yield the optimal solutions. Heuristic methods are well-suited for larger problems, yielding practical results that are generally sufficient for real-world applications. These methods reduce the complexity of the timetabling problem, but may sacrifice some solution quality to expedite the search process.

Recently, hybrid methods have emerged, combining exact and heuristic techniques for better results. Hybrid methods combine the precision of exact methods with the speed and flexibility of heuristic techniques. Hybrid methods have proven effective in generating high-quality solutions while reducing computational time. These methods are gaining popularity because they often outperform single methods, especially for large-scale timetabling problems.

While heuristic and hybrid methods are valuable for solving large and complex problems, exact methods are important when the goal is to obtain the best solution. This research however, focuses on using MILP as it provides high-quality solutions that meet both hard and soft constraints (Zaulir *et al.* 2022). Although heuristic methods are faster, they may not always give the highest-quality results, MILP ensures that the timetable is both feasible and optimized to meet the needs of students, lecturers, and administrators.

Table 2: Methodology

Author	Methodology
(i) Exact	
Abdul Jamil *et al.* (2024)	Integer linear programming (ILP)
Güler *et al.* (2021)	Mixed integer programming (MIP)
Güler & Geçici (2020)	Mixed integer programming (MIP)
Jamaluddin & Aizam (2017)	Binary integer programming (BIP)
(ii) Heuristics	
Muklason *et al.* (2024a)	Steepest-Ascent Hill Climbing
Muklason *et al.* (2024b)	Simulated Annealing
Mandal (2020)	Graph Colouring
Khair *et al.* (2019)	Ant Colony Optimization
(iii) Hybrid Method	
Lei *et al.* (2017)	Evolutionary Algorithm + Memetic Algorithm
Aldeeb *et al.* (2022)	Intelligent Water Drops + Local Search Optimizer

This research applies MILP to overcome UMT's examination scheduling challenges. Building upon the previous work of Chan and Aizam (2020), this study enhances the model by reformulating and introducing new objective functions that were previously overlooked in earlier models. Thus, it enables the generation of timetables in less computational time while maintaining high-quality scheduling outcomes.

3. Examination Timetabling Research in Malaysia

Several studies have focused on examination timetabling problems in Malaysian universities. Table 3 provides a summary of research efforts in Malaysian universities, highlighting the methodologies employed and their impact on examination timetabling solutions.

Table 3: UETP in Malaysia

Author	University / Location	Approach & Findings
Khair *et al.* (2019)	Universiti Sultan Zainal Abidin (UniSZA)	The study applies Ant Colony Optimization (ACO) to automate UniSZA's exam timetabling, improving efficiency over manual scheduling. Using real datasets, the ACO based approach helps find good solutions while handling constraints and demonstrating feasibility, with potential for further enhancement.
Jamaluddin & Aizam (2017)	Universiti Malaysia Terengganu (UMT)	This study addresses the UETP at UMT by developing a BIP model to optimize exam scheduling. Using AIMMS software, the model successfully generates conflict-free timetables while maximizing community preferences for exam assignments. The study demonstrated that different preference settings influence both computational performance and scheduling outcomes. These findings demonstrate the potential for improving UMT's scheduling system by incorporating real datasets and more complex constraints to enhance efficiency over the existing manual system.

Table 3 (Continued)

