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Optimization in University Student Timetables: A Comprehensive Literature Review

Farradini Zabidee[1], Muhamad Hariz Muhamad Adnan[1,*]

[1] Faculty of Computing and Meta-Technology, Universiti Pendidikan Sultan Idris, 35900, Tanjong Malim, Perak, Malaysia

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ABSTRACT

The University Course Timetabling Problem presents a complex optimization problem as it seeks to meet the diverse requirements and constraints of a university's academic program through efficient timetabling. The objective of this research is to conduct comprehensive review of existing studies on optimization approaches in optimizing university timetable problems. The aim of the comprehensive studies is to further analyse the existing studies to discuss comparative studies to compare the performance of the approach methods in satisfying the constraints involved in university timetabling. The methodology used for this paper is systematic literature review which brought three main themes such as constraints, optimization approaches, and datasets involved in the University Course Timetabling Problem. The result showed that the majority of approaches involved hybrid approaches. In conclusion, this comprehensive review summarizes the constraints, optimization approach and datasets involved in the University Course Timetabling Problem in higher educational institutions of ASEAN countries.

1. Introduction

The University Course Timetabling Problem (UCTP) has provided educational institutions with a difficult challenge. It entails efficiently constructing an appropriate timetable while taking into consideration all the constraints and requirements specified by the respective institutions. UCTP is classified as nonpolynomial time hard (NP-Hard) problems and combinatorial optimization problems, specifically the scheduling process cannot be precisely solved in polynomial time due to its exponential complexity and growth [1-4]. UCTP can be addressed to generate the most optimal solution by utilizing optimization algorithms with the objective of maximizing the soft constraints which can vary depending on the institutions [1,3]. The course timetabling process takes place at the beginning of the semester involving the allocation of events such courses, lecturers and students to the fixed timeslots and rooms [3,5].

* *Corresponding author.*
E-mail address: mhariz@meta.upsi.edu.my

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This article aims to narrow down the gap in understanding and identifies the approach taken in solving UCTP in higher educational institutions among ASEAN countries. The article presented a general and baseline overview of approach in the region reviewed. This work fills an important gap in the literature, with most comprehensive review examining on the methodologies approach on UCTP [2], metaheuristic algorithm in UCTP [6], approaches to various types of assignment problems in the education domain [7], and methods on university course and exam timetabling problems [8]. This study holds significant importance as it investigates the recent trend in optimization approaches and requirements needed for timetabling problems in higher educational institutions across the ASEAN countries.

To develop a relevant comprehensive review, the literature study was supported by the main research question – how do institutions in ASEAN countries solve optimization in university timetabling problems? This study focuses on the approaches taken in optimizing university timetabling to solve the UCTP among ASEAN educational institutions. According to the research question, the focus of this study is to conduct a comprehensive review of the existing studies on optimization approaches in optimizing university timetable problems. The study attempts to further analyse the existing studies to discuss recent studies on the challenges and solutions in university course timetabling.

The paper is structured as follows:

i. Introduction (research background and objective);
ii. Methodology (comprehensive review methodology);
iii. Result (findings based on the themes);
iv. Discussion (discussion of the review);
v. Conclusion (conclude the paper);
vi. Acknowledgment;
vii. References.

2. Methodology

2.1 Systematic Literature Review Guidelines

The comprehensive review or systematic literature review was guided by existing systematic literature review and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [2,6-9]. The guidelines helped in systematic reporting to enhance reproducibility and assist in literature review research. The systematic literature review guidelines consist of identification, screening, eligibility, data analysis and reporting phases. For the quality assessment in data analysis, Kitchenham and Charters quality assessment framework is applied in this review [10]. Three main databases were used in this comprehensive review, namely Scopus, Web of Science, and Taylor and Francis.

2.2 Review Process

2.2.1 Identification

The identified keywords used are based on previous studies, thesaurus, and keywords that are similar and related to university timetable optimization. Table 1 shows the keywords used for search strings for the respective database.

Table 1
Summary of keywords used for search strings

Database	Search string
Scopus	TITLE-ABS-KEY (("timetable*" OR "schedule*" OR "course scheduling" OR "course allocation" OR "course planning" OR "course optimization" OR "scheduling problem*" OR "scheduling" OR "timetabling" OR "timetable scheduling" OR "timetable allocation" OR "schedule allocation" OR "timetable planning" OR "schedule planning" OR "timetable optimization" OR "timetabling problem*") AND ("optimi*ation" OR "algorithm*" OR "mechanism*" OR "recommendation system" OR "application*" OR "programming" OR "system") AND ("universit*" OR "college*" OR "academy" OR "school*")) AND PUBYEAR > 2017 AND PUBYEAR < 2024 AND (LIMIT-TO (AFFILCOUNTRY , "Brunei Darussalam") OR LIMIT-TO (AFFILCOUNTRY , "Cambodia") OR LIMIT-TO (AFFILCOUNTRY , "Indonesia") OR LIMIT-TO (AFFILCOUNTRY , "Laos") OR LIMIT-TO (AFFILCOUNTRY , "Malaysia") OR LIMIT-TO (AFFILCOUNTRY , "Myanmar") OR LIMIT-TO (AFFILCOUNTRY , "Philippines") OR LIMIT-TO (AFFILCOUNTRY , "Thailand") OR LIMIT-TO (AFFILCOUNTRY , "Singapore") OR LIMIT-TO (AFFILCOUNTRY , "Viet Nam")) AND (LIMIT-TO (LANGUAGE , "English"))
Web of Science	TS=(("timetable*" OR "schedule*" OR "course scheduling" OR "course allocation" OR "course planning" OR "course optimization" OR "scheduling problem*" OR "scheduling" OR "timetabling" OR "timetable scheduling" OR "timetable allocation" OR "schedule allocation" OR "timetable planning" OR "schedule planning" OR "timetable optimization" OR "timetabling problem*") AND ("optimi*ation" OR "algorithm*" OR "mechanism*" OR "recommendation system" OR "application*" OR "programming" OR "system") AND ("universit*" OR "college*" OR "academy" OR "school*"))
Taylor and Francis	[[Abstract: "timetable"] OR [Abstract: "schedule"] OR [Abstract: "course scheduling"] OR [Abstract: "course allocation"] OR [Abstract: "course planning"] OR [Abstract: "course optimization"] OR [Abstract: "scheduling problem"] OR [Abstract: "scheduling"] OR [Abstract: "timetabling"] OR [Abstract: "timetable scheduling"] OR [Abstract: "timetable allocation"] OR [Abstract: "schedule allocation"] OR [Abstract: "timetable planning"] OR [Abstract: "schedule planning"] OR [Abstract: "timetable optimization"] OR [Abstract: "timetabling problem"]] AND [[Affiliations: brunei] OR [Affiliations: cambodia] OR [Affiliations: indonesia] OR [Affiliations: laos] OR [Affiliations: malaysia] OR [Affiliations: myanmar] OR [Affiliations: philippines] OR [Affiliations: singapore] OR [Affiliations: thailand] OR [Affiliations: vietnam]] AND [Publication Date: (01/01/2018 TO 12/31/2023)]

2.2.2 Screening

The inclusion and exclusion criteria are shown in Table 2. The publication years are between 2018 and 2023 to examine the latest evolution and improvement in the related research. The literature type taken was the article journal with empirical data to make the comparison between proposed approaches according to the data that existed. The English language is chosen as the main language for the literature to ensure understanding of the language without confusion. The country specified is ASEAN countries to analyse on global perspective of university course timetabling problem is being solved based on cultural and societal factors.

Table 2
Summary of inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Literature type	Journal (research articles), conference proceeding (research paper)	Journal (systematic review, review, meta-analysis, meta-synthesis), book series, book, chapter in book, conference proceedings (review, survey)
Language	English	Non-English
Timeline	Between 2018 to 2023	Less than 2018
Countries and territories	Malaysia, Thailand, Laos, Indonesia, Vietnam, Philippines, Brunei, Myanmar, Cambodia, Singapore	Non-ASEAN countries

2.2.3 Eligibility

The eligibility phase is done by reading the title and abstract of the collected article journals to make sure that the research was related to university timetabling optimization. The title and abstract also must fit the inclusion and exclusion criteria stated before. The examination is done manually by the authors.

2.2.4 Data analysis

Data analysis is done to identify the quality of the article journals. The articles were analysed based on the Kitchenham and Charters quality assessment framework [10]. There are five questions used to determine the quality of the article journals. The articles were analysed by 1, 0, or 0.5 points per question. Articles with more than 3 points were taken for data extraction. The questions are as follows:

i. Q1 Is the purpose of the study clearly stated?
ii. Q2 Is the interest and the usefulness of the work clearly presented?
iii. Q3 Is the study methodology clearly established?
iv. Q4 Are the concepts of the approach clearly defined?
v. Q5 Is the work compared and measured with other similar work?
vi. Q6 Are the limitations of the work clearly mentioned?

Figure 1 below shows the flow diagram for the comprehensive review process.

