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REVIEW

A systematic mapping study on solving university timetabling problems using meta-heuristic algorithms

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Abstract

Since university timetabling is commonly classified as a combinatorial optimisation problem, researchers tend to use optimisation approaches to reach the optimal timetable solution. Meta-heuristic algorithms have been presented as effective solutions as proven on their leverage over the last decade. Extensive literature studies have been published until today. However, a comprehensive systematic overview is missing. Therefore, this mapping study aimed to provide an organised view of the current state of the field and comprehensive awareness of the meta-heuristic approaches, by conducting meta-heuristic for solving university timetabling problems. In addition, the mapping study tried to highlight the intensity of publications over the last years, spotting the current trends and directions in the field of solving university timetabling problems, as well as having the work to provide guidance for future research by indicating the gaps and open questions to be fulfilled. Primary studies on mapping study that have been published in the last decade from 2009 until the first quarter of 2020, which consist of 131 publications, were selected as a benchmark for future research to solve university timetabling problems using meta-heuristic algorithms. The majority of the articles based on the publication type are hybrid methods (32%), in which the distribution of meta-heuristic algorithms the hybrid algorithms represent the higher application (31%). Likewise, the majority of the research is solution proposals (66%). The result of this study confirmed the efficiency and intensive application of the meta-heuristic algorithms in solving university timetabling problems, specifically the hybrid algorithms. A new trend of meta-heuristic algorithms such as grey wolf optimiser, cat swarm optimisation algorithm, Elitist self-adaptive step-size search and others with high expectations for reliable and satisfying results can be proposed to fill this gap.

Keywords Systematic mapping review · University timetabling · Meta-heuristic algorithm · Optimisation

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1 Introduction

University timetabling has been classified as an optimisation problem in selecting the best solution from a number of available options. Finding an optimal timetable is a very complex process since the problem has been classified as non-polynomial time (NP) hard as well as combinatorial optimisation problem. In other words, the problem of having variables is different from one institution to another and continues to grow rapidly. For instance, the students' numbers vary from one institution to another and are rapidly growing including the start time of the courses or examinations. Besides this, there are also several and different hard and soft constraints to be fulfilled.

Meta-heuristic algorithms are more elaborated and represent a large part of the techniques used to solve most of the combinatorial optimisation problems [1]. Meta-heuristic is a method to solve very general classes of problems. It employs current information gathered by an algorithm to help decide which alternative solution should be evaluated next, or how the next candidate can be produced. Meta-heuristic algorithms connect objective functions or heuristics in an abstract form, and hopefully in an efficient way, neglecting details of an inside structure. If the relation between a solution candidate and its "fitness" is understandable or not too complex, it becomes easier to solve a problem deterministically [2]. The terms meta-heuristic algorithms, techniques, methods and approaches have been used synonymously in this study.

Several studies in the area of meta-heuristic algorithms for solving university timetabling problems have been published until today. However, a comprehensive systematic review is missing. This paper aims to conduct a systematic mapping study in the area of solving university timetabling problems by using meta-heuristic algorithms. This is done by running an investigation to determine the volume of research conducted in this topic. Some of the open questions and critical concerns that need further attention by researchers as well as identified the recent methods to provide current status of this particular field and suggest potential future directions are also highlighted. In order to lay the foundation of the idea of this paper, a recent survey study conducted by Kitchenham et al. [3] was used as a guidance.

Recently, systematic literature review (SLR) has been appeared as the greatest technique of providing impartial review of the state-of-the-art studies. It uses an orderly selection approach of the published articles involving exclusion and inclusion criteria. SLR is a methodology for evidence-based software engineering that aggregates proof for providing. It appears several advantages compare to classic survey methods.

The study covered the recent publications at the last decade; the idea of adopting this scope comes from the novelty conception. In other words, recent publications come up with solutions to the unsolved problems, overcome former obstacles and present more updated techniques and creative methods. These processes aim to fill the gaps and conducting proper answers to the open questions. This study focuses on survey of meta-heuristic research in recent literature during the last years and comes up with suggestions for the future researches and PhD studies. We excluded the older studies because limited methods were used; most of the older methods introduced genetic algorithm and heuristic approaches which were already covered in this study. We start our research from 2009; during our survey, we found there is published survey of meta-heuristic-based techniques for university timetabling problems in 2008 [4], which is covered in the older studies. Therefore, we start our study from 2009 to first quarter 2020.

The main contributions of this systematic mapping study can be highlighted in the following:

- We present a systematic mapping study to review the existing studies done and determine the volume of research conducted in meta-heuristic for solving university timetabling problems.
- We identifying recent meta-heuristic techniques as a guidance for the researchers and practitioners in the field to provide current status of this particular field and suggest potential future directions.
- We highlight some of the real-life contribution in meta-heuristics applications to better understand the emerging trends and identify techniques for tackling unresolved issues.

The remainder of this paper is structured as follows: In Sect. 2, a brief background of the problem is declared. The related work is highlighted in Sect. 3. The methodology of this mapping study is presented in Sect. 4. In Sect. 5, the results are structured according to the research questions. After that, Sect. 6 reports and discusses the results from performing the review, potential directions for the future research and limitations. Finally, Sect. 7 concludes the paper.

2 Background

The conventional description of timetabling methodology is declared by Wren [5] as the allocation, subject to constraints, of given resources to objects being placed in space-time, in such a way as to satisfy as nearly as possible a set of desirable objectives. From that perspective, timetabling can be defined as a technique of allocating the

stated tasks to sufficient resources in a specific time space, by considering specific constraints. The timetabling constraints can be classified as hard constraints (which must be satisfied) and soft constraints (which could be violated). Consequently, a timetable that satisfies all the hard constraints is called a feasible timetable in which the quality of timetable is usually specified by measuring the range of the violated constraints [6].

The concerned university timetabling problem can be categorised into many fields; however, this paper precisely handles two fields as the most common substantial and significant educational timetabling problems:

1. *Examination timetabling* "The assigning of examinations to a limited number of available time periods in such a way that there are no conflicts or clashes" [7].
2. *Course (or lecture) timetabling* "A multi-dimensional assignment problem in which students, teachers (or faculty members) are assigned to courses, course sections or classes; events (individual meetings between students and teachers) are assigned to classrooms and times" [8].

Meta-heuristic is used to solve optimisation problems by the process of searching optimal solutions to a particular problem of interest. The search can be carried out using multiple agents that essentially form a system of evolving solutions using a set of rules or mathematical equations during multiple iterations. These iterations are carried out until the solution found meets some predefined criterion. This final solution (near optimal solution) is said to be an optimal solution, and a system is deemed to have reached a converged state [9]. Numerous meta-heuristic algorithms exist today, and their conception comes from various sources of inspirations. Some are made by analogy to other scientific fields such as physics (simulated annealing), biology (ant colony and evolutionary algorithms), neurology (tabu search) and sociology (memetic algorithms, particle swarm optimisation, etc.) [10].

Meta-heuristic approaches can be categorised into two:

1. *Single-solution-based approaches.* The single-solution-based approaches manipulate one solution through the use of neighbourhood structures during the search process in order to reach better solutions [11].
2. *Population-based approaches.* The population-based methods introduce a set of initial solutions which is called the initial population. The initial population goes through multiple iterations to conduct the optimal solution. At each iteration of population-based meta-heuristic approaches, a selection mechanism is used to select the best solution from the present population. Then, according to the selected meta-heuristic method, some changes are applied over the selected solutions so that the improvement is obtained in the solution; now these improved solutions are replaced with damaged populations. This procedure continues until it reaches a desirable solution [6]. Normally in university timetabling, an initial solution is constructed using an appropriate heuristic and then the improvement is carried out using meta-heuristic algorithms [1].

3 Related studies

Due to the enormous success of meta-heuristic algorithms in effectively solving both university course and examination timetabling problems, extensive literature has been published until today. Although several studies were extracted from university timetabling problems, the focus in this mapping study was specifically on the survey studies. This is because an overall review that was given is used as the purpose of this study. About 20 related studies elected from 1995 until 2018 are based on formatting the overall status of applying meta-heuristic algorithms to solve university timetabling problems. In 1995, Wren [5] divided the scheduling problem into four classes in the form of main questions and then provided answers to these questions and the relationships between the problem types to structure the final content: (1) What is scheduling?; (2) what is timetabling?; (3) what is rostering?; and (4) what is sequencing?. Carter and Laporte in [7, 8] described the major components of the course timetabling problem and discussed some of the primary types of algorithms that have been applied to university course timetabling (U.C.T.T.). In addition, they investigated and compared several algorithmic strategies for the examination timetabling problem, and the computational results were reported on randomly generated problems and on some real problems in [12]. Schaerf [13] made a survey of the various formulations of the timetabling problem, as well as the techniques and algorithms used for its solution. Burke and Petrovic [14] in their paper gave a brief introduction to some recent approaches to timetabling problems that have been developed or are under development in the Automated Scheduling, Optimisation, and Planning Research Group (ASAP) at the University of Nottingham. They also suggested a number of approaches that comprised three parts: (1) recent heuristic and evolutionary timetabling algorithms; (2) an approach that considers timetabling problems as multi-criteria decision problems; and (3) a case-based reasoning approach that employs previous experience to solve new timetabling problems. Blum and Roli [15] made a survey of today's most important meta-heuristic from a conceptual point of view, where they came up with two very important concepts in meta-heuristics:

intensification and diversification. In addition, they outlined the advantages and disadvantages of different meta-heuristic approaches. Lewis [4] classified the meta-heuristic algorithms into three general classes: (1) one-stage optimisation; (2) two-stage optimisation; and (3) algorithms that allow relaxation. Burke et al. [16] in their paper highlighted the new trends and key research achievements that have been carried out in the last decade on examination timetabling. They outlined a range of relevant important research issues and challenges, discussed previous survey papers and presented the state-of-the-art methodologies. Some important issues that have come to light concerning the public benchmark examination timetabling data were also discussed. Hosne and Fatima [17] described some genetic algorithm (GA) techniques that have recently been applied to different variants of the university timetabling problem and produced promising results. The description focuses on the chromosome representation and the crossover and mutation operators. Turabieh et al. [18] proposed a hybrid approach to solve the university course timetabling problem. The proposed method has been applied to a range of benchmark university course timetabling test problems from the literature. The viability of the method has been tested by comparing its results with other reported results from the literature, demonstrating that the method is able to produce improved solutions to those currently published. Martín et al. [19] used a methodology that was tested with several meta-heuristic algorithms over some well-known set instances such as Patat (2002) and (2007). The main objective is to find which meta-heuristic algorithm shows better performance in terms of quality, used together with the design methodology. Kristiansen [20] highlighted some of the main trends and research achievements within educational planning problems. He also made a comparison between the different planning problems. Arbaoui in [10] conducted a thesis on university timetabling and discussed the following points: (1) investigated university timetabling problems by addressing examination timetabling and student scheduling problems; (2) proposed a hybridisation solution to solve university timetabling problems (U.T.T.P.); (3) investigated new methods and formulations and compared them to the existing approaches; and (4) presented a new formulation for the student scheduling problem and investigated its performance on a set of real-world instances. Karimpour et al. [21] analysed available approaches in the study of university course timetabling problems, including operational researches, meta-heuristic methods and intelligent novel methods. The distributed multiagent systems-based approach (cooperative search method) was investigated due to its scalability, which enables the timetabling of common events between departments. A complete introduction of reliable datasets was given to test and evaluate the structure of considered algorithms. Wibowo et al. [22] did a survey on the properties of academic scheduling problems, such as the complexity of the problem and the constraints involved and addressing the various meta-heuristic techniques and strategies used in solving them. Boufflet et al. [23] presented a meta-heuristic to solve the examination timetabling problem related to the Toronto benchmark. The proposed approach achieved better results when compared to existing approaches. Pandey and Sharma [24] described different types of timetabling problem and some widely used methodologies to solve the timetabling problem like artificial ant colony (ACO), hybrid bee colony (HBC) optimisation method, particle swarm optimisation (PSO), genetic algorithm (GA), etc. Alhashimi et al. [25] in their survey focused on examining the major solution approaches for the timetabling problem and comparing them in order to provide directions for academicians and researchers for further work. Alzubair et al. [2] conducted a systematic literature review in the field of educational timetabling problems concerning the meta-heuristic approaches to solve the problems. All the selected primary studies were focused on Swarm Intelligence techniques. They came up with results that showed the research gaps in using swarm intelligence techniques (SI) for the timetabling problems. They also conducted the study using techniques such as firefly algorithm (FA), which had never been implemented in the area of educational timetabling, since the systematic study method proved to be an efficient tool for finding all trends in the areas searched. In addition, the paper investigated the use of hybridisation algorithms to solve timetabling problems.