Aizam *et al.* (2016)	Universiti Malaysia Terengganu (UMT)	This study examines the examination timetabling problem, highlighting the importance of considering student and lecturer preferences. A survey at UMT identified factors affecting satisfaction, including the need for adequate time gaps between exams. Using Cronbach's alpha and factor analysis, the study highlights the importance of balancing institutional requirements with community demands.
Abdul-Rahman *et al.* (2014)	Universiti Utara Malaysia (UUM)	They proposed a graph coloring heuristic to solve the examination timetabling problem at UUM. Their approach utilized graph theory to effectively allocate exams to time slots while minimizing conflicts and improving resource utilization. These studies highlight the significance of heuristic techniques in addressing real-world timetabling timetabling challenges in Malaysia.
Othman & Mashhod (2012)	Multimedia University Malaysia (MMU)	The study focused on utilizing heuristic methods, such as graph coloring and clustering, to optimize exam timetables at MMU, specifically to reduce exam duration while addressing constraints for students and invigilators. These techniques effectively prevent clashes and improve scheduling efficiency. However, the study does not implement an automated system.
Kahar & Kendall (2010)	Universiti Malaysia Pahang (UMP)	This study considered unique constraints, such as room distance and exam splitting, which had previously been unmodeled. It introduces a formal problem definition and develops a constructive heuristic that outperforms the university's existing software by generating higher quality solutions while satisfying all hard constraints.
Ayob *et al.* (2007b)	Universiti Kebangsaan Malaysia (UKM)	This study explores the application of the Greedy Least Saturation Degree (G-LSD) heuristic, an adaptation of the least saturation degree heuristic, to solve the UETP at UKM. The research introduces a new objective function that prioritizes minimizing the number of consecutive exams for students and distributing exams evenly across the timetable. The study validates its method using the UKM dataset and modifies the Carter benchmark dataset to include real-world constraints. Findings suggest that the G-LSD heuristic, derived from graph coloring techniques, has potential applications in broader timetabling problems, including course and school scheduling.

Researchers in Malaysian universities have explored various approaches to solving the UETP. Unlike heuristic-based studies that prioritize speed over optimality, this research focuses on solution quality in scheduling while maintaining computational efficiency. This ensures that the generated timetable is mathematically optimized and practical for real-world implementation.

4. Problem Description

Examination scheduling is a challenging task that involves assigning exams to time slots and venues without causing conflicts for students, lecturers, and venues. Beyond these basic requirements, university examination timetabling also needs to consider additional demands, such as minimizing the number of consecutive exams for students, optimizing venue usage to avoid resource wastage, and balancing strict rules (hard constraints) with flexible preferences (soft constraints). These added challenges make the process more complicated and time-consuming to produce a practical timetable. UMT initially focused on marine sciences and has evolved into an institution that offers a diverse range of academic programs and a large student body, making exam scheduling increasingly complex and challenging.

The current system, which combines automated processes with manual adjustments, struggles to handle the task's complexity, often failing to meet the needs of students, staff, and the institution effectively. This research builds upon the mathematical model by Chan and Aizam (2020), aiming to enhance the quality of examination timetables by incorporating new requirements and reformulating certain parts to reduce computational time. Additionally, it seeks to improve the percentage of optimal solutions achieved, better serving the university community. Below are the constraints used in this study:

Hard Constraints:

(1) Completeness: All exams must be assigned to a venue at a time slot.
(2) Conflict: No student may take more than one exam in the respective venue at the same time slot.
(3) Unavailable Time Slot: The unavailable time slot for the exam to happen.
(4) Venue Capacity: The number of students assigned to each exam at a venue must be equal to or less than the venue capacity.
(5) Venue Limitation: The maximum number of exams that can be assigned for each venue and each time slot.
(6) Gap: The gap between consecutive exams is at least two time slots.
(7) Non-consecutive Time Slots: If two exams for the same student are scheduled on the same day, they must not be assigned to consecutive time slots.
(8) Different Duration Separation: Exams with different durations must not be assigned to the same venue.
(9) 3-Hour Exam: Exams with a duration of 3 hours must be scheduled in designated venues.

Soft Constraints:

(1) The student's preferences must be fulfilled.
(2) Minimize space wastage by assigning as many exams as possible to the earliest time slot.
(3) Maximize the usage of venue DSM by assigning as many exams as possible to DSM.

5. Mathematical Formulation

In this research, a mathematical model is developed to address the examination timetabling problem at UMT, building upon the work of Chan and Aizam (2020). The previous model faced limitations, including underutilization of the DSM venue and prolonged computational time, achieving only 87.61% optimality. To overcome these problems, this study reformulates the objective function to improve computational efficiency and achieve optimality. Additionally, a new objective function is introduced to maximize DSM utilization to reduce space wastage. The model constructed using MILP, includes approved requirements provided by UMT's

Academic Management Division (AMD). The complete list of constraints and notations used in the model is demonstrated below:

