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Solving Educational Timetabling Problem Using Swarm Intelligence – A Systematic Literature Review

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Abstract Timetabling is commonly identified by many researchers as NP-complete problem. Such a complex problem is represented as an optimization challenge due to its difficulty in implementing and resource consumption. Many optimization approaches such as swarm intelligence have been implemented in an attempt to find an optimal timetable solution. Therefore, this paper presents a systematic literature review concerning the meta-heuristics approaches needed for solving the educational timetabling problem. The systematic review includes 143 papers with a protocol focused on finding primary studies addressing the techniques of swarm intelligence. The reported results showed that techniques such as Firefly algorithm have never been implemented in the area of educational timetabling. The systematic review method proved to be an efficient tool for finding all trends in the areas searched. Therefore, its recommend using it as a method for investigating scientific fields for future development.

***Index Terms*— Swarm Intelligence, Timetabling, Educational Timetabling, Metaheuristics, Systematic Literature Review.**

I. Introduction

OVER the last decade, educational timetabling problems (especially those relating to course timetabling) have warranted a considerable amount of researchers' interest. Such a complex problem requires a huge amount of effort and determination to solve. Providing an efficient solution to this problem requires changing the manual solutions to automated ones. Many artificial solutions have been conducted throughout the years, and the existing amount of literature in the field of scheduling and timetabling has contributed a great deal to this research branch. The issue of timetabling problems has gained quite a sensational interest which has resulted in the number of available solutions becoming inordinately large and difficult to generalize.

Scheduling generally and timetabling specifically are classified as a combinatorial optimization problem (NP-complete problem). This kind of classification is commonly solved through optimization techniques. Interest in such techniques has been ultimately recognized in the last decade; moreover, the revolution of meta-heuristics optimization techniques took the "lion's share" in this global recognition in both fields of operational researches and computer science.

Metaheuristic is a method to solve very general classes of problems. It usually 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. Metaheuristic methods connect objective functions or heuristics in an abstract form, and hopefully efficient way, neglecting details of an inside structure. If the relation between a solution candidate and its "fitness" are understandable or not too complex, it becomes easier to solve a problem deterministically.

Objective and motivation

This paper aims to conduct a systematic literature review on the area of meta-heuristic optimization techniques to solve timetabling problems. The review investigates and illustrates the limitations found in this area of research and proposes promising topics for future studies. Further, the main contribution includes an emphasized scientific investigation into the educational timetabling problem. Therefore, this paper reveals a detailed analysis on the types of instances used in the educational timetabling experiments. Moreover, it highlights the gap in the area of

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swarm intelligence utilization and empowerment to solve the timetabling problem.

Research Problem

Achieving optimality in timetabling is a heavily complicated task which can consume a great deal of time. Therefore, many probabilistic optimization algorithms have already been addressed in an attempt to solve the timetabling problem. The research in this field is still growing and more effort is demanded to come up with better solutions. Hence, this research is concerned with the following questions:

- RQ1: How to improve meta-heuristics to solve timetabling problems using real datasets?
- RQ2: How can real datasets contribute to provide better evaluation for meta-heuristics algorithms?
- RQ3: How can optimization-based approaches to solve timetable problems be classified and reviewed?

Related Work

Related review studies concerning the educational timetabling problem are discussed in this section, together with a description of the metaheuristics methods utilized to solve the timetable problem. In addition, the most discussed techniques in these studies are also highlighted.

The emergence of meta-heuristics techniques by which to achieve satisfying results in academic scheduling problems was the focus of the state-of-the-art review by Teoh [20]. The study explained that there is no precise superior technique to solve academic scheduling problems. Additionally, each technique has its own unique strength, although the study focused on two single-based optimization techniques, i.e.: tabu search and simulated annealing. The study explained that both techniques provide high quality solutions. On the other hand, the study also demonstrated the use of genetic algorithms and particle swarm optimization in enhancing the exploration of the search space but with more computation time. [20]

Computational approaches to solve timetabling problems differ in accordance with the instability and complexity of the problem. A survey given by Lewis [21] discussed university timetable problems and the applications of meta-heuristics particularly in regard to how hard and soft constraints vary from one particular problem to another. Furthermore, the study focused on timetabling instances such as Carter’s exam problems and the International Timetabling Competition ITC instance set. [21]

II. RESEARCH METHODOLOGY

A systematic literature review has been performed in order to conduct this study. In this part, we describe the design of the SLR and how it was used to attain the research objective.