4 Methodology

There are several methods to outline the overall concept of the selected subject such as primary study, systematic literature review (also referred to as a systematic review) and sensitivity analysis. But the strength of the systematic mapping study (also referred to as scoping study) becomes clear in the evaluation methodology results of the gathered studies, considering the fact conducted results essentially count on the stated research strategy. This research paper aims to perform a systematic mapping study in the area of using meta-heuristic algorithms for solving university timetabling problems. Systematic mapping review aims to provide a solid ground as a robust foundation for future studies. The mapping study outlines the overall framework of the selected studies by collecting relevant studies as many as possible and then going through fair evaluation to elect the primary studies that answer the research questions. The evaluation methodology must be accurate and

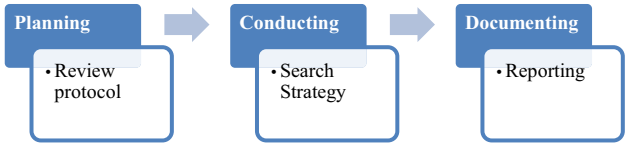

Fig. 1 Systematic mapping review general concepts

precise to state a comprehensive description to the selected studies and summarise the benefits and limitations. Likewise, systematic mapping provides a critical contribution in closing the gap between practice and theory by identifying any lacks in the current research and suggesting future works and recommendations.

The difference between a classic survey paper and a systematic mapping paper becomes clear when the systematic mapping methodology is used; it is more sophisticated; and the overall structure consists of three main concepts: the review protocol, search strategy and documentation, as shown in Fig. 1.

In order to perform a systematic study, three review guideline steps were adopted as introduced by Kitchenham and Charters [3] shown generally in Fig. 1 and by detail in Fig. 2. These phases consist of planning the review, conducting the review and documenting the results. It involves of well-defined phases to analyse and evaluate the research papers in order to identify gaps in the existing research as well as to review their contributions to the RQs for drawing a conclusion. The different components of each phase summarise the results of each phase. Each phase is described in the next subsection. Each phase is explained and described in the following:

4.1 Planning the review (Phase 1)

The study framework adopts some prime questions, and the substantial aim is answering these questions to structure the review. This phase is the milestone activity since it determines the review questions and guides the next phases. The planning phase goes through three processes as described in the following subsections:

4.1.1 Identifying the need for a review

The increasing number of literature on meta-heuristic algorithms for solving university timetabling problems in the last decade reflects how much it is a crucial and rising issue. Nevertheless, there is a lack of systematic review publication in the field of university timetabling in general.

4.1.2 Specifying the research questions

The research questions were prepared to set the boarders of the targeted publications according to the relevance inclusion and exclusion criteria which are followed in this study. Thus, specifying the criteria is substantial primary step as well as setting the right questions is a crucial point since they forming the whole framework of the study. After the collecting process of the candidate publications comes the evaluation under the stated standards as a rule of relativity, intensity and diversity.

The main objective of this systematic mapping study is to detect the most effective and relevant university timetabling approaches to reach the optimal solution and state the feasible timetable. At the same time, this study aim to find out the techniques to analyse, conduct and evaluate the experiments on the optimisation algorithms. To achieve

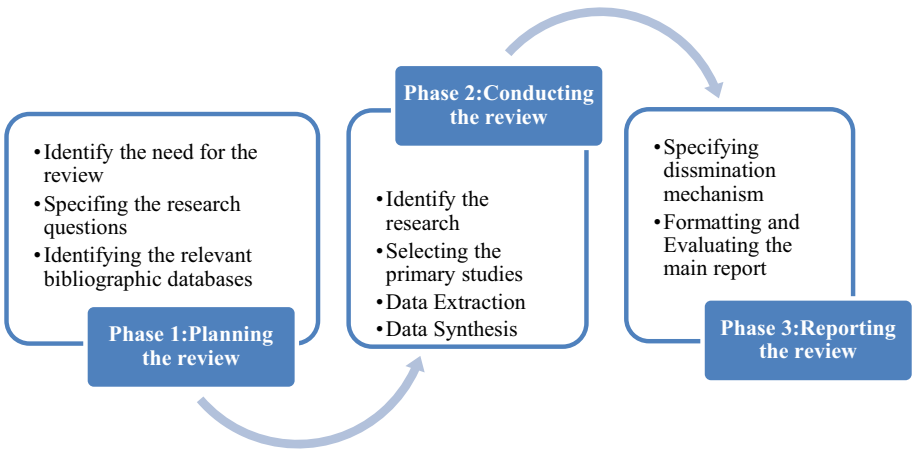

Fig. 2 Systematic mapping review methodology and processes

Table 1 Systematic mapping data sources

Source	URL
Google Scholar	http://scholar.google.com
Springer	http://www.springerlink.com
Elsevier	http://www.elsevier.com
ACM	http://portal.acm.org
IEEE	http://www.ieee.org
IOP publishing	http://www.ioppublishing.org
MISTA	http://www.schedulingconference.org

this aim, the following four research questions (RQs) were stated as the focus of this study:

RQ1 What is the intensity of publication in the field of meta-heuristic algorithms for solving university timetabling problems?

RQ2 What are the recent meta-heuristic algorithms exploited for solving university timetabling problems?

RQ3 Which research types and diversity in the literature can be identified on using meta-heuristic algorithms for solving university timetabling problems?

RQ4 What is the diversity of meta-heuristic publications in the field of university course timetabling problems versus university examination field?

We stated the RQ1 to find the relevant studies in meta-heuristic algorithms that are used for solving university timetabling problems. As well, the RQ2 aims to identify the various meta-heuristic algorithms that proposed in the literature for solving university timetabling problems. Furthermore, we defined the RQ3 to determine how the collected evidence in meta-heuristic algorithms for solving university timetabling problems can be classified and categorised based on their characteristics. Finally, the aim of RQ4 is to classify the collected meta-heuristic algorithms studies for solving university timetabling problems into two substantial and significant fields in educational timetabling problems: examination timetabling and course timetabling.

4.1.3 Identifying the relevant bibliographic databases

Documenting the search data sources is a major process to perform the review; there are several provenance to gathering data like digital library, journal, conference proceedings and efforts to identify unpublished studies and others like internet pages [3]. The relevant studies were collected from different sources, like journals, conferences and workshops in order to make the review. Table 1 lists some of the major selected data references.

These databases were chosen because it is well-known and recommended sources for conducting systematic studies as well most commonly used in the area of computer science. The selected data sources contain high-quality researches that enable to conduct scientific and reliable researches and also extract strict and accurate results.

Table 2 Search strategy

Term 1	AND	Term 2	AND	Term 3
University		Timetabling		Problems
OR				OR
Educational				Problem
OR				
Course				
OR				
Lecture				
OR				
Examination				
OR				
Examinations				
Optimisation	AND	Algorithms	AND	For solving university timetabling problems
Meta-heuristic		OR		
		Approaches		
		OR		
Meta-heuristics		Techniques		
		OR		
		Methods		

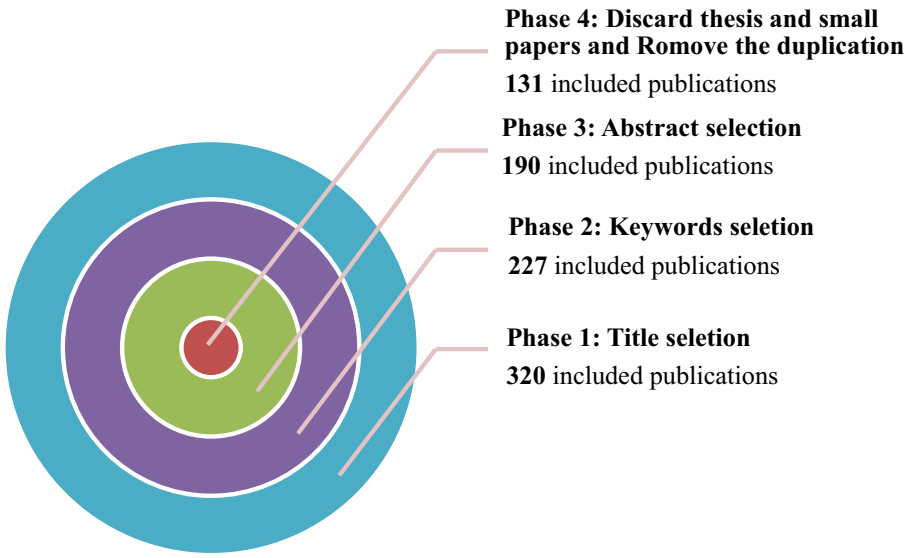

Fig. 3 Selection process

4.2 Conducting the review (Phase 2)

As previously mentioned, the review questions drive the entire systematic review methodology. From that perspective, this phase collected the relevant studies that gave convenient answers to the deduced questions and then elicited primary studies by conducting three processes: search process, data extraction process and data analysis process. The relevant papers were selected by reviewing their title, abstract and keywords. The search strategy is represented in Table 2.

4.2.1 Identifying and selecting the primary studies

The relevant publications including journal articles, book chapters and conference and workshop proceedings were adopted after title-based selection, keywords-based selection and abstract-based selection. The selection process went through four phases: at first, the collecting phase was carried out by checking the title from all the previously mentioned data sources in Table 2. The total number of the included publications was 320. At the second phase, the data were filtered by reviewing the keywords and the total number of the included publications was 227. After that, the abstracts were reviewed and the total number of the included publications was 190. Finally, all the duplications, small papers and thesis were discarded and the total number of the included publications was 131. Figure 3 illustrates the four phases of the selection process.

To allocate the primary studies, a set of specific criteria were stated, and the selected papers must confirm at least one of the following criteria:

Inclusion criteria

- The paper discussed university timetabling problems.
- The paper discussed educational timetabling problems.
- The paper discussed university course timetabling problems.
- The paper discussed university examination timetabling problems.
- The paper discussed meta-heuristic approaches/techniques/methods/algorithms for solving university timetabling problems.
- The paper discussed optimisation algorithms for solving university timetabling problems.

Exclusion criteria

- The publications are not related to meta-heuristic and university timetabling.
- Articles with less than 5 pages.

4.2.2 Data extraction and synthesis

After reviewing the selected papers through the abstract, introduction and conclusion with considering the declared criteria, 131 papers were selected for the final review in order to provide answers to the identified questions. Table 3 summarises the applied extracted criteria to conduct the systematic study as each criteria aims to provide answers to the stated research questions.

Table 3 Data extraction form

Data extraction criteria	Description	Related question
Publication source	Journal, conference, etc.	RQ1
Publication year	Year of publication	RQ1
Data sources	Google Scholar, Springer, etc.	RQ1
Publication type	New method, modified, etc.	RQ2
Approaches	All used methods/algorithms	RQ2
Research type	Solution proposal, opinion article, etc.	RQ3
University timetabling problem's type	Course or examination	RQ4

5 Results

The final phase outcome is an inclusive report that discussed the selected primary studies and came up with a final result. The report summarised the open issues and gaps to be fulfilled by researchers. It also concluded outlines and future recommendations. This is a significant phase for reflecting the accuracy, reliability and the whole valuation of the systematic review.

Conclusively, the fundamental method to extract this phase is by providing a convenient and comprehensive answers to the declared four research questions one by one, illustrated by tables and figures.

RQ1 What is the intensity of publication in the field of meta-heuristic algorithms for solving university timetabling problems?

The selected primary studies suggest that an extensive research has been conducted in the field of meta-heuristic algorithms for solving university timetabling problems. The intensity of publications year-wise is shown in Fig. 4. It is evident from the mentioned figure that meta-heuristic algorithms attracted researchers more effectively in 2009 and 2012.

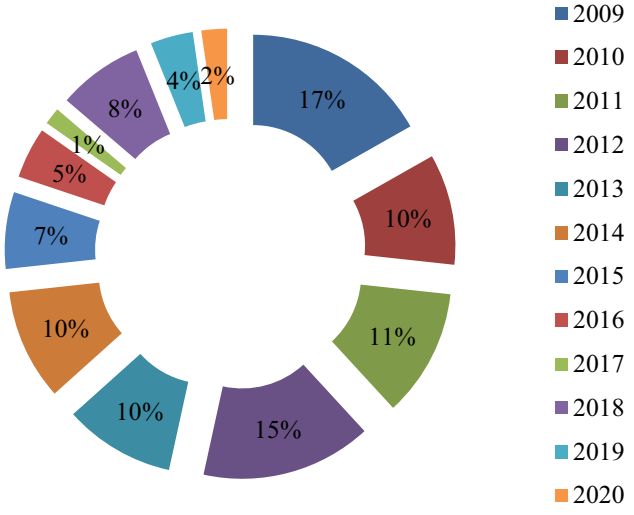

Fig. 4 Distribution of the primary studies by publication year in percentage

"Appendix" was created to record different characteristics of a publication to address the research questions and objectives of the study. The information covered in this table includes reference number, paper number, paper title, author (s), publication year, publication source (conference, workshop, book chapter or journal), publication type (new method, method, modification, hybrid, comparisons, analysis, review, case study and survey) and research type (solution proposal, evaluation search, conceptual article, experience article and opinion article).