Notation

Sets

C	Sets of exams
T	Set of time slots
V	Set of venues
P	Sets of programs
R	Set of TU *(Teras Universiti)* Venues, where $R \subseteq V$
SR	Venue of DSM, where $SR \subseteq V$
A	Exams that need to be assigned earlier, where $A \subseteq C$
B	Exams that need to be assigned after, where $B \subseteq C$
D	Exams with a two-hour length, where $D \subseteq C$
E	Exams with a three-hour length, where $E \subseteq C$

Index

c	Exams
t	Time slots
v	Venues
p	Programmes
r	TU Venues
sr	DSM
a	The first exam to happen
b	The second exam to happen
d	Two-hour exams
e	Three-hour exams

Parameter

$P_{c,t,v}$	Preferences for exams assigned to venues and time slots
$Q_{c,t,v}$	Preferences of exams assigned to venues and into the earliest time slots (first 2 weeks)
$R_{c,t,v}$	Preferences of exams assigned to time slots in DSM
$E_{c,p}$	Enrolment of students for each exam
E_{TU}	University core examinations
T_{TU}	Time slots for the university's core examinations (only first slot during the first three days)
V_{TU}	Venues for the university's core examinations. TU Venue is reserved exclusively for university's core examinations.
$E_{TU'}$	All exams except university core examinations
T_B	Time slots for the rest day (weekends/public holidays)
E_c	Number of students for each exam
V_C	The capacity of each venue
$M_{t,v}$	Maximum number of exams for each venue per time slot
T_{3H}	Time slots for a duration of three hours
V_{3H}	The venue for the three-hour exam
$3H_{ACC3100A}$	Exam ACC3100A is a three-hour exam
$3H_{ACC3100A'}$	All exams are 3 hours except ACC3100A

$EG_{c,p}$	Enrolment of students for all exams for enrolment less than or equal to 15 and all core subject exams for enrolment more than 15
E_{SE}	All exams for enrolment are more than 15 exams
T_G	Time slots for the exam should have a gap in between
T_{GU}	Unavailable time slots for the enrolment of more than 15 exams

Decision Variable

$$X_{c,t,v} = \begin{cases} 1, if\ an\ exams, c\ is\ assigned\ to\ venue, v, at\ timeslot, t \\ 0, otherwise \end{cases} \quad (1)$$

Objective Function

Maximize

$$Max\ Y = Z + S + U \quad (2)$$

where

$$Z = \sum_{c \in C} \sum_{t \in T} \sum_{v \in V} P_{c,t,v} X_{c,t,v}$$ Maximize the preferences for assigning exams to venues at time slots (3)

$$S = \sum_{c \in C} \sum_{t \in T} \sum_{v \in V} Q_{c,t,v} X_{c,t,v}$$ Maximize the preferences for assigning exams to venues into the earliest time slots (first two weeks) (4)

$$U = \sum_{c \in C} \sum_{t \in T} \sum_{v \in V} R_{c,t,v} X_{c,t,v}$$ Maximize the preferences for assigning exams to time slots in DSM by minimizing the total number of unused seats in DSM (5)

Subject to:

Table 4: Description of each constraint

Constraints	Condition	Description	
$\sum_{t \in T} \sum_{v \in V} X_{c,t,v} = 1$	$\forall c \in C$	Ensure that all exams are assigned to the venue at a time slot.	(6)
$\sum_{t \in T_{TU}} \sum_{r \in R} X_{c,t,r} = 1$	$\forall c \in E_{TU}$	Ensure that the University Core courses are assigned to the TU Venue and TU Time Slot only. As these courses exceed the main venue's capacity (DSM), they must be split across multiple venues while maintaining the same time slot.	(7)
$\sum_{c \in E_{c,p}} \sum_{v \in V} X_{c,t,v} \leq 1$	$\forall p \in P$ $\forall t \in T$	Ensure no students are taking more than one exam at the respective venue at the same time slot.	(8)
$\sum_{c \in E_{TU}'} \sum_{t \in T_{TU}} X_{c,t,v} = 0$	$\forall v \in V_{TU}$	Ensure that exams not included as university core courses (exam enrolment more than 660 number of students) are not assigned to the TU Time Slot and in certain restricted venues.	(9)
$\sum_{c \in E_{TU}'} \sum_{t \in T} X_{c,t,r} = 0$	$\forall v \in R$	Ensure that exams not included as university core courses (exam enrolment more than 660 number of students) are not assigned to the "TU Venue" in any time slot.	(10)
$\sum_{t \in T_B} X_{c,t,v} = 0$	$\forall c \in C$ $\forall v \in V$	Ensure that no exams are assigned in the unavailable time slots.	(11)