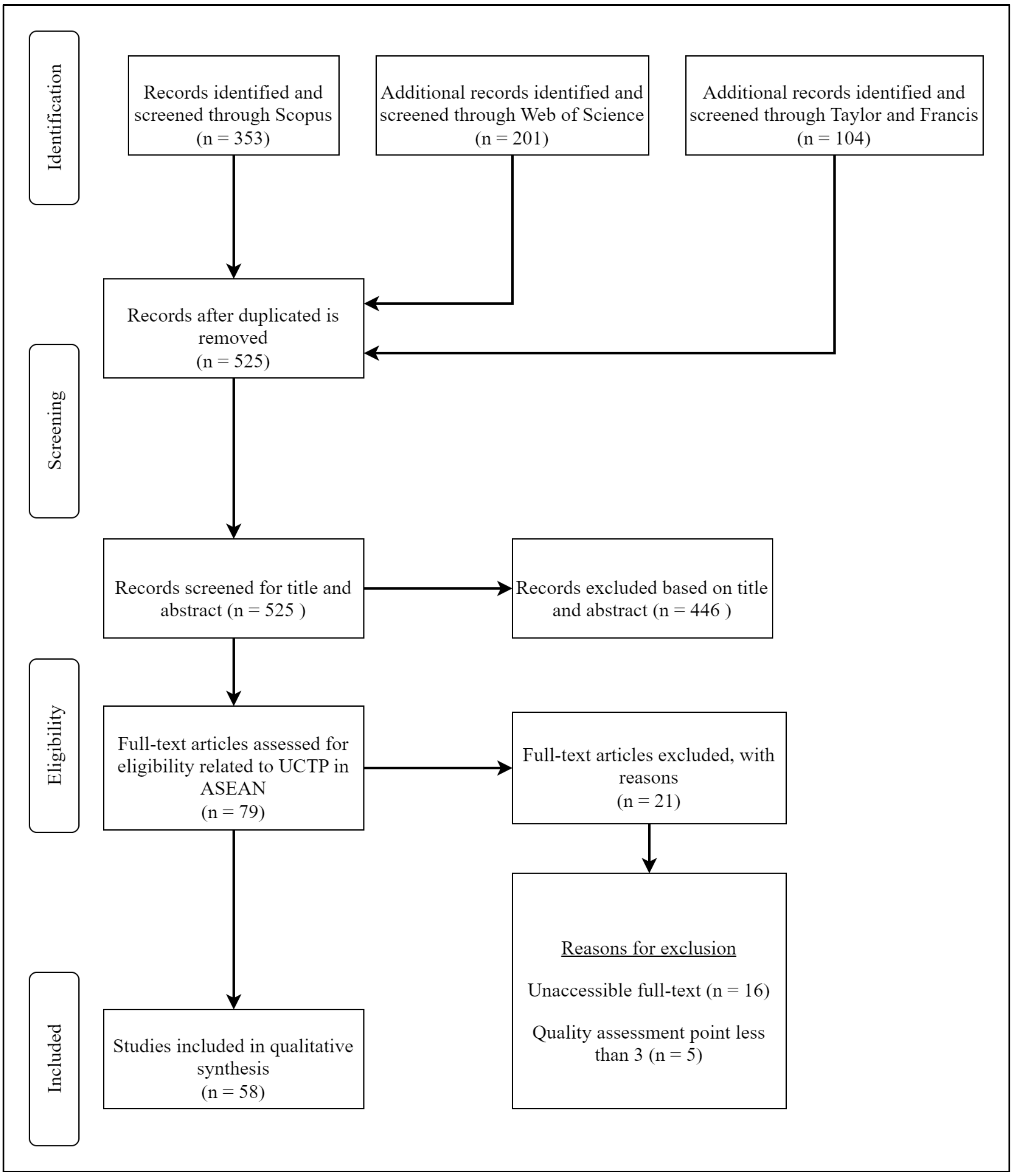

Fig. 1. Flow Diagram of Review Process

Table 3 below shows the title of the studies included in this review.

Table 3
Title of studies included for comprehensive reviews

Reference	Title	Year	Country
[11]	Developing a mobile-based application system to accelerate the efficiency of the course rescheduling process	2023	Malaysia
[12]	Modified and hybridised bi-objective firefly algorithms for university course scheduling	2023	Thailand
[13]	A general mathematical model for university courses timetabling: Implementation to a public university in Malaysia	2022	Malaysia
[14]	A genetic algorithm for the real-world university course timetabling problem	2022	Malaysia
[15]	Grouping and heuristics for a multi-stage class timetabling system	2022	Malaysia

[16]	Hybrid whale optimization algorithm for solving timetabling problems of ITC 2019	2022	Indonesia
[17]	Investigation of heuristic orderings with a perturbation for finding feasibility in solving real-world university course timetabling problem	2022	Malaysia
[18]	Lecturer-course assignment model in national joint courses program to improve education quality and lecturers’ time preference	2022	Indonesia
[19]	A compromise programming for multi-objective task assignment problem	2021	Vietnam
[20]	A hybrid of heuristic orderings and variable neighbourhood descent for a real-life university course timetabling problem	2021	Malaysia
[21]	An SHO-based approach to timetable scheduling: a case study	2021	Vietnam
[22]	Application of genetic algorithm to optimize lecture scheduling based on lecturers' teaching day willingness	2021	Indonesia
[23]	Automation and optimization of course timetabling using the iterated local search hyper-heuristic algorithm with the problem domain from the 2019 international timetabling competition	2021	Indonesia
[24]	Class scheduling framework using decorator and facade design pattern	2021	Philippines
[25]	Effective solution of university course timetabling using particle swarm optimizer based hyper heuristic approach	2021	Malaysia
[26]	Lecturer teaching scheduling that minimizes the difference of total teaching load using goal programming	2021	Indonesia
[27]	Multi-agent class timetabling for higher educational institutions using Prometheus platform	2021	Philippines
[28]	Particle swarm optimisation variants and its hybridisation ratios for generating cost-effective educational course timetables	2021	Thailand
[29]	Stemming the educational timetable problems	2021	Indonesia
[18]	University course timetabling model in joint courses program to minimize the number of unserved requests	2021	Indonesia
[30]	An effective hybrid local search approach for the post enrolment course timetabling problem	2020	Malaysia
[31]	An investigation of generality in two-layer multi-agent framework towards different domains	2020	Malaysia
[32]	Guided genetic algorithm to solve university course timetabling with dynamic time slot	2020	Indonesia
[33]	Heuristic algorithm for multi-location lecture timetabling	2020	Malaysia
[34]	New hybrid flower pollination algorithm with dragonfly algorithm and Jaccard index to enhance solving university course timetable problem	2020	Thailand
[35]	Self-adaptive and simulated annealing hyper-heuristics approach for post-enrolment course timetabling	2020	Indonesia
[36]	Sequential constructive algorithm incorporates with fuzzy logic for solving real world course timetabling problem	2020	Malaysia
[37]	A formal model of multi-agent system for university course timetabling problems	2019	Malaysia
[38]	Academic timetable optimization for Asia pacific university, Malaysia using graph colouring algorithm	2019	Malaysia
[39]	Agent based integer programming framework for solving real-life curriculum-based university course timetabling	2019	Malaysia
[40]	An enhanced genetic algorithm-based courses timetabling method for maximal enrolments using maximum matching on bipartite graphs	2019	Vietnam
[41]	Application of representation and fitness method of genetic algorithm for class scheduling system	2019	Philippines
[42]	Automated course timetabling optimization using tabu-variable neighbourhood search based hyper-heuristic algorithm	2019	Indonesia
[43]	Constructing population of initial university timetable: design and analysis	2019	Malaysia
[44]	Graph edges colouring to determine lecture classroom of mathematics education department at Muhammadiyah University of Surabaya	2019	Indonesia
[45]	Lecture scheduling system using Welch Powell graph colouring algorithm in informatics engineering department of Universitas Malikussaleh	2019	Indonesia

[46]	Monte Carlo tree search in finding feasible solutions for course timetabling problem	2019	Malaysia
[47]	Performance comparison of sequential and cooperative integer programming search methodologies in solving curriculum-based university course timetabling problems (CB-UCT)	2019	Malaysia
[48]	Sequential integer programming for solving curriculum-based university course timetabling problem	2019	Malaysia
[49]	Simulated annealing with improved reheating and learning for the post enrolment course timetabling problem	2019	Malaysia
[50]	University course timetabling model using ant colony optimization algorithm approach	2019	Malaysia
[51]	A course planning application for undergraduate students using genetic algorithm	2018	Thailand
[52]	A heuristics approach for classroom scheduling using genetic algorithm technique	2018	Malaysia
[53]	Analysis of artificial bee colony algorithm for optimizing lecture schedule based on willingness of teaching submission	2018	Indonesia
[54]	Ant colony optimisation for solving university course timetabling problems	2018	Malaysia
[55]	Auto-generate scheduling system based on expert system	2018	Malaysia
[56]	Bringing answer set programming to the next level: a real case on modelling course timetabling	2018	Indonesia
[57]	Design of rescheduling of lecturing, using genetics-ant colony optimization algorithm	2018	Indonesia
[58]	Genetic algorithm to solve the problems of lectures and practicums scheduling	2018	Indonesia
[59]	Genetic algorithm with elitist-tournament for clashes-free slots of lecturer timetabling problem	2018	Malaysia
[60]	Hybrid model of particle swarm and ant colony optimization in lecture schedule preparation	2018	Indonesia
[61]	Mathematical model for timetabling problem in maximizing the preference level	2018	Malaysia
[62]	Novel local searches for finding feasible solutions in educational timetabling problem	2018	Indonesia
[63]	Scheduling regular classrooms using heuristic genetic and tabu search algorithms	2018	Indonesia
[64]	Solving university course timetabling problem using memetic algorithms and rule-based approaches	2018	Indonesia
[65]	Solving university course timetabling problems using FET software	2018	Malaysia
[66]	The study of genetic algorithm approach to solving university course timetabling problem	2018	Malaysia
[67]	Vertex and edge colouring method for timetabling problem in minimizing the time frame	2018	Malaysia

2.2.5 Reporting

The reporting phase is done after doing data extraction based on the themes. The themes were generated based on the trends of the data that existed during data extraction. The themes and sub-themes were generated based on thematic analysis. The inductive approach is used by observing the patterns of the articles, grouped into the similarity of the data collected. The findings were reported as results of descriptive reviews. The results are then analysed further to be discussed.