Over the last decade, using meta-heuristic approaches for solving university timetabling problems has obtained a considerable amount of researchers' interest. This systematic study covers the research work published between the years 2009 and the first quarter of 2020 sequentially. We decided to set the search period from 2009 because the extensive use of meta-heuristic approaches for solving university timetabling problems in general began to be published during that year. The survey collected 131 papers since 2009 until the first quarter of 2020, classified by the publication year, publication source, type of publications, publisher, research type, type of applied meta-heuristic algorithms and the problem type either examination timetabling problem or course, as illustrated as the following tables and diagrams. The distribution of the selected primary studies according to the publication year and publication source is presented in Figs. 4 and 5 by both numbers and percentage. In addition, Fig. 6 reflects the distribution by the publication source.

All the selected studies data sources like journals, conferences, workshops and books chapters are listed in Table 4 with their number of publications limited in our target period that mentioned before. Based on the analysis data, the publications were diverse between different sources. There were only two workshop publications in the search period as a lowest number of publication.

Table 5 demonstrates the contribution of the selected studies publishers (data sources) according to the type of the publication; the study comprises nine types of

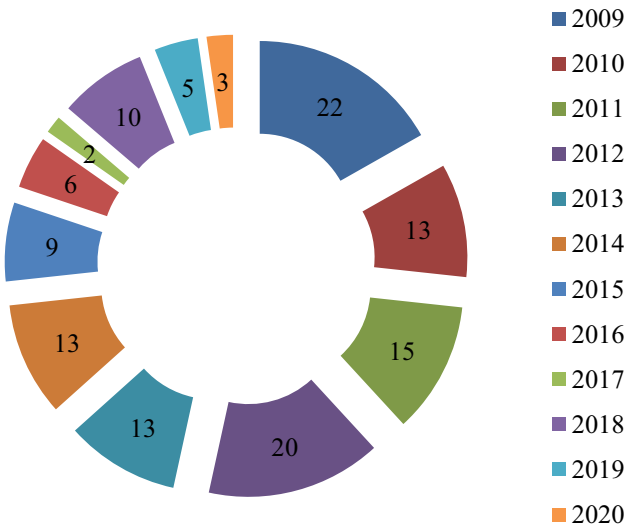

Fig. 5 Distribution of the primary studies by publication year by numbers

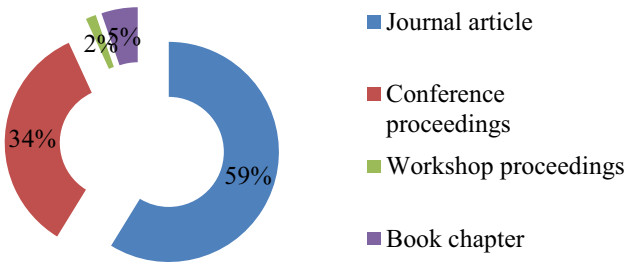

Fig. 6 Distribution of primary studies by publication source

publications based on the nature of the involved meta-heuristic algorithms as follow:

1. *New method*: This type means the algorithm is recently proposed and still under consideration.
2. *Method*: Mean the algorithm is widespread and commonly used.
3. *Modified method*: Refer to particular adjustment/s at the algorithm.
4. *Hybrid method*: Clarify the technique of integrated two or more algorithms to enhance and add more value to the overall performance.
5. *Review*: Indicate a formal assessment or examination of the algorithm, so generally it is an evaluation process.
6. *Comparison*: Related to the process of evaluating the relevant and comparable characteristics of two or more algorithms to mark the similarities and differences between them.
7. *Analysis*: It is a detailed examination process of the algorithm by break the overall concept into smaller notions in order to gain better realisation.
8. *Survey*: It is a research method used to collect data about the algorithm from a former reliable literature to provide a general view or description about the algorithm.
9. *Case study*: The idea is conducted an in depth investigation of the algorithm taking into account its real-life statuses.

RQ2 What are the recent meta-heuristic algorithms exploited for solving university timetabling problems?

The intensive amount of the literature in the field of university timetabling has been raised through the years. Since university timetabling problem has been classified as a combinatorial optimisation problem (COP), this kind of problem is commonly solved through optimisation techniques. Interest in such techniques has been remarkable in the last decade, principally the uprising of meta-heuristic optimisation techniques.

Meta-heuristic algorithms are upgraded algorithms from the sequential heuristics algorithms and have the ability to generate preferable solutions. Numerous meta-heuristic techniques exist, and their conception comes from various sources of inspirations. Some are made by analogy to other scientific fields such as physics (simulated annealing), biology (ant colony and evolutionary algorithms), neurology (tabu search) and sociology (memetic algorithms, particle swarm optimisation, etc.) [10]. Swarm intelligence and artificial intelligence technique that has successfully been applied for solving complicated optimisation problems that mimic the social behaviour of species in nature, like ant colonies or bird's flocks, for example. Swarm-based systems are usually composed from population of individual, which takes effect between each other and the environment. Individuals could communicate directly or through impacting in surroundings.

Hybridisation methods have attracted the interest of many researchers in recent years due to its outstanding performance in solving optimisation problems. The main idea of hybrid methods is to combine constructive elements of different methods into one. With this combination, the searching abilities of the hybrid method will be increased [11]. The aim of the hybridisation is to utilise the benefit of population-based approaches that has the ability of identifying promising areas in the search space and single-based approaches that are good in exploiting the promising area. It is believed that the hybridisation approach is able to give a better performance in obtaining a preferred solution for a given problem [16]. Figure 7 presents the distribution of the selected studies according to their publication type; likewise, Fig. 8 presents the distribution by publication type over the years from 2009 till the first quarter of 2020.

Table 4 Publication of primary studies

Publication source	No
Journal	
Alexandria Engineering Journal	1
Algorithms	1
Annals of Operations Research	4
Applied Intelligence	2
Applied Soft Computing	5
Artificial Intelligence Review	3
arXiv preprint arXiv:1401.5156	1
Computer and Knowledge Engineering (ICCKE)	1
Computer Science and Information Technology	1
Computer Science Letters	1
Computers & Industrial Engineering	1
Computers & Operations Research	2
Doroud, Iran: Islamic Azad University	1
Egyptian Computer Science Journal	1
European Journal of Operational Research	5
Expert systems with applications	2
IEEE Transactions on Evolutionary Computation	1
IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)	2
IFAC-PapersOnLine	1
Indonesian Journal of Electrical Engineering and Computer Science	1
Information Sciences	2
Innovative Systems Design and Engineering	1
Int J ElectrComputSci	1
Int J Soft ComputEng	1
Int. J. Advance. Soft Comput. Appl	1
International Journal	1
International Journal of Advanced Intelligence Paradigms	1
International Journal of Computational Intelligence and Applications	1
International Journal of Computer Applications	1
International Journal of Computer Science and Information Technologies	1
International Journal of Computer Science and Network Security	1
International Journal of Computer Science Issues (IJCSI)	2
International Journal of Intelligent Computing and Cybernetics	1
International Journal of Meta-heuristics	1
International Journal of Physical Sciences	1
International Journal of Recent Trends in Engineering	1
International Journal of Technical Research (IJTR)	1
International Proceedings of Computer Science and Information Technology	1
J. Emerg. Trends Comput. Inf. Sci	1
Journal of Computational Science	1
Journal of Heuristics	1
Journal of Information & Knowledge Management	1
Journal of Information and Communication Technology	1
Journal of Japan Society for Fuzzy Theory and Intelligent Informatics	1
Journal of scheduling	4
Journal of the Operational Research Society	2
JurnalTeknologi	1

Table 4 (continued)

Publication source	No
Modern Applied Science	1
Naresuan University Engineering Journal	1
Nigerian Journal of Technology	1
Omega	1
Proceedings of the 4th multidisciplinary international scheduling: Theory and applications 2009 (MISTA 2009)	1
Swarm and Evolutionary Computation	1
TehnickiVjesnik-Technical Gazette	1
Conference proceedings	
2nd Conference on Data Mining and Optimisation, 2009. DMO'09.	3
3rd International Conference on Computing for Sustainable Global Development (INDIACom), 2016	1
3rd International Conference on Data Mining and Intelligent Information Technology Applications (ICMiA), 2011	1
5th international conference on information technology (ICIT 2011)	1
7th International Conference on Information Technology and Electrical Engineering (ICITEE), 2015	1
8th International Conference on Computer Engineering & Systems (ICCES), 2013	1
8th International Conference on Computing Technology and Information Management (ICCM), 2012	1
Fourth International Conference on Computer Sciences and Convergence Information Technology, 2009. ICCIT'09.	1
Fourth International Multi-Conference on Computing in the Global Information Technology, 2009. ICCGI'09.	1
IEEE 9th International Colloquium on Signal Processing and its Applications (CSPA). 2013	1
IEEE Congress on Evolutionary Computation (CEC), 2011	1
IEEE International Advance Computing Conference, 2009. IACC 2009.	1
IEEE International Conference on Advanced Management Science (ICAMS), 2010	1
IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE), 2015	1
International Parallel Conferences on Researches in Industrial and Applied Sciences, Dubai, UAE	1
International Conference Europe Middle East & North Africa Information Systems and Technologies to Support Learning	1
International Conference in Swarm Intelligence	1
International Conference on Adaptive and Natural Computing Algorithms	1
International Conference on Advanced Computer Control, 2009. ICACC'09.	1
International Conference on Combinatorial Optimisation and Applications	1
International Conference on Computer Engineering and Technology, 2009. ICCET'09.	1
International Conference on Computer, Communications, and Control Technology (I4CT), 2015	1
International Conference on Hybrid Artificial Intelligence Systems	1
International Conference on Learning and Intelligent Optimisation	1
International Conference on Rough Sets and Knowledge Technology	3
IOP Conference Series: Materials Science and Engineering	2
Journal of Physics: Conference Series	1
Multidisciplinary International Conference on Scheduling: Theory and Applications (MISTA 2009) 10-12 August 2009, Dublin, Ireland	1
Proc. Multidisciplinary International Conference on Scheduling: Theory and Applications (MISTA 2009), Dublin, Ireland	1
Proceedings of 8th international symposium on intelligent and manufacturing systems, Sakarya University Department of Industrial Engineering, Adrasan, Antalya, Turkey	1
Proceedings of the 10th international conference on Artificial intelligence and soft computing: Part II	1
Proceedings of the 4th multidisciplinary conference on scheduling: theory and applications (MISTA 2009), Dublin, Ireland	1
Proceedings of the first ACM/SIGEVO Summit on Genetic and Evolutionary Computation	3
Proceedings of the Multidisciplinary International Conference on Scheduling: Theory and Applications (MISTA), Dublin, Ireland	1
Regional Conference on Science, Technology and Social Sciences (RCSTSS 2016)	1
second international conference on Computer and Network Technology	1
Sixth International Conference on Bio-Inspired Computing: Theories and Applications (BIC-TA), 2011	1
the 8th Int. Conf. Practice and Theory of Automated Timetabling (PATAT 2010)	1
Workshop proceedings	
12th UK Workshop on Computational Intelligence (UKCI), 2012	1

Table 4 (continued)

Publication source	No
7th International Workshop on Systems, Signal Processing and their Applications (WOSSPA), 2011	1
Book's chapter	
Computational Science and Technology	1
Designing with Computational Intelligence	1
Handbook of meta-heuristics	3
Recent advances in Harmony search algorithm	1
Recent Advances on Hybrid Intelligent Systems	1
Total	131

Table 5 Distribution of primary studies by the publisher's type

Publisher	Number of publication	%	Type of publication								
			New method	Method	Modified method	Hybrid method	Review	Comparison	Analysis	Survey	Case study
Elsevier	22	17	1	5	1	6	3	0	3	2	1
Springer	30	23	0	7	1	7	4	1	6	3	1
ACM	3	2	0	1	0	2	0	0	0	0	0
IOP publishing	3	2	0	2	0	1	0	0	0	0	0
MISTA	5	4	0	3	0	1	1	0	0	0	0
IEEE	25	19	2	7	0	9	2	3	1	1	0
Google Scholar	43	33	2	15	3	16	1	3	0	3	0
Total	131	100	5	40	5	42	11	7	10	9	2

All the involved meta-heuristic algorithms in this study including the hybrid algorithms and others—the others classification includes 9 articles and 2 book chapters, which conducted an analysis, comparison or investigation between multiple meta-heuristic algorithms at the same time, and thus, it is difficult, complicated and inaccurate to specify a certain meta-heuristic category—are listed in Table 6 with their number of publication and references. Respectively, the covered algorithms are illustrated in Fig. 9 in a chart paradigm to facilitate the comparison between those algorithms.

Most of the selected meta-heuristic algorithms present the popular and frequently used ones those prevent their eligibility like the artificial bee colony (ABC), ant colony optimisation (ACO), particle swarm optimisation (PSO), simulated annealing (SA) and tabu search (TS) algorithms, and their performance and experimental results have proved the efficient and effective achievement. Particularly, the genetic algorithm (GA) comparing with all the mentioned algorithms has recorded the high publications, except the hybrid algorithms. The hybridisation technique has proved an outstanding performance since it utilises the leverage of combining population-based algorithms and single-based algorithms to reach the optimal solution. Recently, researchers tend to adopt this technique according to its adequacy, which is presented by the supreme record of publications, even higher than the genetic algorithm record.