$\sum_{c\in C} X_{c,t,v}E_c \le V_C$	$\forall t \in T$ $\forall v \in V$	Ensure that the total number of students assigned to each exam at a venue is equal to or less than the venue's capacity.	(12)
$\sum_{c\in C} X_{c,t,v} \le M_{t,v}$	$\forall t \in T$ $\forall v \in V$	Ensure that the total number of exams at each venue does not exceed the maximum number of exams that can be allocated to each time slot and venue.	(13)
$x_{a,t,v} - \sum_{b\in B} X_{b,t+2,v} = 0$	$\forall a \in A$ $\forall b \in B$ $\forall t \in T$ $\forall v \in V$	Ensure that the selected course exams for certain groups are scheduled to occur at an earlier time.	(14)
$\sum_{c\in E_{c,p}} \sum_{v\in V} X_{c,t,v} + X_{c,t+1,v} + X_{c,t+2,v} \le 1$	$\forall p \in P$ $\forall t \in T$	Ensure that there are at least two time slot gaps between consecutive exams.	(15)
$\sum_{c\in E_{SE}} X_{c,t,v} = 0$	$\forall t \in T$ $\forall v \in V$	Ensure students who enrolled for more than 15 exams have a gap of at least one time slot between two exams on the same day.	(16)
$X_{d,t,v} + X_{e,t,v} \le 1$	$\forall d \in D$ $\forall e \in E$ $\forall t \in T$ $\forall v \in V$	Ensure that three-hour exams are allocated to the different venues from two-hour exams for all time slots.	(17)
$\sum_{t\in T_{3H}} \sum_{v\in V_{3H}} X_{e,t,v} = 1$	$\forall e \in E$	Ensure that three-hour examinations are scheduled in three-hour time slots and three-hour venues.	(18)
$\sum_{t\in T_{3H}} \sum_{v\in V} X_{e,t,sr} = 1$	$\forall e \in E$	Ensure that the exam for ACC3100A is assigned at DSM.	(19)
$X_{c,t,v} \in \{0,1\}$		Defines a binary decision variable, which is essential for determining whether an exam is assigned to a specific room at a particular time slot.	(20)

6. Experimental Data

Data analysis is a crucial component of this research, encompassing the processes of inspecting, organizing, modifying, and transforming collected data into meaningful information. The model developed for this study was verified and validated using real data from UMT. Specifically, data from the undergraduate exam schedule for the second semester of the 2018/2019 academic year was utilized. The dataset is presented in Table 5, while Table 6 provides the parameters used in AIMMS.

Table 5: Dataset of the second semester of the 2018/2019 academic year

Schools	8
Programs	27
Registered Courses	468
Total Courses with Final Exams	313
- Open Elective Courses	37
- Compulsory Courses	276
3-Hour Exams	15
2-Hour Exams	298
No. of Students	36,800
Exam Period	19 days / 57 time slots 3 time slots per day
Room Availability	27 rooms
Range Seating Capacity	30 – 660

Table 6: Parameter data used in AIMMS

Parameters	Notation	Data	
Preferences for exams assigned to time slots and venues	$P_{c,t,v}$		Range: {1, 5} 5 – most preferred 4 – more preferred 3 – moderate preferred 2 – less preferred 1 – least preferred
Preferences of exams assigned to venues and into the earliest time slots (first 2 weeks)	$Q_{c,t,v}$	Day 1 – 14 Day 15 Day 16 Day 17 Day 18 – 19	Range: {1, 5} 5 – most preferred 4 – more preferred 3 – moderate preferred 2 – less preferred 1 – least preferred
Preferences of exams assigned to time slots in DSM	$R_{c,t,v}$	{DSM} {DS1, … , BK4-08} {BK1-02, … , BK2-05} {BK3-03, … , BK3-07} {BK4-03}	Range: {1, 5} 5 – most preferred 4 – more preferred 3 – moderate preferred 2 – less preferred 1 – least preferred
Maximum number of time slots per day	N	3	
Maximum number of exams for each venue per time slot	$M_{t,v}$	DSM – Maximum 7 exams DS1 – Maximum 2 exams Other venues – Maximum 1 exam	
The venue for the three-hour exams	V_{3H}	{DS1, … , BK4-08}	