3. Results

The review resulted in three main themes and 14 sub-themes related to the optimization of university timetabling. The main themes are constraints, optimization approaches (seven subthemes) and datasets (seven subthemes). The results provided a comprehensive analysis of the optimization of university timetabling in ASEAN countries. The majority of the studies included in the review are from Malaysia with 28 studies, followed by Indonesia with 20 studies, Thailand with 4 studies, Philippines with three studies, and Vietnam with three studies.

3.1 Constraints

The constraints vary depending on the requirements of the institutions or datasets used. Hence, the constraints were categorized as below. Figure 2 and Figure 3 show the constraints based on real-world datasets, and Figure 4 shows the constraints based on public datasets.

i. Events scheduled - All events must be scheduled on the respective timeslots and rooms.
ii. Student conflict - The student can't attend more than one event scheduled at the same time.
iii. Lecturer conflict – The lecturer can't teach more than one event scheduled at the same time.
iv. Room compatibility - The room capacity and resources must be suitable for the event.
v. Room occupancy - The room can only be occupied by one event at one time.
vi. Timeslot limitation - The event needs to be scheduled at preassigned timeslots if given.
vii. Precedence events - The events must be assigned in a specific order if given.
viii. Number of events - The number of events of specific courses that can be conducted in an entire semester.
ix. Static events - The allocation of events should not disrupt ongoing scheduled events.
x. Workload specification - The minimum working days or maximum working hours per day.
xi. Timeslot reservation - The timeslot is reserved for another event.
xii. Early or late events - No event assigned at early or late timeslots.
xiii. Consecutive events - No more than certain consecutive events for a day.
xiv. Isolated event - The student needs to have more than one event in one day.
xv. Lecturer preferences – The allocation of the event must satisfy the lecturer's preferences in terms of room and timeslot.
xvi. Room utilization - The size of the room must be utilized as much as possible.
xvii. Room stability - The events are taken into consideration on travel time from one room to another room.
xviii. Blocked timeslots – The events are not allowed to be assigned on certain timeslots.
xix. Cross-program - The student can cross-program while registered for a particular subject depending on circumstances.
xx. Lecturer expertise – The lecturer needs to have certain qualification requirements and course proficiency.
xxi. Lecturer availability - The event in a certain timeslot is cancelled if there is no lecturer available.
xxii. Curriculum compactness - The events for related courses should be scheduled consecutively or uniformly in a day.

Authors	Dataset description	Constraints (Hard constraint as HC, Soft constraint as SC)																					
		Events scheduled	Student conflict	Lecturer conflict	Room compatibility	Room occupancy	Timeslot limitation	Precedence events	Number of events	Static events	Workload specification	Timeslot reservation	Early or late events	Consecutive events	Isolated event	Lecturer preferences	Room utilization	Room stability	Blocked timeslots	Cross program	Lecturer expertise	Lecturer avaibility	Curriculum compactness
[14]	Semester 1 2018/2019, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia		HC	HC	HC	HC	HC						SC	SC	SC								
[15]	Semester 2016/s6 and semester 2016/s2, i-Cats University College (ICATS), Malaysia		HC	HC	HC	HC				HC		SC					SC		SC				
[17]	Semester 1 2019/2020 and semester 2 2019/2020, Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak (UNIMAS), Malaysia	HC	HC	HC	HC	HC													HC				
[19]	Spring semester of 2020 for Computing Fundamental Department, FPT University, Vietnam	HC									HC					SC					HC	HC	
[20]	Semester 1 2019/2020 and semester 2 2019/2020, Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak (UNIMAS), Malaysia	HC	HC	HC	HC	HC			SC										HC				
[21]	Faculty of Information Technology, Nong Lam University (NLU), Vietnam	HC	HC	HC	HC	HC SC	HC				SC			SC		SC	SC		SC			SC	SC
[26]	Department of Mathematics XYZ University			HC							SC			HC		SC					HC SC	HC	
[27]	Semester 1 2018/2019, semester 2 2017/2018, semester 1 2017/2018, semester 2 2016/2017, University of the East , Philippines	HC	HC	HC	HC	HC			HC		SC			SC	SC	SC	SC					HC	SC
[28]	Eleven datasets obtained from Naresuan University , Thailand	HC	HC	HC	HC	HC		HC								SC	SC	SC				HC	
[31]	Semester 2 2014/2015 and semester 1 2015/2016, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia		HC	HC	HC	HC	HC							SC			SC						
[32]	Two different datasets from Odd and Event semester, Operational Division of Universitas Teknologi Yogyakarta, Indonesia		HC	HC	HC	HC					SC			SC								HC SC	
[33]	Semester 1 2017/2018 and semester 2 2017/2018 from Faculty of Cognitive Sciences and Human Development, Universiti Malaysia Sarawak (UNIMAS), Malaysia		HC	HC					HC		SC											HC	SC
[36]	Semester 1 2016/2017, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia		HC	HC	HC	HC	HC						SC	SC	SC		SC						
[37]	Semester 2 2014/2015 and semester 1 2015/2016, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia		HC		HC	HC	HC							SC			SC						
[38]	Undergraduate programs such Business, Accounting and Finance, Asia Pacific University (APU), Malaysia		HC	HC	HC	HC			HC		SC				SC								

Fig. 2. Part 1 of 2 constraints for the real-world datasets

Authors	Dataset description	Constraints (Hard constraint as HC, Soft constraint as SC)																					
		Events scheduled	Student conflict	Lecturer conflict	Room compatibility	Room occupancy	Timeslot limitation	Precedence events	Number of events	Static events	Workload specification	Timeslot reservation	Early or late events	Consecutive events	Isolated event	Lecturer preferences	Room utilization	Room stability	Blocked timeslots	Cross program	Lecturer expertise	Lecturer avaibility	Curriculum compactness
[39]	Semester 1 2016/2017 and semester 2 2016/2017, Universiti Malaysia Labuan International Campus (UMSLIC), Malaysia			HC	HC	HC	HC		HC					SC		SC	SC						
[40]	Faculty of Information Technology, Hanoi Open University, Vietnam			HC	HC			SC			SC					SC	SC				HC SC	HC	
[42]	Odd and Even semester, academic year 2017/2018 from open dataset	HC	HC		HC	HC							SC	SC	SC								
[43]	Semester 1 2019/2020 and semester 2 2019/2020, Faculty of Computer Science and Information Technology (FCSIT), Universiti Malaysia Sarawak (UNIMAS), Malaysia	HC		HC	SC	HC					SC							SC				HC	SC
[47]	Semester 1 2016/2017 and semester 2 2016/2017, Universiti Malaysia Labuan International Campus (UMSLIC), Malaysia			HC	HC	HC	HC		HC					SC		SC	SC						
[48]	Semester 1 2016/2017 and semester 2 2016/2017, Universiti Malaysia Labuan International Campus (UMSLIC), Malaysia			HC	HC	HC	HC		HC					SC		SC	SC						
[50]	Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin (UniSZA), Malaysia		HC		HC	HC							SC	SC	SC								
[54]	Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin (UniSZA), Malaysia		HC		HC	HC							SC	SC	SC								
[55]	Faculty of Electrical Engineering, Pasir Gudang campus, Universiti Teknologi MARA (UITM), Malaysia		HC	HC	HC	HC		HC				HC		HC		SC				SC	SC		
[56]	Faculty of Computer Science, Universitas Indonesia, Indonesia	HC		HC	HC	HC			HC					SC				SC				HC	
[57]	Academic year 2015/2016, Indonesian Computer University (UNIKOM) Bandung, Indonesia		HC	HC	SC	HC										SC							
[58]	Information Technology Department, University of Sumatera Utara	HC	HC	HC	HC									SC		SC	HC						SC
[59]	Faculty Of Computer And Mathematical Sciences, Universiti Teknologi MARA (UITM), Malaysia		HC	HC		HC					SC						SC						
[60]	Datasets obtained from a Higher Education Institution			HC			HC	SC						HC				SC	HC				
[64]	Even semester of year 2015/2016 for study program Informatics Engineering, University Computer Indonesia (UNIKOM), Indonesia			HC		HC													HC			HC	
[66]	Semester 2 2014/2015 and semester 1 2015/2016, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia		HC		HC	HC	HC							SC			SC						

Fig. 3. Part 2 of 2 constraints for the real-world datasets

Dataset	Constraints (Hard constraint as HC, Soft constraint as SC)																					
	Events scheduled	Student conflict	Lecturer conflict	Room compatibility	Room occupancy	Timeslot limitation	Precedence events	Number of events	Static events	Workload specification	Timeslot reservation	Early or late events	Consecutive events	Isolated event	Lecturer preferences	Room utilization	Room stability	Blocked timeslots	Cross program	Lecturer expertise	Lecturer availibility	Curriculum compactness
ITC 2002		HC		HC	HC							SC	SC	SC								
ITC 2007 (Track 2)		HC		HC	HC	HC	HC					SC	SC	SC								
ITC 2007 (Track 3)	HC		HC	SC	HC					SC							SC				HC	SC
Socha		HC		HC	HC							SC	SC	SC								
Hard		HC		HC	HC																	

Fig. 4. Constraints for the public datasets

3.2 Optimization Methods

In this theme, seven subthemes are operational research, heuristic, metaheuristic, multi-agent system, rule-based system, declarative programming, and hybrid approaches. Table 4 shows the summary of the optimization approaches in this review.