A systematic literature review (SLR), or systematic review, it differs from traditional reviews in that SLR is a form of literature review that collects and looks at multiple studies. It is a way of extracting useful information from a large number of different studies and databases so as to contribute and provide answers to a precise research question related to the study field. The SLR will produce the following results: 1) provide a full background on the timetabling problem; 2) find any gaps in order to facilitate future improvements; 4) provide a critical discussion on timetabling instances and experiments.

SLR Research Questions

The following table (Table .1) shows the research questions for the SLR:

Table .1

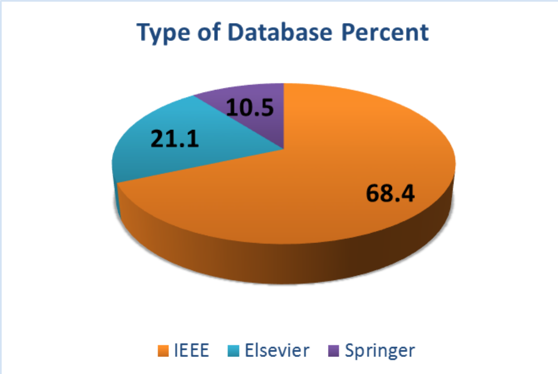
ID	Questions for the Systematic Review
RA1	Is the aim of the research sufficiently explained? What are the recent optimization based approaches to solve timetable problems and how can they be evaluated?
RA2	What are the current and future trends, directions and gaps to be full filled by researchers?
RA3	What types of common issues face researchers in the field of timetabling?

The following table (Table .2) describes the type of criteria used in the SLR:

Table .2

Criteria	Details
Types of studies	Experimental studies.
Field	Computer science, optimization, swarm intelligence (Ant Colony, ABC, PSO, Firefly Algorithm), scheduling, Educational timetabling.
Date of publication	2010- 2016 present.
Publication language	English
Database and journals	IEEE, Elsevier, Springer, Google Scholar

As a result to the data collection process, it was possible to collect a total of 143 papers. With the use of the SLR protocol, the papers were reviewed through their abstract and keywords. The number of papers was restricted and only 19 papers fell in the scope of the protocol, which is 13% out of the collected papers (see Table .1).



III. Background

Timetabling

What is timetabling?

Timetabling is a type of scheduling problem which based on allocating the number of events to a predetermined number of time periods. Abdullah [22] defined timetabling as follows:

"Timetabling problems are a specific type of scheduling problem and are mainly concerned with the assignment of events to timeslots subject to constraints with the resultant solution constituting a timetable."

There are certain terminologies concerning the timetabling problem that need to be explained and they are detailed in Table .3 below:

Table .3

Terminology	Definition
Timeslot	A period of time in which events are scheduled
Event	A scheduled action or an activity e.g. courses.
Constraint	A condition of measure or restriction for scheduling events, e.g. courses conflict or room capacity
Conflict	Collision of events clashing with each other for being scheduled at the same timeslot

Timetable constraints vary from one kind to another; usually they can be divided into two types, hard constraints and soft constraints. The type and number of constraints vary according to the timetabling problem itself. This kind of variation makes the timetabling problem difficult to solve easily. Hard constraints have a superior priority than soft constraints. Hard constraints cannot be violated; on the other hand, while soft constraints can be reconciled as much as possible, and the more of them that are satisfied the better. Therefore, a timetable is considered feasible if all of the hard constraints are satisfied [22].

3.2 General description of the problem

General timetabling problems are concerned with assigning a collection of events whether they are lectures of a course or examinations into a predetermined number of timeslots or rooms into a range of specified constraints.

Generally, there is a group of events E, and a set of timeslots T in addition to a set of constraints (hard and soft) C. The timetabling process is accomplished by assigning event E into the timeslot T, with minimum violation of the hard constraints in order to achieve a feasible timetable outcome.

Educational timetabling

In a survey by Schaerf [175], he classified educational timetabling into three types based on the type of institution (school or university) and the type of constraints, i.e., school timetabling, course timetabling and examination timetabling respectively. The classification is not quite strict, as Schaerf [175] explained that the problem can be broken down to two types only. In the next section, the researchers classify the educational timetable into two classes, course and examination timetabling. More details about educational timetabling can be obtained by both Schaerf [175] and Burke [24].