Meta-heuristic algorithms performance varies from one problem to another. The algorithm may perform better than others in a certain problem and furthermore the worse in other set of problems; this is based on the nature of the used problem. Thus, generally the proper way to compare meta-heuristic algorithms is applied to a particular problem. Even though every algorithm indicates a set of features and preferences, it does not exclude some limitations. For instance, the evolutionary algorithms (EA) show some shortcomings such as: (1) The nature of evolutionary algorithms is stochastic which means there is no guarantee that two runs under the same conditions will find the same solutions, or the algorithm has really converged on the best candidate solution it could find. (2) The evaluation process

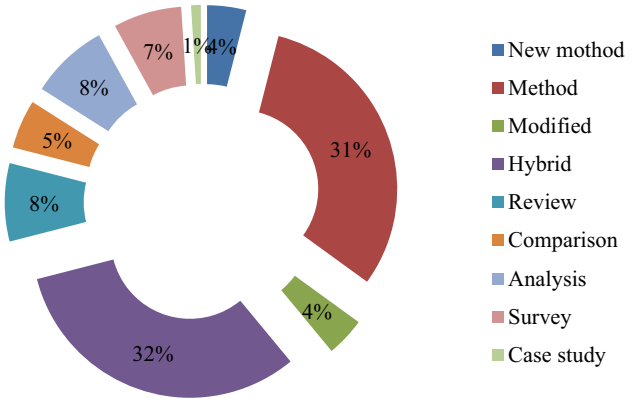

Fig. 7 Distribution of primary studies by type of publications

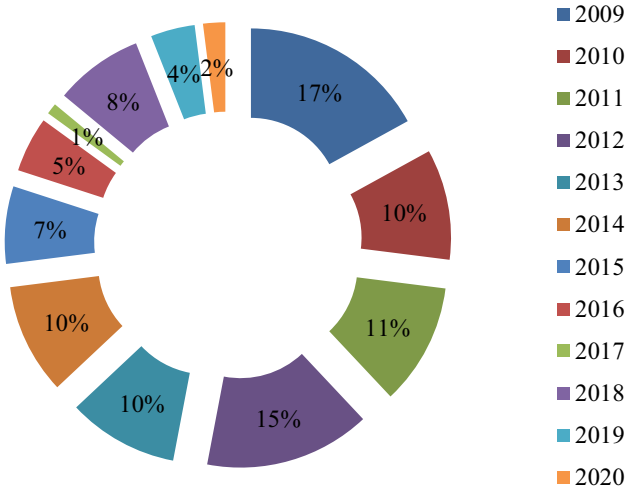

Fig. 8 Distribution of primary studies' publication type over the years

of the candidate solution is computationally expensive and may require a long time, so evolutionary algorithms might become impractical for some applications. One of the most popular meta-heuristic algorithms is the genetic algorithm (GA) which also has some limitations like: (1) the optimal solution is located by comparison with other solutions and there is no clear standard to define the stop criteria for every problem. (2) Genetic algorithm cannot effectively solve the single fitness measure problems, like the decision problems where the only fitness measure is a single right or wrong measure and there is no way to converge on the solution. (3) For some optimisation problems, genetic algorithm shows less efficiency in terms of speed of convergence; consequently other optimisation algorithms may be more competent and effective. Also, the artificial bee colony algorithm (ABC) (1) requires new fitness tests on new algorithm parameters, (2) demands a high number of objective function evaluation and (3) presents a slow performance in sequential processes. Likewise, in the ant colony optimisation algorithm (ACO), (1) the probability of distribution can change for each iteration, (2) the theoretical analysis process is complex and complicated, (3) it has more experimental researches rather than theoretical ones, and (4) it has uncertain time to convergence. As well in the particle swarm optimisation (PSO) algorithm: (1) the state of the initial parameters could be difficult, and (2) it can converge prematurely and trapped into a local minimum. In addition, in the simulated annealing algorithm (SA): (1) for problems where there are few local minima, simulated annealing is rigorous and (2) the algorithm cannot tell whether it has found an optimal solution or not.

The convergence of meta-heuristic algorithms is a complex concept with multiple viewpoints. "Convergence to what?" is a proper and basic question, and there are many types of convergence (to local optima, stability, in expectation, variance, to global optima, etc.) to begin with. If we take the short, quick and simple notion of this complicated concept, it would be there is no formal conception of meta-heuristic convergence. On the other hand, there are many different definitions for convergence that could be categorised into two main classes:

1. Convergence to a point (also known as stability analysis)

It has nothing to do with the quality of the solutions at the end of the run; it only talks about a sequence that will end up inside the search space rather than going to infinity.

The idea is: is there any guarantee that the sequence of the generated solutions by the algorithm converges to a single point?

2. Convergence to an optimum

It comes after a proof that the generated solution will converge to a local optimum (or global optimum) eventually.

The idea is: the generated solutions will be close to a local optimum when time goes to infinity.

The heuristic algorithm (genetic algorithms, ant algorithm, etc.) never guarantees its convergence to the best and unique solution (if any) nor the best solution. It only gives you one solution (probably a good one). For the genetic algorithm as an example, we can note that the time cost of iteration depends on the inner operations (crossovers, mutation, etc.), finding best solutions, generating random solutions, calculating cost of the population, etc. In general, they depend on the size of a solution. The execution time of a genetic algorithm also depends on the number of iterations. Typically, we want to stop when we converge to a solution that is hardly improved. About how to find the number of iterations that guarantees this, there are some probabilistic analyses to find the average

Table 6 Distribution of meta-heuristic algorithms

Meta-heuristic algorithm	Abbreviation	Number of publications	%	References
Artificial bee colony	ABC	6	4	[88, 94, 99, 100, 128, 130]
Ant colony optimisation	ACO	6	4	[73, 75, 108, 158, 167, 170]
Chicken swarm optimisation	CSO	1	1	[163]
Evolutionary algorithm	EA	2	2	[72, 126]
Fish swarm algorithm	FSA	1	1	[85]
Genetic algorithm	GA	23	17	[17, 56, 61, 63, 70, 74, 76, 77, 80, 91, 95, 112, 114, 115, 118, 119, 131, 140, 153, 155, 157, 164, 173]
Harmony search	HS	5	4	[78, 86, 105, 141, 142]
Honey bee mating algorithm	HBMA	2	2	[69, 106]
Intelligent water drops	IWD	1	1	[26]
Migrating birds optimisation algorithm	MBOA	1	1	[139]
Memetic algorithm	MA	4	3	[60, 81, 137, 143]
Particle swarm optimisation	PSO	3	2	[59, 125, 150]
Simulated annealing	SA	7	5	[65, 66, 109, 117, 152, 160, 166]
Scatter search	SS	2	2	[52, 87]
Tabu search	TS	3	2	[58, 79, 169]
Great deluge algorithm	GD	3	2	[55, 57, 147]
Gravitational emulation local search algorithm	GELS	1	1	[159]
Hill climbing search	HCS	1	1	[148]
Hybrid algorithms	//	41	31	[11, 18, 53, 62, 64, 67, 68, 71, 82–84, 89, 90, 92, 93, 96–98, 103, 104, 107, 110, 111, 116, 120, 122–124, 127, 129, 132, 135, 136, 138, 144, 146, 149, 161, 162, 171, 172]
Others	//	18	14	[19, 21–24, 54, 101, 102, 113, 121, 133, 134, 145, 151, 154, 156, 165, 168]
Total	//	131	100	

convergence time. But it could be noted that we did not reach yet the level of analysing the complex problems where genetic algorithms are used. Therefore, in many cases, the number of iterations in a genetic algorithm is decided experimentally.

Local search sometimes allows you to prove convergence depending on your problem. It's often by indirect proof using a potential function. Sometimes you're lucky with your problem and can use this technique to provide an approximation algorithm as oppose to something less specific that isn't guaranteed to terminate in polynomial time. Taking into account that we talk about algorithms with respective to a problem, it's a very bold statement to claim a certain kind of algorithm can never converge to an optimal solution, but that's aside the point.

In general, you cannot prove the convergence of a meta-heuristic independently of the problem at hand. The structural properties of some "easy" problems could allow you to do so. I don't know if you can be as lucky with the "difficult" problems, though. Meta-heuristics are based on systematic progression of random evolution, and it has no mathematical proof. Hence, its convergence cannot prove. However, it can be measure in terms of best, average and standard deviation. Such comparison can judge effectiveness of meta-heuristics.

Based on the findings of this review, the results showed that hybridisation technique is the current trend by applying a swarm intelligence algorithm with a single-solution-based technique for adaptation and enhancement to reach the optimal solution. Hybridisation techniques have been developed by combining two or more algorithms. This idea came to enhance or improve overall search efficiency. For this reason, most of the researchers often try to use the advantages of individual algorithms for the common good; this process is the intention in principle. In fact, whether a hybrid method can actually achieve better performance,

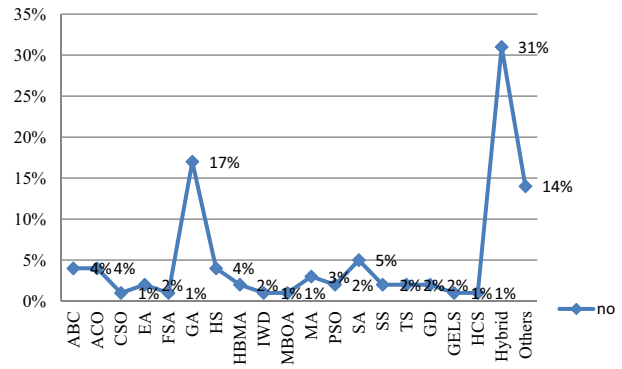

Fig. 9 Distribution of meta-heuristic algorithms

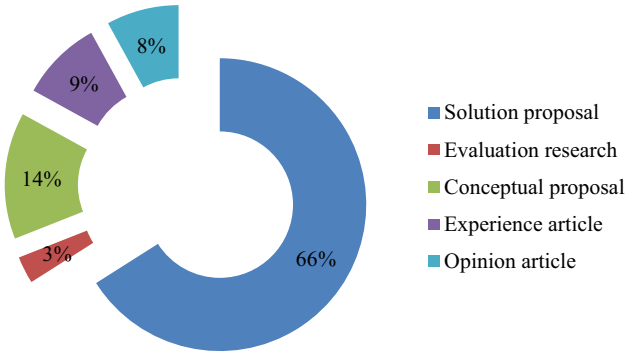

Fig. 10 Distribution of primary studies by research type

and outcome conducts to combine different algorithms to develop new algorithms is still an open problem.

RQ3 Which research types and diversity in the literature can be identified on using meta-heuristic algorithms for solving university timetabling problems?

The research-type classification aims to characterise the articles based on their degree of novelty, as well as to investigate and validate the articles. Based on the analysis of the selected primary studies, it categorised all research studies into five types as follows:

1. *Solution proposal*: This type of research solves a problem with a novel solution or significant expansion of an existing technique.
2. *Evaluation research*: This type of research investigates a solution that can be implemented practically. It examines the results using practical case studies or field studies.
3. *Conceptual proposal*: A conceptual proposal looks at existing things in a different way to solve a specific problem using techniques such as theoretical frameworks or taxonomies.
4. *Experience article*: This is a report of the author's personal experience of actual life projects. It describes what was performed in the real project and how it was done.
5. *Opinion article*: This type of research reports the author's personal opinions about a specific technique or tool and how it has been developed.

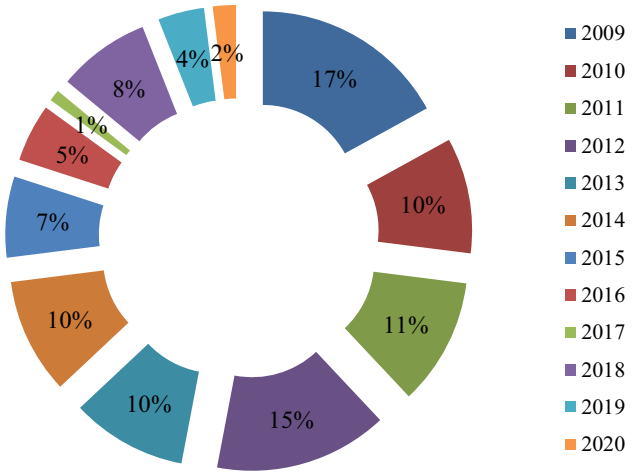

Fig. 11 Distribution of primary studies' research type over the years

Figure 10 reflects the distribution of the selected studies according to their research type, and Fig. 11 demonstrates the distribution by research type from 2009 to the first quarter of 2020.

According to our review on meta-heuristic algorithms for solving timetabling problems, the highest number of publications focused to develop a novel algorithm in existing field of meta-heuristic algorithms that can help to solve timetabling problems. Meanwhile, only a few studies performed investigation a solution that can be implemented practically such as conducting practical case studies or field studies point of view.

RQ4 What is the diversity of meta-heuristic publications in the field of university course timetabling problems versus university examination field?