Table 4
Summary of approaches related to timetable optimization

	Optimization method(s)	Reference
Operational Research (OR) Method	Mathematical Model with Mixed Integer Linear Programming (MILP)	[13]
	Linear goal programming	[26]
	Graph colouring method with module requirement matrix with graph colouring technique, and bipartite graph colouring	[38]
	Graph edges colouring	[44]
	Sequential integer programming framework	[48]
	Mathematical Model with Mixed Integer Linear Programming (MILP)	[61]
Heuristic Method	Graph heuristics	[43]
	Welch Powell graph colouring algorithm	[45]
	Monte Carlo tree search (MCTS)	[46]
	Recursive swapping technique using FET software	[65]
	Graph Colouring Method involving vertex and edge colouring	[67]
Metaheuristic	Genetic algorithm (GA)	[14]
	Improved genetic algorithm	[19]
	Genetic algorithm	[22]

	Guided genetic algorithm	[32]
	Representation and Fitness Methods of Genetic Algorithm	[41]
	Ant colony optimization (ACO)	[50]
	Genetic algorithm	[51]
	Genetic algorithm	[52]
	Artificial bee colony (ABC)	[53]
	Ant colony optimization (ACO)	[54]
	Genetic algorithm	[58]
	Genetic algorithm (GA)	[66]
Multi Agent System	Multi-agent system (MAS)	[31]
	Multi-agent system (MAS)	[37]
Rule Based	AI-based Expert System	[55]
Declarative Programming	Answer set programming (ASP)	[56]
Hybrid Method	Course Rescheduling Application System (CRAS) with implemented checking algorithm	[11]
	Modified and hybridized bi-objective firefly algorithm (BOFA) with Pareto dominance approach	[12]
	Multi-stage approach incorporating heuristics and grouping	[15]
	Hybrid whale optimization algorithm that was a combination of the adapted whale optimization algorithm (WOA) and late acceptance hill climbing (LAHC) algorithm	[16]
	Heuristic Ordering with a Perturbation technique (HO-P)	[17]
	Lecturer-course assignment model developed by using integer linear programming and optimized by using cloud theory-based simulated annealing	[18]
	Two stage heuristic algorithms with heuristics orderings, and hybrid of heuristic orderings and variable neighbourhood descent	[20]
	Spotted Hyena Optimizer (SHO) and hybridization of SHO and Simulated Annealing (SA)	[21]
	Iterated Local Search-Hill Climbing (ILS-HC) and Iterated Local Search-Simulated Annealing (ILS-SA) algorithms within hyper-heuristics	[23]
	Class scheduling model using decorator and facade design patterns	[24]
	Particle Swarm Optimizer based Hyper Heuristic (HH PSO)	[25]
	Multi Agent System with Prometheus platform	[27]
	Hybrid Particle Swarm Optimisation-based Timetabling (HPSOT)	[28]
	General framework with four layers model with Layer 1 to Layer 3 is called Stemming Phase involving preprocessing steps, and the Layer 4 is called Solution Finding Phase with enhanced simulated annealing-based search	[29]
	Model leveraged by artificial bee colonies (ABC), cloud theory-based simulated annealing (CTB-SA), and genetic algorithm (GA)	[18]
	Two phase hybrid local search algorithm with Tabu Search with Sampling and Perturbation with Iterated Local Search (TSSP-ILS) and Simulated Annealing with Reheating (SAR) with two preliminary runs (SAR-2P)	[30]
	Two-stage heuristic algorithm consists of Lecturer Grouping Stage and Group Allocation Stage	[33]
	Two hybrid variants of flower pollination algorithm (FPA) which were Jaccard FPA (JFPA) which uses the Jaccard index and a greedy selection mechanism, and Dragonfly FPA (DFPA) which incorporates the navigational traits of the dragonfly algorithm (DA)	[34]
	Hybridization of Self-Adaptive and Simulated Annealing Hyper-Heuristic approach	[35]
	Sequential constructive algorithm and Fuzzy Logic	[36]
	Multi-Agent System (MAS) incorporating Integer Programming (IP)	[39]
	Genetic algorithm based combined with maximal matching on bipartite graphs	[40]

	Hyper-heuristic approach of tabu search hybridize with variable neighbourhood search	[42]
	Sequential and cooperative integer programming in multi agent system	[47]
	Two-stage approach with tabu search algorithm, and Simulated Annealing with Improved Reheating and Learning (SAIRL)	[49]
	Combinations of Genetic-Ant Colony Algorithm (GA-ACO)	[57]
	GA with Tournament Selection scheme combined with Elitism (TE) and a GA with Tournament (T) selection scheme	[59]
	Hybridization of particle swarm optimization (PSO) and ant colony optimization (ACO)	[60]
	Two stage approach consists of Constructive Heuristic and two local searches with single and perturbation moves	[62]
	Heuristic algorithms using genetic algorithm and tabu search	[63]
	Memetic algorithms with rule-based combination	[64]

3.2.1 Operation research (OR)

Among the 58 studies examined, six of them specifically focused on the utilization of operational research techniques for optimizing the timetables of university students.

Mohd Zaulir, Abdul Aziz and Aizam [13] proposed a mathematical model with MILP to solve UCTP. The algorithm was evaluated utilising the UMT semester 1 session 2017/2018 dataset. The result validates the applicability of the mathematical model to the real-world issue.

Hasanah, Hanum, and Ruhiyat [26] presented linear goal programming to minimize deviation variables while fulfilling both hard and soft constraints, focusing on optimizing lecturer assignments. The model effectively minimized the difference in total teaching load, achieving balance among lecturers due to the constraint on deviation value. However, the model fell short in preventing lecturers from teaching courses outside their division.

Gadapa *et al.,* [38] proposed a graph colouring method (GCM) with a graph colouring technique in the module requirement matrix during the first phase and bipartite graph colouring during the second phase to solve UCTP. The algorithm was evaluated using datasets from APU's Business, Accounting, and Finance undergraduate programmes. This research resulted in the discovery of a conflict-free, optimal solution for overcoming UCTP.

Mursyidah [44] presented graph edge colouring to allocate lecture rooms based on student needs and space availability at Muhammadiyah University. The experiment result demonstrated the effectiveness and efficiency of the proposed method in aligning with student needs and available space.

Abdalla *et al.,* [48] proposed two-stage sequential integer programming (IP) framework for CB-CTTP resolution. The algorithm was evaluated utilising datasets from the UMSLIC semester 1 session 2016/2017 and semester 2 session 2016/2017. The result demonstrated that the algorithm was able to minimise the soft constraints while maintaining CB-CTTP reliability.

Malik and Nordin [61] proposed a mathematical model with MILP to examine the optimal solution by maximising the total preference level for lecturer to course to timeslot assignments. The algorithm was evaluated on the semester 2 session 2016/2017 dataset for the Faculty of Science, UTM's Department of Mathematical Sciences' undergraduate programme. The result satisfied the lecturer's needs and generated a conflict-free schedule for all parties concerned.

3.2.2 Heuristic

Among the studies examined, five of them specifically focused on the utilization of the heuristic approach for optimizing the timetables of university students.

Wahid *et al.,* [43] proposed a graph heuristic for CB-CTTP. The algorithm was evaluated using the ITC 2007 dataset. Single and combination graph heuristics were evaluated and compared. Compared to the use of a single graph heuristic, the combination of the Largest Degree along Saturation Degree heuristics produced the greatest number of populations.

Abdullah *et al.,* [45] presented the Welch Powell Graph Colouring Algorithm to develop an efficient lecture scheduling system. The study demonstrated using multiple years of datasets from Universitas Malikussaleh concluded that it successfully resolves lecture scheduling problems by preventing scheduling conflicts.

Goh, Kendall and Sabar [46] suggested MCTS as a solution for UCTP. Socha, ITC 2002, and ITC 2007 datasets were implemented for testing the algorithm. In MCTS, the result demonstrated that heuristics-based simulation outperforms random simulation. MV-ALL is superior to both SD-ALL and DSR. In comparison to other algorithms, MCTS is superior to Graph Colouring Heuristic (GCH) and Tabu Search (TS) in ITC 2002 and Socha. In comparison to other algorithms, MCTS was unable to outperform TS, but it did surpass GCH in ITC 2007. This is because MCTS lacks flexibility, necessitating that each iteration's movements be designated constructively and unchangeable. MCTS lacks the search space connectivity of local search systems such as TS.