7. Results and Discussion

The mathematical model in this research was executed using AIMMS software with CPLEX 20.1 as the solver. Despite hardware limitations affecting computational capacity, the model achieved 98.1% optimality with a 5% relative tolerance applied during execution. This reformulation reduced computational time significantly while maintaining solution quality. This demonstrates the model's ability to tackle the UETP, a challenging task due to its large dataset and complex constraints.

Table 7 presents the computer specifications used, highlighting the differences in hardware and software between the previous study and the current research. Both studies were implemented using AIMMS software. However, the computational time difference can be attributed to the hardware specifications. The previous study employed a system with lower memory and a slower processor, which may have limited the solver's efficiency in handling complex constraints. The current research was conducted on a system with higher processing speed and increased memory, enabling faster data processing and improved handling of optimization constraints.

Table 7: Computer specifications used

Chan & Aizam (2020)	Current Research
CPLEX 12.9	CPLEX 20.1
Core i7 computer with 2.70 GHz speed	Core i7 computer with 3.40 GHz speed
4GB of RAM	16GB of RAM

The model includes three main objectives:

(1) Objective 1: Assign exams to preferred venues and time slots
(2) Objective 2: Schedule most exams in the first two weeks
(3) Objective 3: Maximize the use of the main venue

The results of these objectives are summarized in Table 8. It demonstrates that the first objective function has a maximum value of 1532. Besides, the second objective function has a maximum value of 1456. The maximum value for the third objective function is 1448. All three objective functions are in the maximum direction with the best solution obtained being 4436.

Table 8: Result summary of the objective values

Objective Function	Direction	Objective Value	Best Solution
1	Maximum	1532	
2	Maximum	1456	4436
3	Maximum	1448	

For Objective 1, exams were assigned based on preference values, where 1 is the least preferred and 5 is the most preferred. As depicted in Table 9, 92.65% of exams were scheduled in venues and time slots with the highest preference (value 5), indicating strong alignment with community preferences.

Table 9: Comparison of the total number of exams assigned based on each preference value and its percentage for the first objective function

Preference Value	Comparison	1	2	3	4	5
Total number of exams assigned based on each preference value	Chan & Aizam (2020)	2	7	10	34	260
	Current Research	0	3	4	16	290
Percentage (%)	Chan & Aizam (2020)	0.64	2.24	3.19	10.86	83.07
	Current Research	0.00	0.96	1.28	5.11	92.65

8. Modification of The Second Objective Function

The second objective function, initially proposed by Chan and Aizam (2020), aimed to prioritize assigning exams to the earliest time slots, primarily within the first two weeks, to minimize space wastage from unused or overcrowded seats. However, their method required a very long computational time to achieve results. In this research, the second objective function was revised to make the process faster as follows:

$$S = \sum_{c}^{C} \sum_{t \in T_{front}}^{T} \sum_{v}^{V} X_{c,t,v} \quad \rightarrow \quad S = \sum_{c}^{C} \sum_{t}^{T} \sum_{v}^{V} Q_{c,t,v} X_{c,t,v}$$

The new formulation significantly reduces computational time by optimizing the assignment of exams to time slots, as the index and the standardized dimension have been adjusted. To improve computational efficiency, the formulation was modified by embedding the T_{front} directly within the preference parameter $Q_{c,t,v}$. Previously, the model enforced an explicit summation over T_{front}, restricting exam assignments to the earliest time slots. While this formulation prioritized early scheduling, it increased problem complexity by introducing additional summation terms, leading to longer solver processing times.