Meta-heuristic approaches

Meta-heuristics and precisely bio-inspired swarm intelligence algorithms are among the most researched topics in computer science and operational research studies in the last two decades. These algorithms are inspired by the natural behavior of biological systems. Inspired behavior organisms such as those existing in ants, bees, birds and fireflies have proved their worth in solving real-world complex optimization problems. Such complex problems as educational timetabling can be solved through the swarm intelligence approach. Additionally, the systematic review protocol focuses on four algorithms, namely: Particle swarm optimization (PSO); Ant colony optimization (ACO); Artificial bee colony (ABC); and Firefly algorithm (FA).

Timetabling Datasets and Instances

In this section, a specific and clear explanation is provided with reference to the common datasets used as benchmarking for problems in both course and examination timetabling.

Standard benchmark datasets

Course timetabling datasets

There are much datasets provided on the internet for the course timetabling problem. In this section, the Meta-heuristics Network benchmark [26], Carter [25] and International Timetabling Competition [27] are discussed. An analysis concerning the percentage of the most-used common datasets is provided in the SLR results section.

The Meta-heuristics Network benchmark (Socha)

The course timetabling problem in this benchmark is categorized into three types, i.e., small, medium and large. The problem consists of scheduling a number of 100 to 400 courses into a timetable with predetermined 45 timeslots (5 days x 9 hours). The dataset also provides a number of students and room features such as room capacity. Table .4 illustrates the values of the problem parameters.

Table .4

Category	Small	Medium	Large
Number of courses	100	400	400
Number of rooms	5	10	10
Number of features	5	5	10
Number of students	80	200	400
Maximum courses per students	20	20	20
Maximum students per courses	20	50	100
Approximate features pre room	3	3	5
Percentage of feature use	70	80	90

The International Timetabling Competition ITC

The first Competition of International Timetabling was held in 2002 [28]. As a result of its success, the timetabling research community continued with organizing new versions of the competition, the fifth of which was held in 2014. Information regarding the ITC-2002 problem instances and solution evaluation is available from the following webpage: http://www.idsia.ch/Files/ttcomp2002/.

The ITC instances gather all types of educational timetables i.e. course, examinations which apply to both universities and schools. The datasets are composed by inspiriting gained from real-world problems. For more information about the rules and evaluation of the ITC-2007, visit the webpage: http://www.cs.qub.ac.uk/itc2007. This is one of the most commonly-used instances (see SLR result section).

ITC divided the course timetabling problem into two types, Curriculum-based course timetabling and Post enrolment-based course timetabling. Both types vary in their constraints and features.

Results and Analysis

In this section the results of the systematic review and its investigation findings are discussed.

Selected Primary Studies

The following table (Table .5) provides a brief summary on the selected primary studies.

Table .5

Ref	No.	Study Focus
[2]	1	Proposes a novel method of solving the UCTP through various Hybrid Search Optimization algorithms combined with Particle Swarm Optimization (PSO) such as LBS & ATS.
[3]	2	Different hybrid state-of-the-art techniques and their use for university course timetabling problems are investigated in this study. There is also an analysis of the occurrence of constraints and their ratio of similarity in recent research trends on university course timetabling problems.
[4]	3	A study is conducted of the Room Slot Address (RSA) selection technique with three variations, namely, Random RSA selection, Earliest RSA selection and Semi-Random RSA selection techniques in class scheduling problems.
[5]	4	A novel genetic grouping approach using techniques obtained from study of an artificial bee colony is used to find a feasible solution for the university course timetabling problem.
[6]	5	The Bees algorithm is applied in an attempt to solve a highly constrained real-world university timetabling problem in Vietnam.
[7]	6	A memetic computing technique that is designed for university course timetabling problem is proposed and is called the hybrid harmony search algorithm (HHSA).
[8]	7	An assignment acceptance strategy in a Modified PSO Algorithm is proposed to elevate local optima in solving class scheduling problems.
[9]	8	A local search heuristic which handles event selection is suggested, namely, Event Selection based on Soft Constraint Violation (ESSCV). This is applied in a modified PSO algorithm to solve class scheduling problems.
[10]	9	The use of discrete particle swarm optimization (DPSO) is investigated for solving examination timetabling problems.
[11]	10	New variants of ant colony optimization called the best-worst ant system (BWAS) and the best-worst ant colony system (BWACS) are used for examination timetables.
[12]	11	A new variant of Ant Colony optimization called Best-Worst Ant Colony System (BWACS) is used to solve university course timetabling problems.
[13]	12	The ABC algorithm used for tackling Curriculum-Based Course Timetabling Problem (CBCTT) has been improved.
[14]	13	There has been a proposal for hybridization of the ant algorithm for automated school timetabling. These include: Really Full Look-ahead + Ant Colony Optimization (RFL+ACO); a constraint propagation-based timetabling algorithm; and Really Full Look-ahead Greedy (RFLG).
[15]	14	Application of an automated hybrid approach in addressing the university timetabling problem. The approach described is based on the nature-inspired artificial bee colony (ABC) algorithm.
[16]	15	By use of the ABC algorithm and the introduction of a disruptive selection strategy for onlooker bees, the diversity of the population and the premature convergence has been improved. Further, a local search (i.e. simulated annealing) is also introduced, in order to attain a balance between the exploration and exploitation processes.
[17]	16	A review was conducted on different hybrid state-of-the-art techniques and their use for university