Wan Muhamad *et al.,* [65] proposed a recursive swapping technique in Free Educational Timetable (FET) software to generate a feasible university course schedule. This technique is limited to the course and classroom assignment problem. The algorithm was evaluated utilising UniMAP datasets. The result demonstrated that the FET software successfully solved UCTP.

Hidzir and Nordin [67] proposed GCM with vertex and edge colouring to solve UCTP and optimize the number of timeframes required. The algorithm was evaluated on undergraduate datasets from the first to fourth year of the Bachelor of Science in Industrial Mathematics and Bachelor of Mathematics programmes during the semester 2 session 2016/2017. The result demonstrated that GCM accomplished the goal without any conflicts.

3.2.3 Metaheuristic

Among the 58 studies examined, 12 of them specifically focused on the utilization of metaheuristic techniques for optimizing the timetables of university students.

Wong, Goh, and Likoh [14] proposed a Genetic Algorithm (GA) method for PE-CTTP. The algorithm was evaluated utilising the UMSLIC semester 1 session 2018/2019 dataset. The results discovered the optimal perimeter configuration for the GA. GA is computationally expensive compared to other single-based meta-heuristics because it considers multiple candidate solutions rather than a single candidate solution when determining the optimal solution.

Ngo *et al.,* [19] presented methodology involves creating a mathematical model for task assignment, formulating it as a multi-objective problem, using the compromise programming approach for optimization, and proposing an improved Genetic Algorithm to solve the introduced model to efficiently assign tasks to the lecturers while considering multiple constraints and objectives. The proposed model and algorithm are tested with FPT University data to demonstrate it worked effectively.

Subagio *et al.,* [22] presented a Genetic Algorithm to solve lecture scheduling in Universitas Catur Insan Cendekia Cirebon. The outcome managed to save time and consider the constraints criteria like teaching days, courses, lecturer preferences, and availability of parallel classes.

Fachrie and Waluyo [32] presented a guided genetic algorithm that involves developing a flexible chromosome for dynamic time slots, improving efficiency by removing time-consuming crossover, and introducing a Guided Creep Mutation to guide chromosome evolution for global optima. Experimental results demonstrated the system's capability to generate an optimal timetable that satisfies all constraints specified by Universitas Teknologi Yogyakarta.

Labuanan, Tapaoan, and Camungao [41] presented Representation and Fitness Methods of Genetic Algorithms to address scheduling inefficiencies at Isabela State University-Main Campus. The representation method creates the pre-scheduling template, while the fitness method determines how it's generated. The adaptation of the two methods effectively enhances scheduling accuracy, reduces time consumption, and minimizes conflicts in plotted schedules.

Mazlan *et al.,* [50] proposed Ant Colony Optimization (ACO) to satisfy all hard constraints and to minimise soft constraints in UCTP. The algorithm was evaluated using datasets from the Faculty of Informatics and Computing at UniSZA. Comparative analysis was conducted between ACOs with and without priority. ACO with priority demonstrates a greater standard deviation than ACO without priority.

Srisamutr, Raruaysong, and Mettanant [51] presented a web application implemented with a genetic algorithm (GA) to assist undergraduate students in planning their course schedules effectively considering prerequisites, opening semesters, total units, GPA, and cumulative GPA. The experiment result on Kasetsart University Sriracha Campus demonstrated its effectiveness in generating optimal course plans in approximately 50 generations.

Ahmad *et al.,* [52] presented GA to reduce conflicts and optimize fitness in classroom scheduling. The study showed that the GA effectively addressed a student timetable problem.

Alam *et al.,* [53] presented Artificial Bee Colony (ABC) to optimize the lecture schedule based on the lecturer's willingness to teach, which is adapted from the behaviour of bees and consists of three phases that are employed bee phase, onlooker bee phase, and scout phase. Several scenarios of experiments have been conducted to test the performance of ABC based on willingness to teach submission.

Mazlan *et al.,* [54] proposed ACO to solve UCTP. The algorithm was evaluated using datasets from the Faculty of Informatics and Computing at UniSZA. The result demonstrated that ACO was capable of solving UCTP but was not the optimal algorithm for UCTP.

Syahputra *et al.,* [58] presented GA for lectures and practicum scheduling at the University of Sumatera Utara. The result demonstrated the most optimal timetable that effectively accommodates available time slots, classrooms, courses, and lecturer schedules.

Junn, Obit, and Alfred [66] proposed using a GA to satisfy all hard constraints and minimise soft constraints in UCTP. The algorithm was evaluated utilising datasets from the UMSLIC semester 2 session 2014/2015 and semester 1 session 2015/2016. Great Deluge (GD) and Simulated Annealing (SA) algorithms have been compared to the verified outcomes. The GA performs better than the competing algorithms.

3.2.4 Multi agent system

Among the 58 studies examined, two of them specifically focused on the utilization of the multi-agent system for optimizing the timetables of university students.

Junn *et al.,* [31] proposed MAS as a solution for UCTP. The algorithm was evaluated using UMSLIC datasets from the semester 2 session 2014/2015, semester 1 session 2015/2016, and semester 1 session 2016/2017. The result was measured against GA, GD, and SA. For both semesters, MAS outperformed other algorithms with a lower average cost function and improvements of over 40%.

Junn *et al.,* [37] proposed a MAS to enhance the quality of the UCTP until the optimal solution is found. The algorithm was evaluated using datasets from the UMSLIC semester 2 session 2014/2015 and semester 1 2015/2016. The result was compared against GD and SA. MAS outperformed both GD and SA.

3.2.5 Rule based system

Among the 58 studies examined, only one of them specifically focused on the rule-based system. Ilham *et al.,* [55] proposed an AI-based expert system to generate user-customizable schedules for the educational sector. The algorithm was evaluated using a dataset from the Faculty of Electrical Engineering (FKE), Pasir Gudang campus, UiTM. The development of the system is successful.

3.2.6 Declarative programming

Among the 58 studies examined, only one of them specifically focused on declarative programming.

Aini, Saptawijaya, and Aminah [56] presented Answer Set Programming (ASP) declaratively to represent and solve the course timetabling problem by expressing it as a logic program and obtaining solutions from the stable models of the program. The proposed method was tested with the Universitas Indonesia dataset to prove its expressiveness and flexibility in solving problem instances.

3.2.7 Hybridisation

Among the 58 studies examined, 31 of them specifically focused on the utilization of hybrid techniques for optimizing the timetables of university students. Each of the 31 studies featured unique combinations of techniques that will be elaborated upon individually.

Kolandaisamy, Subaramaniam and Wong [11] presented Course Rescheduling Application System (CRAS) with implemented checking algorithm as a tool that helps lecturers directly update their subject time through a mobile application. The result confirmed the algorithm successfully resolves timetabling conflicts at UCSI University.

Thepphakorn and Pongcharoen [12] presented a modified and hybridized bi-objective firefly algorithm (BOFA) with the Pareto dominance approach to enhance resource utilization and operating cost efficiency in course timetabling. The approach employed a random key technique to handle continuous firefly movement for discrete timetabling problems and incorporates five constructive heuristics to initialize feasible timetables. The proposed approach outperformed particle swarm optimization, classical firefly algorithm, and modified firefly algorithm in terms of timetable quality, computational times, and convergence speed, and demonstrated superior Pareto frontiers and computational efficiency compared to conventional BOFA across various problem instances from a collaborating university.

Siew *et al.,* [15] proposed a multi-stage approach incorporating heuristics and grouping to solve UCTP. The concept of a multi-stage approach is based on the assessment of the solution's feasibility and perturbative characteristics across various stages. Preprocessing events are carried out for the grouping and ordering operations. The primary objective of the initial stage is to generate a feasible solution, whereas the second stage attempts to minimise the allocation of classes during the third time slot of the day, while simultaneously preserving the solution's feasibility. The approach was evaluated using datasets from semesters 2016/s6 and 2016/s2 of the i-Cats University College. The results demonstrated that the algorithm successfully satisfied both the soft and hard restrictions overall.

Premananda, Tjahyanto, and Muklason [16] presented a hybrid whale optimization algorithm that was a combination of the adapted whale optimization algorithm (WOA) and late acceptance hill climbing (LAHC) algorithm to solve course timetabling problem within the International Timetabling Competition 2019 (ITC 2019). The experiment demonstrated that the WOA algorithm enhances the average penalty value by 65%, while the hybrid WOA further improves it, particularly on four datasets, by 16-43%. Among the competition algorithms, the Hybrid WOA algorithm ranks 7th out of 13.

Chen *et al.,* [17] proposed Heuristic Ordering with a Perturbation technique (HO-P) to solve PE-CTTP. A perturbation technique was used in this work to enhance the initial solution presented using HO techniques. The approach was tested with datasets from the Faculty of Computer Science and Information Technology (FCSIT), UNIMAS semester 1 session 2019/2020, semester 2 session 2019/2020, and ITC 2007. In the event of generating a feasible solution, LD Descending and LDLE Descending orderings outperformed other heuristic orderings, as determined by a comparison of their performance with other heuristic orderings. The results showed that HO-P achieved much better performance than HO without perturbation in developing viable solutions than HO.