In the refined model, instead of forcing exams into T_{front}, the researcher introduced a weighted preference parameter of $Q_{c,t,v}$ that guides exams toward earlier slots more flexibly. $Q_{c,t,v}$ assigns a higher weight to earlier time slots, meaning the model prefers but does not strictly enforce early scheduling. This change eliminates the need for summation over T_{front}, making the model more straightforward. This modification significantly decreases computational time.

Table 10: Comparison in terms of computational time and optimality

Criteria	Result Obtained	
	Chan & Aizam (2020)	Current Research
Relative Optimality Tolerance in the AIMMS Setting	0.30	0.05
Optimality Gap (%)	12.39	1.90
Total Computational Time (sec)	9836.13	3771.86
Percentage Decrease in Computational Time in the Current Research (%)	61.65	

Table 11: Comparison of the total number of exams assigned for each period and its percentage for the second objective function

Criteria	Comparison	First Two Weeks	After First Two Weeks
Total number of exams assigned for each period	Chan & Aizam (2020)	274	39
	Current Research	262	51
Percentages (%)	Chan & Aizam (2020)	87.54	12.46
	Current Research	83.71	16.29

As depicted in Table 10, the current study achieved a better result, as the optimality gap was reduced from 12.39% to 1.90%. The total computational time also decreased by 61.65%, from 9,836.13 seconds to 3,771.86 seconds. Regarding the distribution of exams within the first two weeks, the previous study scheduled 87.54% of exams within this period, whereas the current study scheduled 83.71%, a difference of only 3.83%. Although the previous study performed slightly better in this aspect, the difference is relatively small. In absolute terms, this amounts to only 12 exams.

Notably, while the percentage of exams scheduled in the first two weeks is slightly lower, the revised model greatly improves computational time and solution quality. The proposed approach reduces computational time by 61.65% and improves the optimality gap from 12.39% to 1.90%, making the scheduling process far more efficient. The small trade off in exam distribution is outweighed by these significant improvements, demonstrating that the new model achieves a better balance between early scheduling and overall performance.

9. Additional Objective Function

$$U = \sum_{c}^{C} \sum_{t}^{T} \sum_{v}^{V} R_{c,t,v} X_{c,t,v}$$

An additional objective function or new constraint (soft constraint) was introduced in this study to maximize the utilization of the main venue, which had been underutilized in previous research. This function prioritized the main venue for exam assignments over other venues to reduce overall utilities and space wastage. The results presented in Table 12 demonstrate that this approach effectively increases the room utilization. Note that 62.94% of exams were assigned to the DSM in the current study, compared to 37.06% at other venues, which indirectly optimized venue usage.

Additionally, while both studies utilized the exact total of 57 time slots, a DSM capacity of 660, and a total seating capacity of 36,720 at DSM, the current research reduced the total unused seats at DSM from 5,370 (14.62%) to 4,569 (12.44%), resulting in a saving of 801 seats. This represents a 14.92% reduction in unused seats compared to the previous research, as demonstrated in Table 13. These findings demonstrated that the additional objective function is capable of minimizing space wastage, which in turn reduces the overall utilities used, including electricity wastage. Thus, this improves the efficiency in university exam scheduling.

Table 12: Total number of exams assigned for each venue and its percentage for the third objective function

Venue	DSM	Other Venues
Total number of exams assigned for each venue	197	116
Percentages (%)	62.94	37.06

Table 13: Comparison in terms of space wastage

Criteria	Result Obtained	
	Chan & Aizam (2020)	Current Research
Total Time Slots Used	57	57
Capacity of DSM	660	660
Total Amount of Capacity at DSM in All Time Slots	36720	36720
Total Number of Unused Seats at DSM	5370	4569
Percentage of the Total Number of Unused Seats at DSM (%)	14.62	12.44
Total Number of Save Up Seats at DSM	801	
Percentage Change in the Total Number of Unused Seats at DSM (%)	14.92	

Compared to the work by Chan and Aizam (2020), this study focuses on making better use of venues with a specific objective function. While their study provided foundational insight into exam scheduling, this research takes it a step further by examining how venue usage affects wasted seats and overall efficiency. The findings can also be adapted for use in other universities or institutions with different venue capacities and scheduling constraints. This makes the system flexible and helpful for universities with fewer resources.