		course timetabling problems. This paper also analyzes the occurrence of constraints and the ratio of similarity in recent research trends concerning university course timetabling problems.
[18]	17	There has been a modification to the ABC algorithm for post-enrolment course timetabling problems. The modification is embedded in the study of the behavior of the onlooker bee where the multi swap algorithm is used to replace its process.
[19]	18	A variant of the honey-bee mating optimization algorithm has been proposed for solving educational timetabling problems.
[1]	19	A combined discrete particle swarm algorithm and simulated annealing algorithm have been proposed to settle course timetabling problems.

Quality Assessment

In addition to the inclusion and exclusion criteria, the selected primary studies went through a description and a classification process. In this process, the SLR investigation goes deeper and the strength of the chosen studies is revealed to assess its quality. The assessment helps in gathering the findings and determining the gaps, moreover weighting the strength and importance of each study.

A selected number of questions were provided to be answered for each study during the data extraction process (see Table .6).

Table .6

ID	Quality assessment question	Yes	No
QA1	Is the aim of the research sufficiently explained?	100%	0
QA2	Is the presented idea clearly explained?	100%	0
QA3	Are the findings of the research clearly stated?	94.7%	5.3%
QA4	Is it clear which technique was used?	94.7%	5.3%
QA5	Is it clear how the technique was used?	89.5%	10.5%
QA6	Are threats to validity or limitation reported?	78.9%	21.1%
QA7	Do the publications use more than one dataset?	47.4%	52.6%
QA8	Do the publications use more than one evaluation measure?	52.6%	47.4%

In QA1, it was relatively easy to assess if each study distinctly clarified its aim and goal, and this question was answered positively for all reviewed studies. QA2 assessed whether the studies explained the proposed idea clearly. This question returned a full positive answer for the reviewed studies. With QA3, it was possible to determine if all studies transparently stated their respective results and finding. The result of this question was 94.7% for positive answers, while 5.3% answered negatively. QA4 asked if the technique used to overcome the problem of the study was clearly stated. A total of 94% answered positively, leaving the remaining 5% with a negative answer. QA5 enquired how the selected technique was used and implemented. A total of 89.5% of the studies gave a positive answer; while 10.5% replied with a “No”. QA6 enquired as to whether threats to validity and limitation were reported. A total of 78% answered with yes; while 21% answered with “No”. In QA7, the studies were assessed for using more than one timetabling dataset. The result was almost equal for both answers; showing 47% for positivity and 52% for negativity. In the final question QA8, the aim was to investigate the number of evaluation measures used in the studies. It was found that 52.6% used more than one measure and 47.4% used either one measure or none..

Discussion

In this section, the results of the systematic review are discussed. Moreover, future work directions have been drawn for further contribution and enhancement in the educational timetabling field.

A systematic review by Schepers [23] addressed practices in timetabling in higher education institutions. The review concluded that many research studies into the educational timetabling problem have been done and these have enhanced the solutions proposed to solve the problem. Additionally, the review analyzed state-of-the-art algorithms in the field that assist in providing an optimal solution; however, the review did not focus on hybridization of algorithms. Further, the need for timetabling benchmark instances was also included in the review discussion. The main contribution of the review was to lift the lid on the issues of variance and disharmony existing between theory and practice in higher education timetabling research. In addition, the review reported that the literature lacks real world implementation of the timetabling optimization solutions. Moreover, the review did not identify gaps existing in the field.