As mentioned before, university time tabling problem is a comprehensive concept. In this review it is categorised into two substantial fields and significant educational timetabling problems: examination timetabling and course timetabling. Basically in the examination timetabling process, all the examinations must be assigned to timeslots and spaces (rooms) so that all the students can attend their required examinations [26]. On the other hand, course timetabling (also known as class/teacher timetabling) is a multi-dimensional assignment problem in which students and teachers are assigned to courses; consequently, those courses (lectures) must be assigned specific rooms (spaces) and timeslots [11].

Table 7 Distribution of university timetabling problem type

University timetabling problem's type	Number of publications	%	References
Examination timetabling problems	35	26	[23, 26, 52, 54, 57, 69, 77, 81, 86, 87, 90, 92, 94, 96, 100–102, 115, 116, 122, 124, 127, 128, 136, 137, 141, 143, 147, 148, 150, 152, 163, 164, 166, 172]
Course timetabling problems	71	54	[8, 18, 19, 21, 53, 55, 56, 58–62, 64–66, 71–76, 78–80, 82–85, 89, 91, 93, 95, 97–99, 103, 105, 107–111, 113, 114, 117, 118, 120, 121, 123, 126, 130–132, 134, 135, 138–140, 142, 145, 146, 149, 151, 154, 156, 158, 160–162, 170, 171]
University timetabling problems	25	20	[11, 17, 22, 24, 63, 67, 68, 70, 104, 106, 112, 119, 125, 129, 133, 144, 153, 155, 157, 159, 165, 167–169, 173]
Total	131	100	

The results in Table 7 showed that the selected primary studies were tabulated under two problem classes, namely course timetabling problems and examination timetabling problems. In addition, a third class named university problems was added to present the publications that handle the both mentioned problems at the same time. Thus, Table 7 shows and compares the number of publications in university timetabling problems against the publications of university course timetabling problems and university examination timetabling problems, with their references. Based on the literature review, the majority of publications focused their works to solve course timetabling problems.

Finally, the mapping study's results are presented in Figs. 12 and 13, whereby a bubble plot illustrates the mapping results of the usage of meta-heuristic algorithms in solving university timetabling problems in a more efficient and expressional way than tables.

The bubble plot in Fig. 12 has three facets (the number of articles proportional to a bubble size), and the results are presented by the bubble plot in two dimensions. The first dimension represents the meta-heuristic algorithms by publication type (RQ2), and the second dimension represents the meta-heuristic algorithms by research type (RQ3). In Fig. 13, the results are also presented by the bubble plot in two dimensions: the first dimension represents the meta-heuristic algorithms by publication year (RQ1), and the second dimension represents the meta-heuristic algorithms by university timetabling problem type (RQ4).

From Figs. 12 and 13, we can see that some meta-heuristic algorithms for solving timetabling problems appeared only one time that mean these algorithms recorded lowest number of publication in this area of research, such as intelligent water drops, migrating birds optimisation algorithm, chicken swarm optimisation, cuckoo search, gravitational emulation local search algorithm and hill climbing search. Some of these algorithms were introduced as recent meta-heuristic algorithms. In addition, only two publications appeared as a case study works. For recent publications in the field, we can see from the mentioned figures; in the first quarter 2020, the publication in this area appeared only three studies.

6 Discussion, future works and limitations

This section is categorised into three subsections: discussion, further future works and limitations. Each section presents the outcomes of this systematic mapping study and discussed as follows.

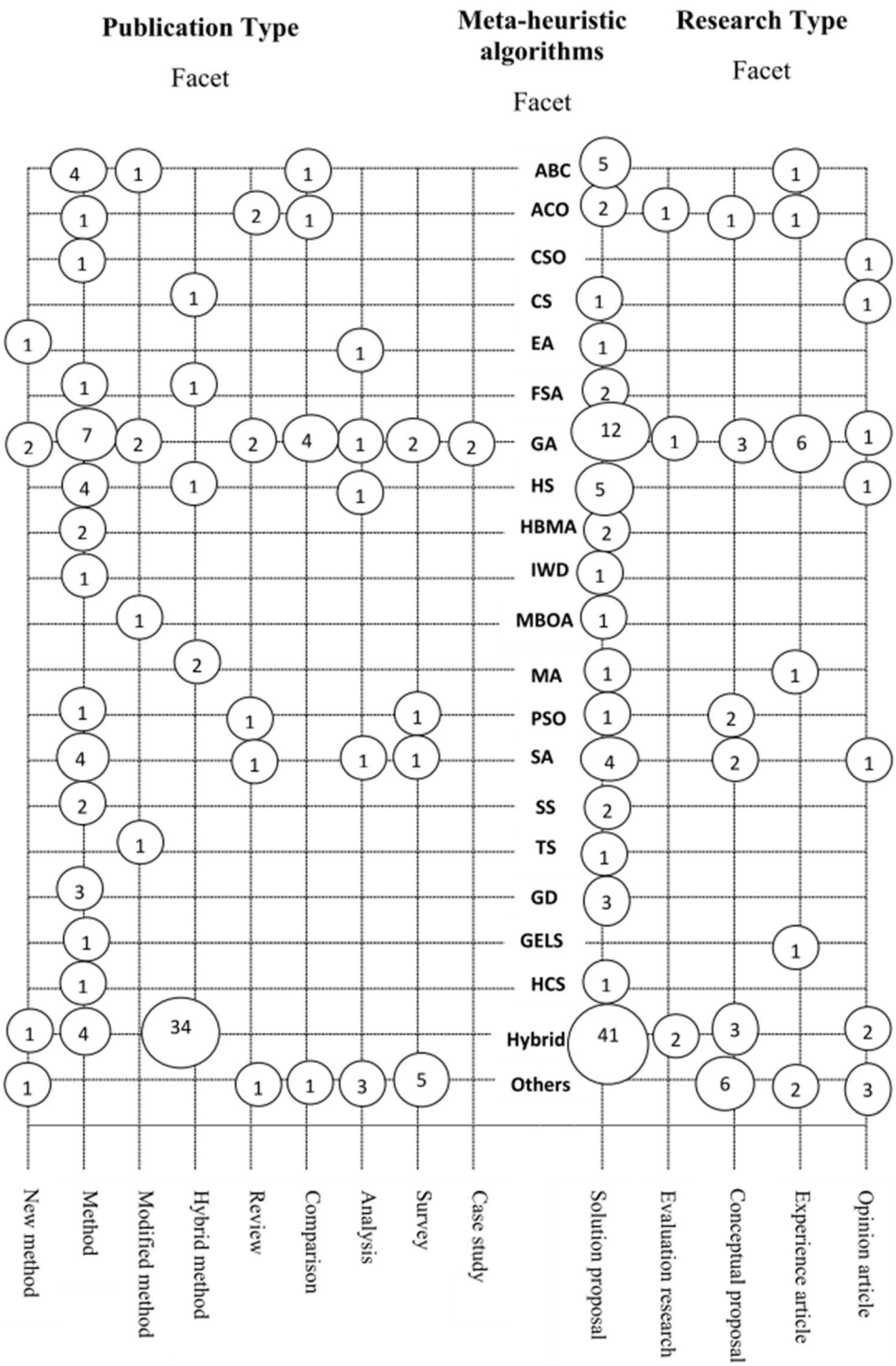

Fig. 12 Map of meta-heuristic algorithms in solving university timetabling problems by publication type and research type

6.1 Discussion

In this systematic mapping study, we provided an overview of the meta-heuristic algorithms in solving university timetabling and problems. Results from the selected primary studies have shown that meta-heuristic algorithms are an important issue and a major goal in solving university timetabling problems. This is due to the increasing demand for meta-heuristic algorithms and growing of the recent meta-heuristic algorithms.

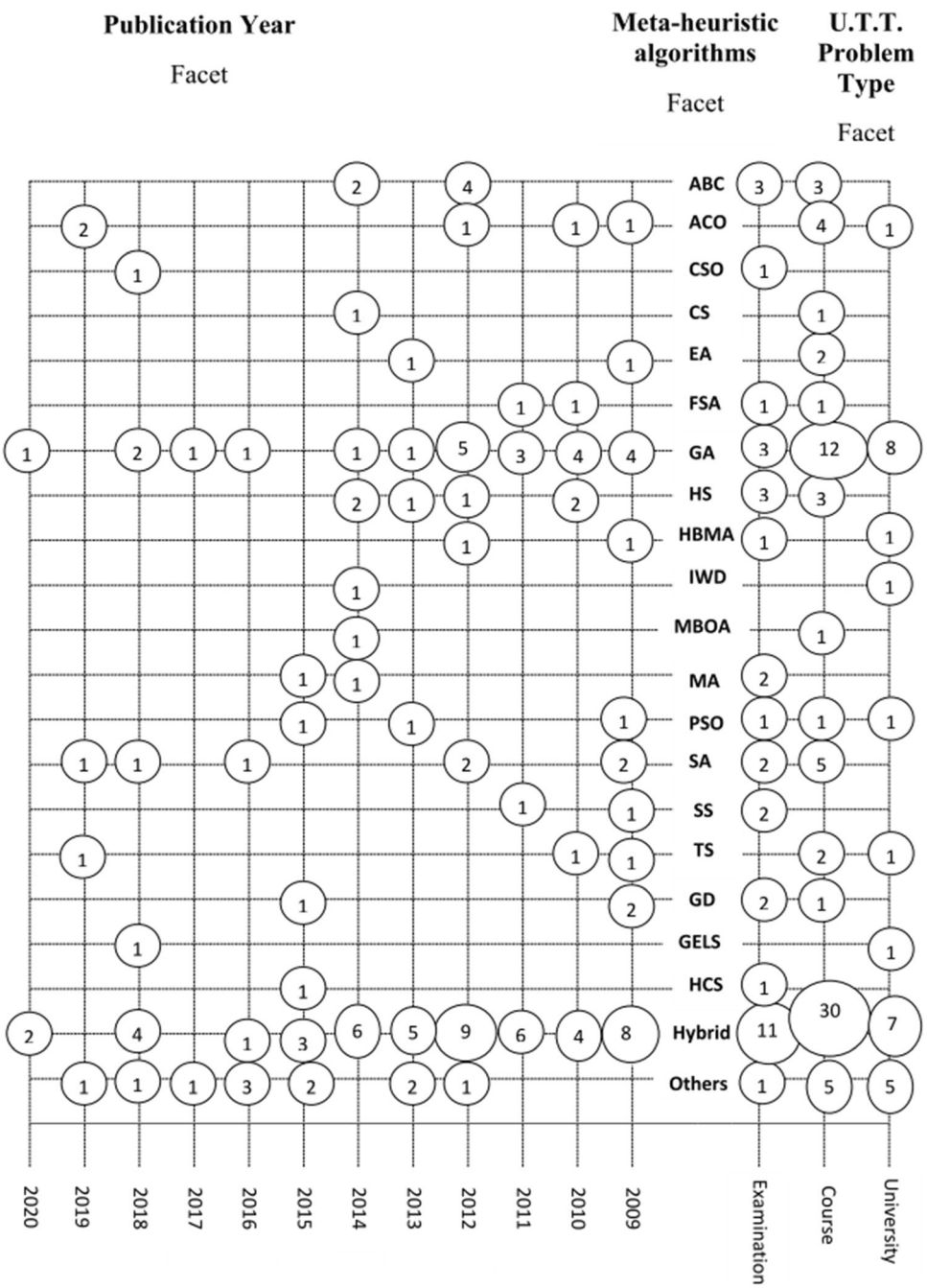

Fig. 13 Map of meta-heuristic algorithms in solving university timetabling problems by publication year and University Timetabling Problem types

The systematic mapping study in this paper covers different types of meta-heuristic such as new methods, methods, modified methods, hybrid methods, review, comparison, analysis, surveys and case study, including examination, course and university timetabling problems. Based on the former overview and the extracted statistical results comes the conclusion remarks phase, which take the mechanism of going through the stated research questions and attempt to detect convenient answers. The following notions were stated as comprehensive concepts:

- University timetabling is a time-consuming task that must be achieved every year for each semester frequently. Likewise, university timetabling has characterised as (NP) non-polynomial time hard as well as combinatorial optimisation problem, which intended to

find the feasible solution according to a given objective function while respecting a set of constraints.