10. Timetable and Discussion

An example of an examination timetable, as illustrated in Figure 2, was successfully generated using AIMMS software and mathematical modelling. The timetable illustrated represents only a part of the complete exam schedule generated by the model, specifically demonstrating 5 days out of the 15-day examination period.

Figure 2 illustrates the generated timetable that follows all the defined constraints. This proves that each exam was scheduled exactly once, with no duplication or omission. Students were not assigned overlapping exams within the same time slot or at the same venue. No student takes more than one exam at the respective venue within a given time slot. All exams were allocated within the available time slots in 15 days, avoiding weekends or other unavailable periods. On the other hand, the three University Core courses, which are NCC2000, NCC2001, and NCC2002, can be assigned to TU time slots (the first three days) and specified venues as requested.

Week / Day	WEEK 1									
	9.00 - 11.00		9.00 - 12.00		12.00 - 2.00		3.00 - 5.00		3.00 - 6.00	
	Course	Venue	Course	Venue	Course	Venue	Course	Venue	Course	Venue
Day 1	AQU4105	BK2-05			ECO4000	DSM	BBB3402	DSM	ACT3402	DS1
	FIZ4102	BK4-05			KIM3201	DSM	BBB3703	DSM		
	KIM4502	BK4-06			MKE4804	DSM	GTN4304	DSM		
	NCC2000	DSM			MMS3101	DSM	KAS4201	DSM		
		DS1			ECO4303	DS1	MKP4602	DSM		
		BK4-08			MKP3600	BK1-01	MMM4306	DSM		
					KEJ3104	BK1-04	MTK3401	DSM		
					COU4500	BK2-03	MMT3202	BK1-01		
							SOC3501	BK2-03		
Day 2	FEI4302	BK4-05			COU3300	DSM	CSF3101	DSM	ACT3502	DS1
	AQU4601	BK4-06			MGM4402	DSM	GTN4303	DSM	ACT4105	BK4-01
	BIO3202	BK4-07			MMM4302	DSM	KIM4102	DSM		
	NCC2001	DSM			MMM4304	DSM	MGM4821	DSM		
		DS1			SOC3104	DSM	MMB4500	DSM		
		BK1-01			MMS3401	DS1	MMM4901	DSM		
		BK3-04			COU3004	BK1-01	MMT4302	DSM		
					CSE3503	BK2-03	STM3110	BK1-01		
							CSF4402	BK2-03		
							BBB3403	BK4-05		
Day 3	FEI4301	BK4-05			BIO	DSM	BBB3603	DSM	ACT4102	BK1-01
	AQU4107	BK4-07			COU3201	DSM	ECO3203	DSM		
	NCC2002	DSM			CSF3107	DSM	GTN3208	DSM		
		DS1			MGM4106	DSM	GTN3501	DSM		
		BK1-01			MKP4303	DSM	KIM4604	DSM		
		BK1-04			STM3106	DSM	MGM4832	DSM		
		BK2-03			ECO4503	DS1	MMM4106	DSM		
		BK3-01			MGM3802	BK1-01	SOC3207	DS1		
		BK3-02					COU3005	BK2-03		
		BK3-05					MMS3003	BK4-04		
		BK4-01								
		BK4-02								
		BK4-04								
		BK4-08								
Day 4	KIM4401	DS1	ACT3201	DSM	BIO3500	DSM	AQU3202	DSM		
	AQU3601	BK1-01	ACT4101	DSM	COU3200	DSM	KIM4701	DSM		
	KIM3401	BK2-03			CSE3504	DSM	MMB4301	DSM		
	BIO3403	BK2-06			GTN3100	DSM	SOC4106	DSM		
	MMT3303	BK3-02			STM3301	DSM	STM3401	DSM		
	BBB3701	BK3-05			MMS4001	DS1	MGM4103	DS1		
	FIZ4402	BK4-01			MKE4808	BK2-03	MKP3300	BK1-01		
							NCC3002	BK2-03		
							BBB3502	BK3-08		
Day 5	FEI3205	DSM			BDV3002	DSM	CSF3401	DSM	FIN4701	BK3-04
	FIZ3103	DSM			ECO4200	DSM	KIM3001	DSM		
	FIZ4104	DSM			KAS3701	DSM	KIM4602	DSM		
	KIM3302	DSM			MGM4824	DSM	MMS3001	DSM		
	MGM3804	DSM			SOC4201	DSM	MTK3600	DSM		
	MMT4501	DSM			SOC3401	DS1	SOC4302	DS1		
	MMM4105	DS1			STM3201	BK2-03	GTN3600	BK1-01		
	FIS3802	BK1-01					STM3105	BK2-03		