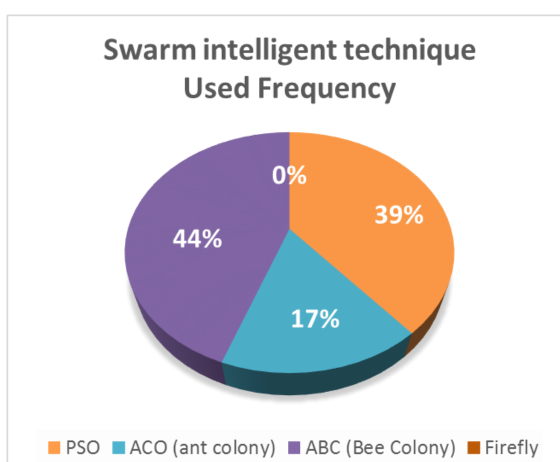


Figure .2

The use of hyper-heuristics in the field of educational timetabling was the concentration of another review study by Pillay [29]. The contribution of this review was to provide a general solution through hyper-heuristics to the educational timetable problem. Accordingly, the level of possible generality was discussed. Three levels of generality were reported i.e.: generalization over problem instances; generalization over problem-sets; and generalization over problem-type. Through these three levels, hyper-heuristics solutions can be generalized.

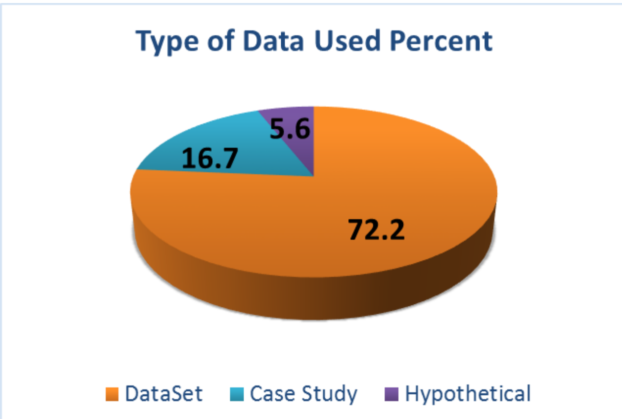


Figure .3

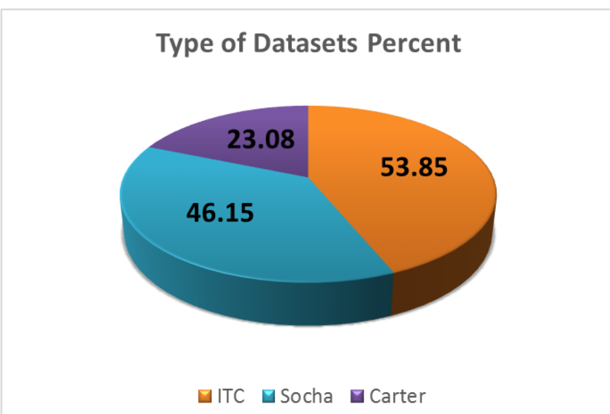


Figure .4

Both Schepers [23] and the researchers agreed upon conducting a systematic review in the same research field. Moreover, they agreed that there is a huge gap between theory and practice concerning the implementation of optimization solutions for the timetable problem. However, they disagreed on the following points:

This systematic review did consider the role of hybridized algorithms as one of the main approved solutions represented by many researchers for the timetable problem. That corresponds to the significance of the study by Pillay [29], where he reported that hyper-heuristics and any kind of hybridization between techniques does bring more outstanding results. In addition, Schepers [23] did not address any statistics on finding the gaps in the optimization utilization and he only considered it as a future work. Along the same lines, the researchers have investigated the research gaps existing in using swarm intelligence techniques for the timetable problem (see Figure .2). They observed that the firefly algorithm has never been used as a solution for the educational timetabling problem and its percentage in the conducted survey is (0%). Moreover, the researchers did notice that the ABC technique is the most frequently-used technique in this field with (44%) out of the full survey.

In relation to the above, the researchers surveyed the most-used type of data in the timetabling experiments (see Figure .3). It was found that datasets are the most-used type with a result of (72%). Additionally, the types of datasets were also statistically observed (see Figure .4) and it was found that the ITC timetabling instances are the most frequently-used dataset with a percentage of (53.8%) out of the full survey.

Conclusion

In this paper, the researchers discussed the educational timetabling problem and the role of metaheuristics to solve it. From the review, it was possible to gather all information relevant to the problem and thereby understand the timetabling problem from its roots and initiate a structure to connect all terminologies related to the problem. Subsequently, all techniques, strategies and available trends were taken into account. Based on this, we can significantly highlight the important gaps found in the review results in order to provide future work and enhancement to the timetabling problem in real world situations.

In summary, this paper aimed to conduct a systematic review on the meta-heuristic optimization techniques utilized to solve the timetabling problem. The researchers theorized the results in such a way that it is hoped that it can provide an entrance for new advancement and innovation in the future.

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