- The concerned university timetabling problem has been categorised into two substantial fields: examination timetabling and course (or lecture) timetabling.
- Meta-heuristic is a method to solve optimisation problems by searching for the optimal solutions according to set of constraint and objectives, as well as proposing the candidate or alternative solutions to the stated problem. Meta-heuristic can be classified to two classes: single-solution-based approaches and population-based approaches.
- There is no timetable that tackles all the hard and soft constraints besides the stated objectives. In most timetables, only some of these constraints are handled and the rest are neglected. Therefore, a more general timetable is essential. In this case, the proposed timetable must be more general and satisfies all the hard constraints and minimises (or maximises) a given objective function that embeds the soft constraints.
- Generally, the published literature on university timetabling problems abounds nowadays more than in former times. Furthermore, the survey papers have specifically been stimulated, but they still need an extensive expansion. Likewise, the systematic mapping review papers need to be animated due to its role in providing a convenient framework as stable background to conduct researches, as well as to state the discovered gaps in order to propose future research areas.
- One of the objectives of conducting a systematic study is to investigate the publishing concentration in the field to present which topics need more concern and which has the most frequent publication, so it is demonstrate the lacks as a foundation to perform more researches, as well as standpoint of the commonly publish.
- The intensity of meta-heuristic publication in the field of university timetabling over the last decade based on the 131 selected primary studies is presented in Figs. 4 and Fig. 5. The distribution of the selected primary studies according to the publication year shows that over the years, the publication was oscillatory. The highest publication rate (22) was recorded in 2009 which represents 17% of the total publications; on the other hand, the lowest percentage was recorded in 2017 (2) publications reflecting (1%) participation. Figure 6 and Table 4 represent the diversity of publications according to the indicated sources. In addition, the results in Fig. 6 show that journals have the higher per cent of publications (59%) that come next the conferences with (34%) and the workshops recorded the lowest per cent (2%), whereas Table 4 shows the publication sources and displays the number of publications for each source.

On the same context, Table 5 presents the distribution of publications based on two components: the data source (publisher) and the type of publications. For each data source the number of publications was declared elaborated by types of publication, and the selected studies were classified under nine categories (new method, method, modified method, hybrid method, review, comparison, analysis, survey and case study) according to their quality. The result shows the most contributed publisher is Google Scholar by 33% of the entire publication; on the other aspect, the hybrid method type recorded the highest publication (16) on Google Scholar as well as over all the data sources.

- Meta-heuristic is an approach to find the optimal solution by exploring the search space (set of feasible solutions) for solving e optimisation problems, and generally it has proved superiority over sequential heuristics methods.
- The comparison between algorithms to mark the preferable one is an ambiguity notion, because different approaches take different objectives and that repeal the standard criteria for formal evaluation and testing before comparison. Recently, the hybridisation techniques have attracted the interest of researchers since it offers an effective and outstanding performance in solving optimisation problems by utilising the benefit of combining a population-based approach with a single-based approach.
- Figure 7 illustrates the previously mentioned nine publication types (new method, method, modified method, hybrid method, review, comparison, analysis, survey and case study); in this classification, the hybrid methods recorded the highest participation (32%), while the case study recorded the lowest (1%). This outcome clarifies the researchers' recent interest, since the hybridisation technique improves its efficiency and provides acceptable results. On the same context, Fig. 8 displays the distribution of publications over the last decade according to their type (new method, method, modified method, hybrid method, review, comparison, analysis, survey and case study).
- Likewise, the hybrid algorithms recorded the highest contribution (37%) compared with other meta-heuristic algorithms when the distribution was based on the type of the conducted meta-heuristic algorithms; Table 6 and Fig. 9 demonstrate the priority of hybridisation technique.
- The research-type classification which is presented in Fig. 10 categorises the publications under five classes (solution proposal, evaluation research, conceptual proposal, experience article and opinion article), and in this distribution the solution proposals recorded the

highest publication (66%) when the evaluation research recorded the lowest (3%). Similarly, Fig. 11 displays the distribution of publications over the years from 2009 to the first quarter of 2020 according to their research type; thus, the year (2009) recorded the highest publications (17%) where the lowest percentage (1%) was recorded in year (2017).

- In Table 7, the primary studies are divided into two classes: university course timetabling and university examination timetabling. The university course timetabling publication intense was predominated with rate (54%), against the university examination timetabling publication (26%).
- Meta-heuristic algorithms have been utilised to find optimum solutions for power generation and distribution in the different fields of science, technology, communications, agriculture, transportation manufacturing and production, engineering, etc. Generally, several industrial applications require scheduling jobs to be assigned on sequential or parallel processes in order to optimise the cost using meta-heuristic algorithms. The choosing or selecting appropriate meta-heuristic algorithms for optimisation purpose is not easy. It depends on the problem that will use the method to find the optimal solution. However, there are some problems that have a complexity which makes difficult to search for all possible solutions.
- The meta-heuristic algorithms for solving university timetabling problem can focus on high-quality solutions and running computational times. The computational times are different in each application and depend on the size of each instance. In real-world timetabling, time is not a critical issue and typically the timetables are generated several weeks or months before actual used. Therefore, most of the works done in the literature do not report computational time. Moreover, algorithms employed through diverse platforms make it impossible to compare the computational time based on the same problems. In fact, in timetabling problems most algorithms care about the capability to generate high-quality solutions rather than computational times. Thus, the running time is not a key constraint since timetabling is not conducted frequently enough to require methods to provide real-time solutions.

6.2 Future works

According to the previously deductions and extracted outlines, the following points represent some potential future topics and spotting the unsettled problems and open issues:

- Despite successful meta-heuristic algorithms in different areas of research, there is still a gap concerning the implementation of the optimisation algorithms as solution for university timetabling problems. Some meta-heuristic algorithms such as biogeography-based optimisation (BBO) [27], symbiotic organisms search (SOS) [28], grey wolf optimiser (GWO) [29], cat swarm optimisation algorithm (CSOA) [30], sine–cosine algorithm (SCA) [31], moth-flame optimisation (MFO) [32], whale optimisation algorithm (WOA) [33], monkey algorithm (MA) [34], bat algorithm (BA) [35], sheep flocks algorithm (SFA) [36], Elitist self-adaptive step-size search (ESASS) [37] and charged system search algorithm (CSS) [38] have never been used as solutions for the university timetabling problem. The researchers can examine more recent optimisation algorithms on the problem thereafter analyse and compare the conducted results between new or former algorithms to state the strength and shortcomings points for each one to build up a rich data references base for future studies as a guideline.
- Explore the novel meta-heuristic algorithms for solving university timetabling problems, and summarise the concluded privileges as well as the limitations for future utilisation.
- Based on the analysis, the hybridisation method of meta-heuristic algorithms can take advantages of their operators (global search with the local search) to enhance the balance between global and local exploitation in the search space. In addition, some of the meta-heuristic algorithms suffer from the problem of convergence speed which can be faced in solving real challenging applications. Therefore, hybridisation methods could be proposed with other approaches such as quantum computing and chaotic theory to enhance the performance of meta-heuristic algorithms. We hybridise more meta-heuristic algorithms and investigate the combination leverage, to confirm the efficiency and qualification of the hybridisation technique.
- The researchers should increase the studies and conduction on university examination problems to enhance the publications and contributions on this field.
- We enhance the publication of systematic reviews and surveys to provide a solid platform and reliable foundation for future studies.
- In our review, we did not find any study that considers some of the very recent meta-heuristic algorithms that proven successes in different applications. Furthermore, the majority of the studies utilised genetic algorithm and simulated annealing as standalone method. Therefore, we recommend researchers in future studies to identify different recent meta-heuristic algorithms were introduced in last few years.

- There is lack of real-life contribution in meta-heuristics applications, and also there is need to test and evaluate more real datasets. The listed references represent different fields of real-life meta-heuristic algorithms [39–44], and some approaches may stand out to enhance the field of university timetabling as example the adaptive dimensional search algorithm; for more contribution, check the following references as a kick-off [37, 38, 45–47].
- There are emerging techniques to handle university timetabling problems, for example the probability collectives tool which is an artificial intelligence tool for modelling and controlling distributed multiagent systems; the essential idea is reduce the complexity of the problem by decompose it into sub-problems; and for more review, check the following references [48–51].
- Development of adaptive, modified and multi-objective versions of meta-heuristic algorithms to enhance current available versions.
- Comparison of the performance of the recent mentioned and suggested meta-heuristics such algorithms.
- More applications can be done using meta-heuristic algorithms that introduced in recent years to solve other practical problems in computer science fields, different engineering fields (electrical, mechanical, chemical, civil, etc.) and other real-world applications.

6.3 Limitations

This systematic mapping study has been conducted to study and analyse the meta-heuristic algorithms for solving university timetabling problem. The study has some limitations such as:

- The findings may impact with multiple factors such as the researchers who conducted the study, the selection of database sources, the study search string developed, study selection bias and time constraints.
- This systematic study has disregarded the single-solution-based approaches, and it substantially has focused more and covered the population-based approaches and swarm intelligence algorithms. In addition, it focused more on the meta-heuristic algorithms than the heuristic one.
- To extend the body of knowledge, the future work should concentrate on these factors when conducting more systematic literature reviews and mapping study papers in order to enhance the publication's attribution and to provide a solid platform for future research.

7 Conclusion

A systematic mapping study of meta-heuristic algorithms for solving university timetabling problems is presented in this paper. University timetabling problem has been classified as NP-hard combinatorial optimisation problem; consequently, it is understandable why researchers have been concentrating on meta-heuristic algorithms for solving this kind of problems. This systematic mapping study investigated the efficiency and evaluated the qualification of meta-heuristic algorithms in solving university course and examination timetabling problems. In order to evaluate and explicate the collected relevant researches, the research questions methodology was adopted to provide rigorous and reliable results. The review process covered the last decade from 2009 to the first quarter of 2020; as a result, 131 publications were selected as primary studies to conduct and extract strict and accurate results. Conclusively, the hybridisation technique has proved quite competency and qualification in solving recent university timetabling problems. Furthermore, the year 2009 recorded the highest publication rate over the last decade, while 2017 recorded the lowest rate. In addition, most of the publications were conducted on university course timetabling field. The study also identified the most common meta-heuristic algorithms that are used for the university timetabling problems, the future research directions as well as the open issues for the recent meta-heuristic algorithms to solve other practical problems in different fields and other real-world applications.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

Appendix

See Table 8.

Table 8 Summary of primary studies classification

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[52]	1	Examination timetabling using scatter search hyper-heuristic	NR Sabar, M Ayob	2009	Conference proceedings	2nd Conference on Data Mining and Optimisation, 2009. DMO'09.	Method	Solution proposal
[53]	2	Hybridization Multi-Neighbourhood Particle Collision Algorithm and Great Deluge for solving course timetabling problems	A Abuhamdah, M Ayob	2009	Conference proceedings	2nd Conference on Data Mining and Optimisation, 2009. DMO'09	Hybrid	Solution proposal
[54]	3	A study of heuristic combinations for hyper-heuristic systems for the uncapacitated examination timetabling problem	N Pillay, W Banzhaf	2009	Journal article	European Journal of Operational Research	Review	Conceptual article
[55]	4	Evolutionary non-linear great deluge for university course timetabling	D Landa-Silva, JH Obit	2009	Conference proceedings	International Conference on Hybrid Artificial Intelligence Systems	Method	Solution proposal
[56]	5	A guided search genetic algorithm for the university course timetabling problem	S. J. Naseem, S. Yang	2009	Conference proceedings	Multidisciplinary International Conference on Scheduling: Theory and Applications (MISTA 2009) 10-12 August 2009, Dublin, Ireland	Method	Solution proposal
[57]	6	An extended great deluge approach to the examination timetabling problem	B McCollum, P McMullan, AJ Parkes	2009	Journal article	Proceedings of the 4th multidisciplinary international scheduling: Theory and applications 2009 (MISTA 2009)	Method	Solution proposal
[58]	7	The effect of neighbourhood structures on tabu search algorithm in solving course timetabling problem	CH Aladag, G Hocaoglu, MA Basaran	2009	Journal article	Expert systems with applications	Analysis	Opinion article
[59]	8	A study on PSO-based university course timetabling problem	SFH Irene, S Deris, MHS Zaiton	2009	Conference proceedings	International Conference on Advanced Computer Control, 2009. ICACC'09.	Review	Conceptual article
[60]	9	Incorporating tabu search into memetic approach for enrolment-based course timetabling problems	H Turabieh, S Abdullah	2009	Conference proceedings	2nd Conference on Data Mining and Optimisation, 2009. DMO'09.	Hybrid	Solution proposal
[61]	10	An investigation of a genetic algorithm and sequential local search approach for curriculum-based course timetabling problems	S Abdullah, H Turabieh, B McCollum	2009	Conference proceedings	Proc. Multidisciplinary International Conference on Scheduling: Theory and Applications (MISTA 2009), Dublin, Ireland	Review	Evaluation research
[62]	11	A hybrid harmony search for university course timetabling	MA Al-Betar, AT Khader	2009	Conference proceedings	Proceedings of the 4th multidisciplinary conference on scheduling: theory and applications (MISTA 2009), Dublin, Ireland	Hybrid	Solution proposal