Chen *et al.,* [20] proposed two-stage heuristic algorithms with heuristic orderings (HO) and variable neighbourhood descent (VND) to solve UCTP. The approach was tested with datasets from the Faculty of Computer Science and Information Technology (FCSIT), UNIMAS. In phase one, comparisons were made between various heuristic orderings and various combinations of heuristic orderings and neighbourhood structure (NS) in VND. The results of the first stage indicate that the LD Descending and LDLE Descending orders generate feasible solutions. The results of the second phase showed that the greatest orderings for VND were LE Ascending, LD Descending, LE Descending, LDLE Descending, and Random orderings. All heuristic orderings with VND showed zero violations. However, the order of NS affects the number of violations of soft constraints.

Nguyen and Nguyen [21] presented Spotted Hyena Optimizer (SHO), a swarm-based algorithm inspired by spotted hyena hunting behaviour, and its hybridization with Simulated Annealing (SA) for university timetabling. Experimental results with Nong Lam University datasets revealed that the proposed approach, particularly the SHO-SA hybrid, outperformed other competitive metaheuristic algorithms like the PSO algorithm in finding feasible timetables.

Widayu, Mukhlason, and Nurkasanah [23] presented Iterated Local Search-Hill Climbing (ILS-HC) and Iterated Local Search-Simulated Annealing (ILS-SA) algorithms within hyper-heuristics for solving the university course timetabling problem of the ITC 2019 datasets. Experimental results indicated that ILS-SA outperformed ILS-HC for both tiny and small datasets of the ITC 2019 problem domain, achieving lower objective function values. Specifically, ILS-SA achieved a reduction in objective function values to 6 compared to 37 for ILS-HC in the tiny dataset, and a reduction to 776 compared to 1034 in the small dataset.

Sermeno and Secugal [24] presented a class scheduling model using decorator and façade design patterns implemented. The facade pattern offers operations for schedule creation, while the decorator pattern enables temporary modifications. The algorithms utilized for performing local moves to lesson placements within time slots in the model are Hill Climbing, Simulated Annealing, and Tabu Search. The proposed model and algorithms were tested with generated datasets based on assumptions that have proven successful.

Iqbal *et al.,* [25] proposed a Particle Swarm Optimiser-based Hyper Heuristic (HH-PSO) to solve UCTP with PSO work as a higher-level methodology that employs low-level heuristics to find the best solution. According to the results of the study, the proposed low-level heuristic is effective for organising events during the initial phase. The proposed heuristic assigns a greater number of events than other low-level heuristics for 14 of 24 data instances in ITC 2002 and 15 of 20 data instances in ITC 2007. The study demonstrates that HH-PSO obtains a lower rate of soft constraint violations on six instances of ITC 2002 data and seven instances of ITC 2007 data. This study proves that the proposed low-level heuristic may achieve a feasible solution if given priority.

Guia and Ballera [27] presented a multi-agent timetabling method using the Prometheus platform which the system's five agents collaborate using Prometheus to efficiently handle hard and soft constraints to generate an optimized university timetable. The system was tested on the University of the East data and proven successful in scheduling classes for higher educational institutions.

Thepphakorn, Sooncharoen, and Pongcharoen [28] presented hybrid particle swarm optimization-based timetabling (HPSOT) that integrates Standard PSO (SPSO) and Maurice Clerc PSO (MCPSO) variants, alongside five combinations of Insertion Operator (IO) and Exchange Operator (EO) to enhance timetabling performance. The comparison results with Naresuan University datasets revealed that the hybrid SPSO and MCPSO variants with IO and EO combinations outperformed original PSO variants in terms of optimization quality across all problem instances with faster computational times and a ratio of 75%:25% being the best IO:EO combination in convergence speed.

Mauritsius, Binsar, and Legowo [29] presented a general framework with a layers model with Layer 1 to Layer 3 called Stemming Phase involving preprocessing steps, and Layer 4 is called Solution Finding Phase with enhanced simulated annealing-based search. The proposed framework was tested on different datasets and resulted in competitive performance of solutions, proving the significant contribution of the framework.

Kusuma and Albana [18] presented a timetabling model leveraged by artificial bee colonies (ABC), cloud theory-based simulated annealing (CTB-SA), and genetic algorithm (GA) tailored for a national joint courses program. Among the metaheuristic methods, CTB-SA demonstrated superior performance in minimizing unserved requests, outperforming GA and ABC, with ABC being the second best and GA being the worst.

Goh *et al.,* [30] proposed a two-phase hybrid local search algorithm by utilising Tabu Search with Sampling and Perturbation with Iterated Local Search (TSSP-ILS) in the first phase and Simulated Annealing with Reheating with Two Preliminary runs (SAR-2P) in the second phase to solve PE-CTTP. In the first phase, the first phase is to find a feasible solution. SAR uses preliminary run data to minimise soft constraint breaches in the second phase. The approach was tested on Hard, Socha, ITC 2002, and ITC 2007 datasets. The first phase result showed that TSSP-ILS outperformed TSSP, ILS, GA, Hybrid SA, Clinique-Based Algorithm, and SA in every case for the Hard dataset. The second phase showed that SAR-2P is comparable to SAR and SAIRL in Socha, ITC 2002, and ITC 2007 datasets. For Socha dataset, SAR-2P is comparable to GA with Local Search, Fish Swarm, Honey Bee Mating, SA, and Random Partial Neighbourhood Search (RPNS), while for the ITC 2002 dataset, it is comparable to Hybrid Algorithm, SA, and RPNS.

Sze *et al.,* [33] presented a two-stage heuristic algorithm consisting of the Lecturer Grouping Stage and Group Allocation Stage to solve the postgraduate coursework timetable problem. In the first stage, lecturers are grouped into four groups, ensuring no repetition of lecturers within the same group. Subsequently, in the second stage, these groups are distributed across academic weeks during the semester. The proposed algorithm demonstrated significant enhancement in timetabling solutions compared to manually designed timetables, particularly in the distribution of lecture sessions.

Sapul, Setthawong, and Setthawong [34] presented two hybrid variants of the flower pollination algorithm (FPA) which were Jaccard FPA (JFPA) which uses the Jaccard index and a greedy selection mechanism, and Dragonfly FPA (DFPA) which incorporates the navigational traits of the dragonfly algorithm (DA) to enhance diversity and neighbourhood relationships in the population. The results showed that the proposed JFPA and DFPA algorithms offer better exploration ability and faster convergence than previous methods; JFPA outperformed AFPA in 3 out of 4 datasets, and DFPA outperformed Adapted FPA (AFPA), GA, and PSO in various datasets, including both small and large datasets.

Kartika and Ahmad [35] presented a hybridization of the Self-Adaptive and Simulated Annealing Hyper-Heuristic approach to tackle Post-Enrollment Course Timetabling (PE-CTT). The approach involved employing a Self-Adaptive Strategy to select Low-Level-Heuristics (LLH) and using Simulated Annealing as a Move Acceptance (MA) strategy to enhance optimization for solving PE-CTT problems. Comparative results showed that the hybridized Self-Adaptive and Simulated Annealing Hyper-Heuristic approach yielded competitive outcomes when compared to Simple Random and Simulated Annealing Hyper-Heuristic.

June *et al.,* [36] proposed a sequential constructive algorithm and Fuzzy logic to solve UCTP. The concept of the algorithm is to designate events based on their degree of difficulty using sequential heuristics. The most common sequential heuristics are largest enrolment (LE), largest degree (LD) and saturation degree (SD). The degree of difficulty assigned to an event is determined differently by each sequential heuristic. The study proposes using fuzzy logic to evaluate multiple sequential heuristics to determine the difficulty value of the events. The algorithm was tested using data from the UMSLIC semester 1 session 2016/2017 dataset. Different fuzzy multiple sequential heuristics were compared in this study. The results demonstrated that Fuzzy SDLE did better in the construction part, while Fuzzy SDLD did better in improving the outcome.

Abdalla *et al.,* [39] suggested an Agent-based IP Framework that uses an Integer Programming-based Multi-Agent System to solve the CB-CTTP. The proposed framework is based on a distributed MAS environment in which a central agent coordinates different IP agents that work together by sharing the best part of the solution and directing the IP agents towards a more promising search space, which improves a common global list of the solutions. All agents use an IP search method, which is also used to come up with the initial solution in this case. The algorithm was evaluated utilising datasets from the UMSLIC semester 1 session 2016/2017 and semester 2 session 2016/2017. The study is compared based on the number of agents, which are three and six agents. According to the outcomes, the solution quality in the framework improves as the number of IP agents increases.

Long [40] presented a genetic algorithm based for timetabling problems in credits training at universities and combined with maximal matching on bipartite graphs for a sub-optimization of achieving maximal student enrolments. The results of experiments tested on the Hanoi Open University dataset show effectiveness and faster compared to the previous GA-based method.