Figure 2: Examination schedule generated for Semester 2018/2019

The scheduler can manage venue capacities by ensuring that no venue exceeds its maximum capacity. All students can secure their seats in the respective time slots and venues. For exams with enrollments that exceed the main venue's capacity, DSMs, such as NCC2000, NCC2001, and NCC2002, the exams were appropriately split into multiple venues, as illustrated in Figure 2. Furthermore, the number of exams assigned to each venue was kept within the allowable limit, as DSM is 7, DS1 is 2, and the other venues are 1.

On the other hand, the schedule ensured that students were not required to sit for consecutive exams on the same day, and all exams were scheduled with a minimum gap of two time slots. For core courses in programmes with more than 15 exams, a minimum gap of two time slots is required to provide sufficient preparation time. For smaller programmes with enrolments of fewer than 15 exams, students were not required to take more than two exams in a single day, thereby reducing stress and fatigue.

The precedence constraint was also adhered to, as the selected course exams for certain groups will occur earlier. For example, theory-based courses have to be scheduled before the practical-based courses. Hence, it also applies to continuous courses, such as Numerical Analysis (MTK3300) and Advanced Numerical Analysis (MKP4301). MTK3300 is set to be assigned before MKP4301. The result demonstrate that MTK3300 is assigned from 9:00 am to 11:00 am, whereas MKP4301 is assigned from 3:00 pm to 5:00 pm on the same day, which is day 9. It has been demonstrated that the result satisfies the precedence constraint.

The two-hour and three-hour exams were successfully assigned to different time slots and venues. This approach prevents disruptions caused by students leaving the exam hall early, ensuring a smooth and uninterrupted examination process. Figure 2 illustrates that the three-hour exams, marked in red, were successfully separated from the two-hour exams, marked in white.

Overall, the examination timetable demonstrates the model's effectiveness in meeting all constraints and objectives. It successfully balances the needs of students, university policies, and other requirements.

11. Conclusion

This research successfully improves the UETP for Semester II 2018/2019 at UMT by improving the mathematical model proposed by Chan and Aizam (2020). Through reformulation of the previous objective function and the addition of one new requirement, the model achieves better efficiency and optimality. The model, constructed using MILP, fulfils all hard and soft constraints while delivering a 98.1% optimal solution. The improvements include a 61.65% reduction in computational time and a 14.92% decrease in unused seats at the main venue (DSM). Additionally, the new model ensures that there are no exam conflicts and provides gaps between consecutive exams, indirectly reducing stress among students.

The research applies three objective functions to optimize examination scheduling. These functions maximize preferences for assigning exams to time slots and venues, with a particular emphasis on prioritizing the first two weeks and optimizing the use of DSM. The model's performance demonstrates improvements over previous approaches, with preferences achieving 92.65%, 83.71%, and 62.94%, respectively. Despite computational challenges, the model efficiently handles UMT's large dataset, demonstrating its practical applicability to real-world scenarios in academic timetabling.

However, achieving a fully optimal solution remains a challenge due to several factors. One of them is the soft constraint on maximizing the use of the DSM venue, which does not guarantee full utilization. Future studies could consider reclassifying this as a hard constraint to ensure the venue is fully assigned. Another limiting factor is the gap constraint imposed on students from programs with more than 15 exams, which increases computational time. Reformulating this constraint could reduce complexity and improve solution efficiency, potentially leading to a fully optimal solution. To further enhance the solution, future research should investigate the utilization of high-performance computing resources. This allows the model to accommodate more constraints without compromising computational time. By implementing these improvements, future models have the potential to achieve a 100% optimal solution. This research highlights the applicability of the improved mathematical model across educational institutions, offering a practical approach to reducing manual workload, and producing efficient timetables that balance institutional and community needs.

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