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[63]	12	Self-fertilization based genetic algorithm for university timetabling problem	Z Wang, J Liu, X Yu	2009	Conference proceedings	Proceedings of the first ACM/SIGEVO Summit on Genetic and Evolutionary Computation	Method	Solution proposal
[64]	13	University course timetable planning using hybrid particle swarm optimisation	HSF Irene, S Deris, SZM Hashim	2009	Conference proceedings	Proceedings of the first ACM/SIGEVO Summit on Genetic and Evolutionary Computation	Hybrid	Solution proposal
[65]	14	A survey of simulated annealing methodology for university course timetabling	M Nandhini, S Kanmani	2009	Journal article	International Journal of Recent Trends in Engineering	Survey	Conceptual article
[66]	15	Solving the course scheduling problem using simulated annealing	E Aycan, T Ayav	2009	Conference proceedings	IEEE International Advance Computing Conference, 2009. IACC 2009.	Method	Solution proposal
[67]	16	A simulated annealing algorithm with a new neighbourhood structure for the timetabling problem	Y Liu, D Zhang, SCH Leung	2009	Conference proceedings	Proceedings of the first ACM/SIGEVO Summit on Genetic and Evolutionary Computation	Hybrid	Solution proposal
[68]	17	Incorporating of constraint-based reasoning into particle swarm optimisation for university timetabling problem	S Fen, I Ho	2009	Journal article	Computer Science Letters	Hybrid	Solution proposal
[69]	18	Solving examination timetabling problems using honey-bee mating optimisation (ETP-HBMO)	NR Sabar, M Ayob, G Kendall	2009	Conference proceedings	Proceedings of the Multidisciplinary International Conference on Scheduling: Theory and Applications (MISTA), Dublin, Ireland	Method	Solution proposal
[70]	19	On improvement of effectiveness in automatic university timetabling arrangement with applied genetic algorithm	Khonggamnerd, P., Innet, S.	2009	Conference proceedings	Fourth International Conference on Computer Sciences and Convergence Information Technology, 2009. ICCIT'09.	Method	Solution proposal
[71]	20	A combination of PSO and local search in university course timetabling problem	ISF Ho, D Safaai, MHS Zaiton	2009	Conference proceedings	International Conference on Computer Engineering and Technology, 2009. ICCET'09.	Hybrid	Solution proposal
[72]	21	University course scheduling using evolutionary algorithms	M Aldasht, M Alsaheb, S Adi	2009	Conference proceedings	Fourth International Multi-Conference on Computing in the Global Information Technology, 2009. ICCGI'09.	New method	Solution proposal
[73]	22	Experimental Design and Analysis on Parameter Investigation and Performance Comparison of Ant Algorithms for Course Timetabling Problem	T Lutuksin, A Chainual, P Pongcharoen	2009	Journal article	Naresuan University Engineering Journal	Comparison	Experience article

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[74]	23	[PDF]Fuzzy genetic heuristic for university course timetable problem	A Chaudhuri, K De	2010	Journal article	Int. J. Advance. Soft Comput. Appl	Modified	Solution proposal
[75]	24	Best–worst ant colony system parameter investigation by using experimental design and analysis for course timetabling problem	T Lutuksin, P Pongcharoen	2010	Conference proceedings	second international conference on Computer and Network Technology	Review	Evaluation research
[76]	25	Comparison of performance between different selection strategies on genetic algorithm with course timetabling problem	W Chinnasri, N Sureerattanan	2010	Conference proceedings	IEEE International Conference on Advanced Management Science (ICAMS), 2010	Comparison	Experience article
[77]	26	An informed genetic algorithm for the examination timetabling problem	N Pillay, W Banzhaf	2010	Journal article	Applied Soft Computing	Case study	Experience article
[78]	27	A harmony search with multi-pitch adjusting rate for the university course timetabling	MA Al-Betar, AT Khader, IY Liao	2010	Book chapter	Book's title: Recent advances in Harmony search algorithm	Analysis	Opinion article
[79]	28	Adaptive tabu search for course timetabling	Z Lü, JK Hao	2010	Journal article	European Journal of Operational Research	Modified	Solution proposal
[80]	29	An informed genetic algorithm for university course and student timetabling problems	S Suyanto	2010	Conference proceedings	Proceedings of the 10th international conference on Artificial intelligence and soft computing: Part II	Case study	Experience article
[81]	30	A tabu-based memetic approach for examination timetabling problems	S Abdullah, H Turabieh, B McCollum	2010	Conference proceedings	International Conference on Rough Sets and Knowledge Technology	Hybrid	Solution proposal
[82]	31	A hybrid algorithm for the university course timetabling problems	F. Makoto	2010	Journal article	Journal of Japan Society for Fuzzy Theory and Intelligent Informatics	Hybrid	Solution proposal
[83]	32	Hybrid genetic algorithms with great deluge for course timetabling	R Nabeel	2010	Journal article	International Journal of Computer Science and Network Security	Hybrid	Solution proposal
[84]	33	Using improved Memetic algorithm and local search to solve University Course Timetabling Problem (UCTTP)	M Joudaki, M Imani, N Mazhari	2010	Journal article	Doroud, Iran: Islamic Azad University	Hybrid	Solution proposal
[85]	34	Fish swarm intelligent algorithm for the course timetabling problem	H Turabieh, S Abdullah, B McCollum	2010	Conference proceedings	International Conference on Rough Sets and Knowledge Technology	Method	Solution proposal
[86]	35	A combination of metaheuristic components based on harmony search for the uncapacitated examination timetabling	MA Al-Betar, AT Khader	2010	Conference proceedings	the 8th Int. Conf. Practice and Theory of Automated Timetabling (PATAT 2010)	Method	Solution proposal

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[87]	36	Scatter search technique for exam timetabling	N Mansour, V Isahakian, I Ghalayini	2011	Journal article	Applied Intelligence	Method	Solution proposal
[88]	37	Artificial bee colony algorithm for curriculum-based course timetabling problem	AL Bolaji, AT Khader, MA Al-betar	2011	Conference proceedings	5th international conference on information technology (ICIT 2011)	Method	Solution proposal
[89]	38	Optimisation of university course scheduling problem with a hybrid artificial bee colony algorithm	A Oner, S Ozcan, D Dengi	2011	Conference proceedings	IEEE Congress on Evolutionary Computation (CEC), 2011	Hybrid	Solution proposal
[90]	39	Hybrid artificial bee colony search algorithm based on disruptive selection for examination timetabling problems	M Alzaqebah, S Abdullah	2011	Conference proceedings	International Conference on Combinatorial Optimisation and Applications	Hybrid	Solution proposal
[91]	40	Genetic algorithms with guided and local search strategies for university course timetabling	S Yang, SN Jat	2011	Journal article	IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)	Comparison	Experience article
[92]	41	An integrated hybrid approach to the examination timetabling problem	H Turabieh, S Abdullah	2011	Journal article	Omega	Method	Solution proposal
[17]	42	A survey of genetic algorithms for the university timetabling problem	M Hosny, S Fatima	2011	Journal article	International Proceedings of Computer Science and Information Technology	Survey	Conceptual article
[93]	43	A hybrid particle swarm optimisation for a university course scheduling problem with flexible preferences	DF Shiau	2011	Journal article	Expert systems with applications	Hybrid	Solution proposal
[94]	44	Artificial bee colony search algorithm for examination timetabling problems	M Alzaqebah, S Abdullah	2011	Journal article	International Journal of Physical Sciences	Method	Solution proposal
[95]	45	A novel genetic algorithm technique for solving university course timetabling problems	OMK Alsmadi, S Za'er, DI Abu-Al-Nadi	2011	Workshop proceedings	7th International Workshop on Systems, Signal Processing and their Applications (WOSSPA), 2011	New method	Solution proposal
[96]	46	A hybrid fish swarm optimisation algorithm for solving examination timetabling problems	H Turabieh, S Abdullah	2011	Conference proceedings	International Conference on Learning and Intelligent Optimisation	Hybrid	Solution proposal
[97]	47	A fuzzy genetic algorithm with local search for university course timetabling	MS Kohshori, MS Abadeh	2011	Conference proceedings	3rd International Conference on Data Mining and Intelligent Information Technology Applications (ICMiA), 2011	Hybrid	Solution proposal

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[98]	48	A hybrid genetic algorithm and tabu search approach for post enrolment course timetabling	SN Jat, S Yang	2011	Journal article	Journal of scheduling	Hybrid	Solution proposal
[99]	49	An improved artificial bee colony for course timetabling	AL Bolaji, AT Khader, MA Al-Betar	2011	Conference proceedings	Sixth International Conference on Bio-Inspired Computing: Theories and Applications (BIC-TA), 2011	Method	Solution proposal
[100]	50	Comparison on the selection strategies in the artificial bee colony algorithm for examination timetabling problems	M Alzaqebah, S Abdullah	2011	Journal article	Int J Soft ComputEng	Comparison	Experience article
[101]	51	Evolving hyper-heuristics for the uncapacitated examination timetabling problem	N Pillay	2012	Journal article	Journal of the Operational Research Society	Review	Evaluation research
[102]	52	A hyperheuristic approach to examination timetabling problems: benchmarks and a new problem from practice	P Demeester, B Bilgin, P De Causmaecker	2012	Journal article	Journal of scheduling	Analysis	Opinion article
[103]	53	Design and statistical analysis of a hybrid local search algorithm for course timetabling	R Bellio, L Di Gaspero, A Schaerf	2012	Journal article	Journal of scheduling	Analysis	Opinion article
[18]	54	A hybrid metaheuristic approach to the university course timetabling problem	Salwani Abdullah, Hamza Turabieh, Barry McCollum, Paul McMullan	2012	Journal article	Journal of Heuristics	Hybrid	Solution proposal
[104]	55	On the use of multi neighbourhood structures within a Tabu-based memetic approach to university timetabling problems	S Abdullah, H Turabieh	2012	Journal article	Information Sciences	Hybrid	Solution proposal
[105]	56	A harmony search algorithm for university course timetabling	MA Al-Betar, AT Khader	2012	Journal article	Annals of Operations Research	Method	Solution proposal
[106]	57	A honey-bee mating optimisation algorithm for educational timetabling problems	NR Sabar, M Ayob, G Kendall, R Qu	2012	Journal article	European Journal of Operational Research	Method	Solution proposal
[107]	58	University course timetabling using a hybrid harmony search metaheuristic algorithm	MA Al-Betar, AT Khader	2012	Journal article	IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)	Hybrid	Solution proposal
[108]	59	Solving the post enrolment course timetabling problem by ant colony optimisation	C.Nothegger, A Mayer, A Chwatal, GR Raidl	2012	Journal article	Annals of Operations Research	Method	Solution proposal

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[109]	60	Design, engineering, and experimental analysis of a simulated annealing approach to the post-enrolment course timetabling problem	S Ceschia, L Di Gaspero, A Schaerf	2012	Journal article	Computers & Operations Research	Review	Conceptual article
[110]	61	Hybrid genetic algorithms for university course timetabling	MS Kohshori, MS Abadeh	2012	Journal article	International Journal of Computer Science Issues (IJCSI)	Hybrid	Solution proposal
[111]	62	A hybrid algorithm of harmony search and bees algorithm for a university course timetabling problem	K Nguyen, P Nguyen, N Tran	2012	Journal article	International Journal of Computer Science Issues (IJCSI)	Hybrid	Solution proposal
[112]	63	University timetabling based on hard constraints using genetic algorithm	SR Sutar, RS Bichkar	2012	Journal article	International Journal of Computer Applications	Method	Solution proposal
[113]	64	A survey of approaches for University course timetabling problem	MR Feizi-Derakhshi, H Babaei	2012	Conference proceedings	Proceedings of 8th international symposium on intelligent and manufacturing systems, Sakarya University Department of Industrial Engineering, Adrasan, Antalya, Turkey	Survey	Conceptual article
[114]	65	[PDF]University course timetabling using a new hybrid genetic algorithm	AH Karami, M Hasanzadeh	2012	Journal article	Computer and Knowledge Engineering (ICCKE)	New method	Solution proposal
[115]	66	Comparing performance of genetic algorithm with varying crossover in solving examination timetabling problem	OI Obaid, MS Ahmad, SA Mostafa	2012	Journal article	J. Emerg. Trends Comput. Inf. Sci	Comparison	Experience article
[116]	67	Hybrid particle swarm optimisation transplanted into a hyper-heuristic structure for solving examination timetabling problem	MA Ahandani, MTV Baghmisheh, MAB Zadeh	2012	Journal article	Swarm and Evolutionary Computation	Hybrid	Solution proposal
[117]	68	A greedy gradient-simulated annealing hyper-heuristic for a curriculum-based course timetabling problem	M Kalender, A Kheiri, E Özcan	2012	Workshop proceedings	12th UK Workshop on Computational Intelligence (UKCI), 2012	Method	Solution proposal
[118]	69	Performance comparison of genetic algorithm's crossover operators on university course timetabling problem	W Chinnasri, S Krootjohn	2012	Conference proceedings	8th International Conference on Computing Technology and Information Management (ICCM), 2012	Comparison	Experience article