Muklason, Irianti, and Marom [42] presented a hyper-heuristic approach of tabu search hybridised with variable neighbourhood search to overcome the need for intensive problem-specific parameter tuning in a meta-heuristics approach. The method consists of two main parts that utilise a greedy algorithm to generate a feasible solution and a tabu search algorithm to optimize the initial solution. The comparison results demonstrated the proposed method outperformed the hill climbing algorithm.

Abdalla *et al.,* [47] proposed sequential and cooperative integer programming in a multi-agent system to solve CB-CTTP. The concept is that MAS is superior to standalone IP due to the ability of IP agents to share the best parts of solutions and the possibility of the agent heading towards a more promising search space. The algorithm was tested utilising datasets from the UMSLIC semester 1 session 2016/2017 and semester 2 session 2016/2017. The comparison between standalone IP, IP with 3 agents, and IP with 6 agents, shows the result that cooperative search outperformed standalone IP and the quality of the solution increases as the number of IP agents increases.

Goh, Kendall, and Sabar [49] proposed two-stage approaches with Tabu Search and Simulated Annealing with Improved Reheating and Learning (SAIRL) to solve PE-CTTP. In the initial stage, we search for a feasible solution. In the second stage, the solution is enhanced further in terms of soft constraint violations. SAIRL is an improved variant of the Simulated Annealing with Reheating (SAR) algorithm. A reinforcement-learning-based method is proposed for obtaining an effective neighbourhood structure for the search. It incorporates the average cost adjustments into the function for reheating temperature. The approach was tested on the Socha, ITC 2002, and ITC 2007 datasets. The first stage results showed that TS can generate feasible solutions. The results of the second stage showed that SAIRL outperformed SAR and SARL. SAIRL outperformed other state-of-the-art methods on the Socha dataset, performed comparably or better on the ITC 2002 dataset, and performed comparably on the ITC 2007 dataset.

Palembang [57] presented combinations of the Genetic-Ant Colony Algorithm (GA-ACO) to develop a scheduling system that minimizes the impact and error rate of the schedule applied with University Computer Indonesia (UNIKOM) data. The experimental result with three different examples of rescheduling problems proved that the scheduling system has a success rate above 50% without error and clash.

Yusoff and Othman [59] presented a GA with a Tournament Selection scheme combined with Elitism (TE) and a GA with a Tournament (T) selection scheme for solving lecturer timetabling problem in Universiti Teknologi MARA. The comparison between different GA variations reveals that GA-TE performs well in generating lecturer timetables that satisfy all constraints, demonstrating the effectiveness of the embedded penalty measures and elitism composition.

Yunita, Pranowo, and Santoso [60] presented the hybridization of particle swarm optimization (PSO) and ant colony optimization (ACO) in preparing lecture schedules. The method consists of three stages that were setting up the number of particles and dimensions, arranging schedules using the ant algorithm function, and optimizing ACO parameters using PSO. The comparison results demonstrated that PSO-ACO outperformed ACO and GA-ACO.

Mauritsius *et al.,* [62] presented a two-stage approach consisting of a Constructive Heuristic and two local searches with single and perturbation moves to generate feasible timetables. The comparison results against five different algorithms demonstrated the proposed method outperformed three GA based, and comparable with hybrid simulated annealing with Kempe chain neighbourhood and Clinique based algorithm.

Fauziah and Putra [63] presented heuristic algorithms to schedule regular classrooms using a genetic algorithm and tabu search algorithm with GA is employed to determine high-probability values, while TS optimizes search quantity and maintains already achieved high values. The study demonstrated that the proposed method led to improved quality of schedules for a several students, achieving better fitness values through a higher number of iterations, thereby enhancing the scheduling quality while minimizing the time required.

Nugroho and Hermawan [64] presented memetic algorithms with rule-based combinations to optimize course timetabling. The method consists of three main parts that were input data, optimization by the memetic algorithm until an optimal solution is found, and output data. The experimental result on Universitas Komputer Indonesia (UNIKOM) shows that the proposed method is effective in optimizing course timetabling.

3.3 Datasets

In this theme, seven subthemes ITC 2002, ITC 2007, ITC 2019, Socha, Lewis or Hard, synthetic and real-world datasets. Table 5 shows the summary of datasets used in the review.

Table 5
Summary of datasets used in timetable optimization

Reference	Dataset description
[11]	UCSI University, Malaysia
[12]	Eleven datasets obtained from Naresuan University, Thailand
[13]	Semester 1 2017/2018, Universiti Malaysia Terengganu (UMT), Malaysia
[14]	Semester 1 2018/2019, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia
[15]	Semester 2016/s6 and semester 2016/s2, i-Cats University College (ICATS), Malaysia
[16]	ITC 2019
[17]	ITC 2007 Semester 1 2019/2020 and semester 2 2019/2020, Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak (UNIMAS), Malaysia
[18]	Lecturers-courses assignment simulation
[19]	Spring semester of 2020 for Computing Fundamental Department, FPT University, Vietnam
[20]	Semester 1 2019/2020 and semester 2 2019/2020, Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak (UNIMAS), Malaysia
[21]	Faculty of Information Technology, Nong Lam University (NLU), Vietnam
[22]	Even semester 2018/2019, Informatics Engineering Study Program of Universitas Catur Insan Cendekia Cirebon, Indonesia
[23]	ITC 2019
[24]	Generate 4 datasets based on assumptions
[25]	ITC 2002 and ITC 2007
[26]	Department of Mathematics XYZ University
[27]	Semester 1 2018/2019, semester 2 2017/2018, semester 1 2017/2018, semester 2 2016/2017, University of the East, Philippines
[28]	Eleven datasets obtained from Naresuan University, Thailand
[29]	Socha STKIP (a medium-size Indonesian college from the year 2014 to the year 2016) Lewis Carter ITC 2007
[30]	ITC 2002 ITC 2007 Socha Hard
[31]	Semester 2 2014/2015 and semester 1 2015/2016, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia
[32]	Odd and Event semester, Operational Division of Universitas Teknologi Yogyakarta, Indonesia
[33]	Semester 1 2017/2018 and semester 2 2017/2018 from Faculty of Cognitive Sciences and Human Development, Universiti Malaysia Sarawak (UNIMAS), Malaysia
[35]	Socha
[36]	Semester 1 2016/2017, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia
[37]	Semester 2 2014/2015 and semester 1 2015/2016, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia
[38]	Undergraduate programs such Business, Accounting and Finance, Asia Pacific University (APU), Malaysia
[39]	Semester 1 2016/2017 and semester 2 2016/2017, Universiti Malaysia Labuan International Campus (UMSLIC), Malaysia
[40]	Faculty of Information Technology, Hanoi Open University, Vietnam
[41]	Isabela State University Main Campus, Philippines

[42]	Open dataset Odd and Even semester, academic year 2017/2018
[43]	ITC 2007 Semester 1 2019/2020 and semester 2 2019/2020, Faculty of Computer Science and Information Technology (FCSIT), Universiti Malaysia Sarawak (UNIMAS), Malaysia
[44]	Odd semester 2018/2019, Mathematics Education Department, Muhammadiyah University of Surabaya, Indonesia
[45]	Subjects in 2013, 2014, and 2015 from Informatics Engineering Department of Universitas Malikussaleh, Indonesia
[46]	ITC 2002 ITC 2007 Socha
[47]	Semester 1 2016/2017 and semester 2 2016/2017, Universiti Malaysia Labuan International Campus (UMSLIC), Malaysia
[48]	Semester 1 2016/2017 and semester 2 2016/2017, Universiti Malaysia Labuan International Campus (UMSLIC), Malaysia
[49]	ITC 2002 ITC 2007 Socha
[50]	Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin (UniSZA), Malaysia
[51]	Curriculum from 2017 of Bachelor Program of Computer Engineering and Informatics, in the Faculty of Engineering, Kasetsart University Sriracha Campus, Thailand.
[54]	Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin (UniSZA), Malaysia
[55]	Faculty of Electrical Engineering, Pasir Gudang campus, Universiti Teknologi MARA (UITM), Malaysia
[56]	Faculty of Computer Science, Universitas Indonesia, Indonesia
[57]	Academic year 2015/2016, Indonesian Computer University (UNIKOM) Bandung, Indonesia
[58]	Information Technology Department, University of Sumatera Utara
[59]	Faculty Of Computer and Mathematical Sciences, Universiti Teknologi MARA (UITM), Malaysia
[60]	Datasets obtained from a Higher Education Institution
[61]	Semester 2 2016/2017, undergraduate programme in Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, Malaysia
[62]	Lewis
[64]	Even semester of year 2015/2016 for study program Informatics Engineering, University Computer Indonesia (UNIKOM), Indonesia
[65]	Universiti Malaysia Perlis (UniMAP), Malaysia
[66]	Semester 2 2014/2015 and semester 1 2015/2016, Universiti Malaysia Sabah Labuan International Campus (UMSLIC), Malaysia
[67]	Semester 2 2016/2017, first to fourth year, SSCM (Bachelor of Science in Industrial Mathematics) and SSCE (Bachelor of Science in Mathematics), Universiti Teknologi Malaysia (UTM), Malaysia

3.3.1 ITC 2002

Four studies tested their proposed methods using the ITC 2002 dataset. The ITC 2002 dataset comprises a collection of 20 instances, which were originally obtained from the official website of the International Timetabling Competition 2002 [2]. However, the website link is no longer accessible.