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[119]	70	Genetic algorithm approach to automate university timetable	K Kumar, RS Sikander, K Mehta	2012	Journal article	International Journal of Technical Research (IJTR)	method	Solution proposal
[120]	71	Solving University Course Timetabling Problems Using Constriction Particle Swarm Optimisation with Local Search	Ruey-Maw Chen and Hsiao-Fang Shih	2013	Journal article	Algorithms	Hybrid	Solution proposal
[121]	72	Solution approaches to the course timetabling problem	SA MirHassani and F Habibi	2013	Journal article	Artificial Intelligence Review	Analysis	Opinion article
[122]	73	A hybrid self-adaptive bees algorithm for examination timetabling problems	S Abdullah and M Alzaqebah	2013	Journal article	Applied Soft Computing	Hybrid	Solution proposal
[123]	74	Hybridizing meta-heuristic approaches for solving university course timetabling problems	K Shaker, S Abdullah, A Alqudsi, H Jalab	2013	Conference proceedings	International Conference on Rough Sets and Knowledge Technology	Hybrid	Solution proposal
[124]	75	Harmony search-based hyper-heuristic for examination timetabling	K Anwar, AT Khader, MA Al-Betar	2013	Conference proceedings	IEEE 9th International Colloquium on Signal Processing and its Applications (CSPA). 2013	Hybrid	Solution proposal
[125]	76	Particle swarm optimisation with transition probability for timetabling problems	H Kanoh and S Chen	2013	Conference proceedings	International Conference on Adaptive and Natural Computing Algorithms	Method	Solution proposal
[126]	77	Course timetabling using evolutionary operators	D Qaurooni and MR Akbarzadeh-T	2013	Journal article	Applied Soft Computing	Analysis	Opinion article
[127]	78	An adaptive artificial bee colony and late-acceptance hill-climbing algorithm for examination timetabling	M. Alzaqebah,S. Abdullah	2013	Journal article	Journal of scheduling	Hybrid	Solution proposal
[128]	79	An automated approach based on bee swarm in tackling university examination timetabling problem	FC Weng and H Bin Asmuni	2013	Journal article	Int J ElectrComputSci	Method	Solution proposal
[129]	80	Using simulated annealing and ant-colony optimisation algorithms to solve the scheduling problem	N Chmait and K Challita	2013	Journal article	Computer Science and Information Technology	Hybrid	Solution proposal
[130]	81	A Modified Artificial Bee Colony Algorithm for Post-enrolment Course Timetabling	AL Bolaji, AT Khader, MA Al-Betar	2013	Conference proceedings	International Conference in Swarm Intelligence	Modified	Solution proposal
[19]	82	Comparison of metaheuristic algorithms with a methodology of design for the evaluation of hard constraints over the course timetabling problem	ASA Jorge, C Martín, P Héctor	2013	Book chapter	Book's title: Recent Advances on Hybrid Intelligent Systems	Comparison	Experience article

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[131]	83	Design and implementation of course timetabling system based on genetic algorithm	HM Mousa, AB El-Sisi	2013	Conference proceedings	8th International Conference on Computer Engineering & Systems (ICCES), 2013	Analysis	Opinion article
[132]	84	Effective learning hyper-heuristics for the course timetabling problem	JA Soria-Alcaraz, G Ochoa, J Swan, M Carpio	2014	Journal article	European Journal of Operational Research	Hybrid	Evaluation research
[133]	85	A review of hyper-heuristics for educational timetabling	NelishiaPillay	2014	Journal article	Annals of Operations Research	Review	Conceptual article
[134]	86	Population based Local Search for University Course Timetabling Problems	AnmarAbuhamdah, MasriAyob, Graham Kendall and Nasser R. Sabar	2014	Journal article	Applied Intelligence	Method	Solution proposal
[135]	87	University course timetabling using hybridized artificial bee colony with hill climbing optimizer	AL Bolaji, AT Khader, MA Al-Betar	2014	Journal article	Journal of Computational Science	Hybrid	Solution proposal
[136]	88	Hybrid bee colony optimisation for examination timetabling problems	M. Alzaqebah, S. Abdullah	2014	Journal article	Computers & Operations Research	Hybrid	Solution proposal
[137]	89	Memetic techniques for examination timetabling	MA Al-Betar, AT Khader, IA Doush	2014	Journal article	Annals of Operations Research	Hybrid	Experience article
[138]	90	An adapted cuckoo optimisation algorithm and genetic algorithm approach to the university course timetabling problem	CK Teoh, A Wibowo, MS NGADIMAN	2014	Journal article	International Journal of Computational Intelligence and Applications	Hybrid	Solution proposal
[139]	91	A modified migrating bird optimisation for university course timetabling problem	LW Shen, H Asmuni, FC Weng	2014	Journal article	JurnalTeknologi	Modified	Solution proposal
[140]	92	Development of a university lecture timetable using modified genetic algorithms approach	AO Modupe, OE Olusayo, OS Olatunde	2014	Journal article	International Journal	Modified	Solution proposal
[26]	93	Intelligent Water Drops Algorithm For university examination Timetabling	BA Aldeeb, MA Al-Betar, MN Norita	2014	Conference proceedings	International Parallel Conferences on Researches in Industrial and Applied Sciences, Dubai, UAE	Method	Solution proposal
[141]	94	Optimisation of Examination Timetable Using Harmony Search Hyper-Heuristics (HSHH)	J Rankhambe and S Kavita	2014	Journal article	International Journal of Computer Science and Information Technologies	Method	Solution proposal
[142]	95	Harmony search algorithm for curriculum-based course timetabling problem	J Wahid and NM Hussin	2014	Journal article	arXiv preprint arXiv:1401.5156	Method	Solution proposal

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[11]	96	A new hybrid imperialist swarm-based optimisation algorithm for university timetabling problems	CW Fong, H Asmuni, B McCollum, P McMullan	2014	Journal article	Information Sciences	New method	Solution proposal
[143]	97	A memetic algorithm based on hyper-heuristics for examination timetabling problems	Y Lei, M Gong, L Jiao, Y Zuo	2015	Journal article	International Journal of Intelligent Computing and Cybernetics	Hybrid	Solution proposal
[144]	98	A hybrid swarm-based approach to university timetabling	CW Fong, H Asmuni, B McCollum	2015	Journal article	IEEE Transactions on Evolutionary Computation	Hybrid	Solution proposal
[145]	99	Analysing the effects of solution space connectivity with an effective metaheuristic for the course timetabling problem	R.Lewis and J.Thompson	2015	Journal article	European Journal of Operational Research	Analysis	Opinion article
[21]	100	A survey of approaches for University course timetabling problem	H Babaei, J Karimpour, A Hadidi	2015	Journal article	Computers & Industrial Engineering	Survey	Conceptual article
[146]	101	A hybrid algorithm for university course timetabling problem	B. Rakesh, D. Gupta	2015	Journal article	Innovative Systems Design and Engineering	Hybrid	Solution proposal
[147]	102	Solving examination timetabling problem using partial exam assignment with great deluge algorithm	AK Mandal and MNM Kahar	2015	Conference proceedings	International Conference on Computer, Communications, and Control Technology (I4CT), 2015	Method	Solution proposal
[148]	103	Solving examination timetabling problem using partial exam assignment with hill climbing search	AK Mandal, MNM Kahar	2015	Conference proceedings	IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE), 2015	Method	Solution proposal
[149]	104	A hybrid genetic algorithm with local search and tabu search approaches for solving the post enrolment based course timetabling problem: outperforming guided	S Jaengchuea and D Lohpetch	2015	Conference proceedings	7th International Conference on Information Technology and Electrical Engineering (ICITEE), 2015	Hybrid	Solution proposal
[150]	105	A survey of Particle Swarm Optimisation techniques for solving university Examination Timetabling Problem	SL Marie-Sainte	2015	Journal article	Artificial Intelligence Review	Survey	Conceptual article
[151]	106	Iterated local search using an add and delete hyper-heuristic for university course timetabling	JA Soria-Alcaraz, E Özcan, J Swan, G Kendall	2016	Journal article	Applied Soft Computing	Method	Solution proposal
[152]	107	Simulated annealing for the uncapacitated exam scheduling problem	M Cheraitia and S Haddadi	2016	Journal article	International Journal of Meta-heuristics	Method	Solution proposal
[23]	108	A metaheuristic for exam timetabling	T Arbaoui, JP Boufflet, A Moukrim	2016	Journal article	IFAC-PapersOnLine	Review	Conceptual article
[153]	109	A Utilization-based Genetic Algorithm for Solving the University Timetabling Problem (UGA)	EA Abdelhalim and GA El Khayat	2016	Journal article	Alexandria Engineering Journal	Method	Solution proposal

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[24]	110	Survey on University timetabling problem	J Pandey and AK Sharma	2016	Conference proceedings	3rd International Conference on Computing for Sustainable Global Development (INDIACom), 2016	Survey	Conceptual article
[22]	111	Review of state of the art for metaheuristic techniques in Academic Scheduling Problems	GHG Fonseca, HG Santos, EG Carrano	2016	Journal article	Artificial Intelligence Review	Survey	Conceptual article
[154]	112	Algorithms for university course scheduling problems	M Yazdani, B Naderi, E Zeinali	2017	Journal article	TehnickiVjesnik-Technical Gazette	New method	Experience article
[155]	113	A Recursive Genetic Algorithm-Based Approach for Educational Timetabling Problems	SSA Alves, SAF Oliveira, ARR Neto	2017	Book chapter	Book's title: Designing with Computational Intelligence	Review	Conceptual article
[156]	114	An iterated local search algorithm for the University Course Timetabling Problem	T Song, S Liu, X Tang, X Peng, M Chen	2018	Journal article	Applied Soft Computing	Method	Solution proposal
[157]	115	A Heuristics Approach for Classroom Scheduling Using Genetic Algorithm Technique	IR Ahmad, S Sufahani, M Ali	2018	Conference proceedings	Journal of Physics: Conference Series	Method	Solution proposal
[158]	116	Design of Rescheduling of Lecturing, using Genetics-Ant Colony Optimisation Algorithm	CF Palembang	2018	Conference proceedings	IOP Conference Series: Materials Science and Engineering	Method	Conceptual article
[159]	117	University-timetabling problem and its solution using GELS algorithm: a case study	MN Nategh and AAR Hosseinabadi	2018	Journal article	International Journal of Advanced Intelligence Paradigms	Method	Experience article
[160]	118	Simulated annealing with improved reheating and learning for the post enrolment course timetabling problem	SL Goh, G Kendall, NR Sabar	2018	Journal article	Journal of the Operational Research Society	Method	Solution proposal
[161]	119	Solving University Course Timetabling Problem Using Memetic Algorithms and Rule-based Approaches	MA Nugroho and G Hermawan	2018	Conference proceedings	IOP Conference Series: Materials Science and Engineering	Hybrid	Solution proposal
[162]	120	Hybrid Simulated Annealing with Meta-Heuristic Methods to Solve UCT Problem	I AlHadid, K Kaabneh, H Tarawneh	2018	Journal article	Modern Applied Science	Hybrid	Solution proposal
[163]	121	Enhancing The Performance of the Greedy Algorithm Using Chicken Swarm Optimisation: An Application to Exam Scheduling Problem	TM Mohamed	2018	Journal article	Egyptian Computer Science Journal	Method	Opinion article
[164]	122	Genetic Algorithm Method in Examination Timetabling Problem: A Survey	FA Adnan, S AbSaad, ZR Yahya	2018	Conference proceedings	Regional Conference on Science, Technology and Social Sciences (RCSTSS 2016)	Survey	Conceptual article

Table 8 continued

Ref. no	No	Title	Author (s)	Year	Type	Publication source	Publication type	Research type
[165]	123	Metaheuristic Approaches for Solving University Timetabling Problems: A Review and Case Studies from Middle Eastern Universities	M Hosny	2018	Conference proceedings	International Conference Europe Middle East & North Africa Information Systems and Technologies to Support Learning	Survey	Conceptual article
[166]	124	Implementation of Constraint Programming and Simulated Annealing for Examination Timetabling Problem	TL June, JH Obit, YB Leau, J Bolongkikit	2019	Book chapter	Book's title: Computational Science and Technology	Analysis	Opinion article
[167]	125	Ant Colony Optimisation: Overview and Recent Advances	M Dorigo, T Stützle	2019	Book chapter	Book's title: Handbook of meta-heuristics	Review	Conceptual article
[168]	126	A Classification of Hyper-Heuristic Approaches: Revisited	EK Burke, MR Hyde, G Kendall, G Ochoa	2019	Book chapter	Book's title: Handbook of Meta-heuristics	Analysis	Opinion article
[169]	127	Tabu Search	M Gendreau, JY Potvin	2019	Book chapter	Book's title: Handbook of Meta-heuristics	Review	Conceptual article
[170]	128	University course timetabling model using ant colony optimisation algorithm approach	M Mazlan, M Makhtar, A Khairi	2019	Journal article	Indonesian Journal of Electrical Engineering and Computer Science	Method	Solution proposal
[171]	129	Automated university lecture timetable using heuristic approach	AM Hambali, YA Olasupo, M Dalhatu	2020	Journal article	Nigerian Journal of Technology	Hybrid	Solution proposal
[172]	130	A New Optimisation on Harmony Search Algorithm for Exam Timetabling System	K Alomari, O Almarashdi, A Marashdh	2020	Journal article	Journal of Information & Knowledge Management	Hybrid	Solution proposal
[173]	131	A genetic algorithm approach for timetabling problem: The time group strategy	ABM Sultan	2020	Journal article	Journal of Information and Communication Technology	Method	Solution proposal

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