3.3.2 ITC 2007

There were seven studies tested their proposed methods using the ITC 2007 dataset. The ITC 2007 dataset consists of three distinct tracks tailored to various timetabling scenarios, namely PE-CTTP, CB-CTTP, and examination scheduling. Track 2 is a compilation of 24 instances related to the PE-CTTP category, while Track 3 features 21 instances specific to CB-CTTP. These datasets were accessible through the official website of the International Timetabling Competition 2007 [2]. Regrettably, the link to the dataset mentioned in [2] is no longer accessible.

3.3.3 ITC 2019

There were two studies tested their proposed methods using the ITC 2019 dataset. The ITC 2019 dataset comprises 30 instances divided into three distinct sets of 10 instances each, categorized as early, middle, and late scenarios. These datasets are available for retrieval from the official website of the International Timetabling Competition 2019 [68].

3.3.4 Socha

There were five studies tested their proposed methods using the Socha dataset. The Socha dataset comprises 11 instances. The instances were generated using Ben Paechter's problem instance generator. According to Mauritsius *et al.,* [29], the dataset can be obtained from the supporting material link given [69].

3.3.5 Hard or Lewis dataset

There were three studies tested their proposed methods using this dataset. The Hard dataset, also known as Lewis's dataset, comprises 60 instances with 20 small, 20 medium and 20 large. The instances were generated by Rhyd Lewis using an automated instance generator by Ben Paechter and can be obtained from Centre of Emerging Computing website [70].

3.3.6 Synthetic Dataset

The datasets were generated to mimic the real-world problems based on survey data. These datasets simulate challenges for algorithm testing and development without using the datasets from actual institutions.

3.3.7 Real World Dataset

All the real-world datasets were from different semesters, sessions and institutions that were provided by their respective institution's management.

4. Discussion

In this comprehensive literature review, an overview of the approach proposed for solving the UCTP is provided. Results from the selective studies show the constraints, optimization approaches, and datasets involved in finding solutions for UCTP. The discussion of the reviewed studies was stated as comprehensive concepts.

4.1 Discussion on Constraints

UCTP can be divided into two distinct fields known as the Curriculum-Based Course Timetabling Problem (CB-CTTP) and the Post-Enrolment Course Timetabling Problem (PE-CTTP). In CB-CTTP, the importance remains on the curriculum-related aspects of timetabling, taking into account factors such as course prerequisites, co-requisites, and other curriculum constraints. The objective is to develop a timetable that aligns with the structure and requirements of the academic program. On the other hand, PE-CTTP focuses on the timetabling process that occurs after the enrolment process has taken place. It involves assigning courses to specific timeslots and rooms, considering the preferences and constraints of enrolled students. The aim is to create a timetable that maximizes student satisfaction and minimizes conflicts or disruptions. By distinguishing between CB-CTTP and PE-CTTP, researchers can modify their approaches and methodologies to address the unique challenges and considerations of each timetabling scenario.

The constraints in the UCTP can be categorized as hard and soft constraints. According to Mohd Zaulir, Abdul Aziz and Aizam [13], hard constraints are the requirements that must not be violated in any circumstances to ensure the feasibility of the generated solution, while soft constraints are the requirements that need to minimise the violations to produce a better timetable. The specific list of hard and soft constraints may vary depending on the data requirements and the priorities set by different institutions. However, the fundamental concepts of hard constraints generally remain consistent, with only minor variations in detail.

The key components that influence the constraints in UCTP can be categorized as events, timeslots, resources, constraints, people, and conflicts [3]. Events refer to the scheduled courses or activities, such as lectures, labs, and tutorials. Timeslots indicate the availability of these events during specific time intervals. Resources refer to the facilities and equipment utilized by the events. Constraints represent the specific requirements and restrictions associated with the events. People involve the individuals involved in the events, including lecturers, students, and other relevant stakeholders. Conflicts arise when two or more events clash, such as when they are scheduled for the same timeslot.

The preferences of both students and lecturers are considered through the inclusion of soft constraints in the optimization process. These soft constraints allow for some flexibility, and their violation may occur to a certain extent, as long as the hard constraints are fully satisfied. The primary objective is to ensure that all hard constraints are met as these constraints typically correspond to the policies of the universities [13]. Hence, this guarantees that the generated timetable does not create significant issues that could impact the users' performance. By prioritizing the fulfilment of hard constraints while accommodating the preferences expressed in the soft constraints, an optimal solution can be achieved in the timetabling process.

Cultural differences also play a role in the constraint's requirement. The specifically reserved timeslot is taken as a hard constraint such as to avoid clash for Friday prayer [56,64]. This requirement is prioritized in countries with the Muslim majority.

Two studies from Indonesia have highlighted the timetabling problem focus on national joint courses [18,71]. The timetabling problem is different from conventional timetabling scenarios which only involve individual universities or departments at a time, while national joint course programs involve lecturers and students from different universities [18]. The constraints mainly prioritize the lecturer preferences and qualifications in the courses and minimise the unserved classes. Some constraints that usually treated as soft constraints are taken as hard constraints such as lecturer preferences [71].

4.2 Discussion on Optimization Methods

The reviewed studies have demonstrated that hybrid approaches are widely utilized for solving the UCTP, with the highest number of contributions being 31. These hybrid approaches typically involve the combination of two or more optimization techniques. The combinations may include two-stage approaches, multi-agents within a Multi-Agent System (MAS), multi-stage optimization processes, and enhanced versions of existing approaches. In the two-stage approach, the first phase focuses on satisfying the hard constraints using the proposed approach, while the second stage aims to minimize the soft constraints. In multi-agents, the approach incorporates another approach into the MAS. In multi-stages, the optimization involves multiple stages while preserving the solution from the initial stage that satisfies hard constraints. The enhanced versions of existing approaches represent improved versions of single-method approaches. The reviewed studies indicate the superiority of hybrid approaches over single-method approaches.

In the reviewed studies, the performance of the approaches is commonly evaluated through several metrics, including the average cost function, improvement percentage, standard deviations, and the number of violations for both hard and soft constraints. The average cost function represents the average penalty cost incurred by satisfying the combined hard and soft constraints. It is calculated by determining the minimum cost, indicating the best solution, and the maximum cost, indicating the worst solution, obtained in specific experiment runs. The improvement percentage measures the degree of enhancement achieved compared to the initial solution. The standard deviation is utilized to assess the consistency of the cost function across different runs or iterations.

The reviewed studies highlight certain limitations encountered when optimizing the UCTP. The proposed approaches may require flexibility as timetables can be assigned and unassigned dynamically. One particular challenge arises with the MCTS approach by Goh, Kendall, and Sabar [46], which faces difficulties due to limited search space connectivity when compared to local search methods like TS. However, the MAS approach used in incorporating integer programming by Abdalla *et al.,* [47] involved the stated advantage of MAS as it facilitates optimization by guiding agents towards more promising search spaces in the pursuit of finding the best solution.

When utilizing a metaheuristic approach, population-based algorithms like GA and ACO outperform other methods in terms of exploring the solution space. Following Wong, Goh, and Likoh [14], GA requires more computational time compared to SA that is a single-solution metaheuristic. This is because population-based metaheuristics take into account multiple candidate solutions instead of just a single candidate solution when determining the optimal solution.

4.3 Discussion on Datasets

In the reviewed studies of the UCTP, two types of datasets can be categorized, public datasets and real-world datasets, each with its advantages and disadvantages. Public datasets are easily accessible online and provide standardized constraints, enabling effective comparison with existing research. These datasets serve as valuable benchmark datasets for evaluating different approaches. However, public datasets may lack detailed information about current real-world settings due to potentially being outdated. In contrast, real-world datasets are unique depending on the institutions. Obtaining these datasets requires collaboration with respective institutions. While lacking standardization for comparison purposes, real-world datasets validate the applicability of research approaches in realistic settings. They incorporate real-world constraints, enhancing the accuracy of results in practical scenarios.

The use of the public dataset ITC 2019 isn't a lot compared to other public datasets for being the recent ITC dataset. Not many studies were being conducted using ITC 2019, so it will be interesting to use ITC 2019 as a benchmark dataset since the requirement constraints are also much more complex compared to ITC 2002 and ITC 2007. ITC 2019 constraints consisted of rooms, classes with course structure, distribution constraints, and students with their course preferences [72].

5. Conclusion

In conclusion, this comprehensive review has focused on investigating optimization approaches for university timetable problems. Specifically, within the context of ASEAN countries, the majority of studies utilized real-world datasets obtained from the collaborating institutions. Furthermore, it was observed that hybrid approaches were the most commonly employed methods for addressing university timetabling problems.

The reviews resulted in three themes related to university timetabling problems optimization along with eleven sub-themes. The main themes are constraints, optimization approaches, and datasets.

The review suggests several recommendations for future research. Firstly, it is advised to conduct comparative studies using standardized datasets to facilitate a better understanding of different optimization approaches. Secondly, there is a need to focus on exploring the evolution of enhanced optimization techniques, particularly in the context of university timetabling problems. Lastly, future studies should aim to generate standardized public datasets specifically tailored for ASEAN institutions, which would enable more effective comparisons among optimization approaches while aligning with the preferences and requirements of these institutions.

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