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A NONLINEAR HEURISTIC MODIFIER FOR CONSTRUCTING EXAMINATION TIMETABLE

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ABSTRACT

This research focuses on solving an examination timetabling problem by constructing solution using nonlinear heuristic modifier of Graph Coloring Heuristics. Two graph coloring heuristics i.e. largest degree and saturation degree were used within the nonlinear heuristic modifier to generate difficulty value of each examination, where it was modified nonlinearly whenever an examination cannot be scheduled in the previous iteration. Next, new ordering of examinations was obtained based on the new difficulty values and each examination was scheduled until a complete timetable is obtained. The nonlinear heuristic modifier is proposed to set a difficulty value of an examination within a nonlinear range, so that an effective estimation of examination's difficulty could be obtained. The Toronto benchmark datasets were used in the experiment where the aim is to obtain an examination schedule with minimum penalty value. It is found that the proposed method is comparable with other approaches, hence gives better examination ordering.

Keywords: *Examination Timetabling Problem; Nonlinear Heuristic Modifier; Graph Coloring Heuristics; Toronto Benchmark Datasets*

1 INTRODUCTION

Examination timetabling is one of difficult and important activity which usually appears in universities. The problem involves the process of assigning a set of examinations into a given time horizon. The objective is to produce a good timetable which has no confliction and could satisfy some set of preferences. Since different institutions require different set of preferences, thus it is impossible to model a standard examination timetabling problem that can be used by all institutions.

In solving this problem, there are two phases of solution search which are constructive and improvement phase [1]. Constructive phase involved in building the solution incrementally from empty until a complete solution is generated. Several types of approaches categorized under constructive methodology are graph coloring heuristics [2, 3], fuzzy-based heuristics [4], decomposition [5, 6] and heuristic modifier [7, 8]. Meanwhile, the improvement phase starts from complete solution(s) generated in the constructive phase, and the objective function is improved in the hope that a better solution is obtained. Local search-based methodologies such as tabu search [9, 10], simulated annealing [11] and variable neighbourhood search [12] used a single solution to be improved. Meanwhile, the population-based search methodologies such as genetic algorithm [13], memetic algorithm [14], bees algorithm [15], swarm-based optimization algorithm [16] and harmony search algorithm [17] are approaches which are categorized under improvement methodology. These population-based approaches are used to improve a set of solution qualities in the improvement phase.

It is known that the solution construction in the constructive phase is very important before proceeding to the improvement phase as it would affect the solution search. Therefore, this study focuses on constructive phase where a nonlinear heuristic modifier of graph coloring heuristics is proposed in constructing a good quality of examination timetabling.

The proposed nonlinear heuristic modifier in this study is based on some previous studies related with the heuristic modifier. As proposed in the previous studies [7, 18, 8], a heuristic modifier is performed as a penalty modifier which is called difficulty.

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Heuristic modifier as a penalty modifier is employed whenever an examination is unable to be arranged in the previous iteration due to conflicting with other examinations. This is done by increasing the penalty of the unarranged examination. While the examination assignment is made, the priority is given to the examination with the higher penalty to be arranged first in the next iteration [7].

In most studies related with heuristic modifier, the increment of the penalty value of a problematic examination is performed linearly. Nevertheless, sometimes the increment of the penalty with heuristic modifier does not showing the exact difficulty of the examination assignment [1, 8]. This happened whenever the examination timetable that has been constructed by using heuristic modifier still presenting infeasibility or bad solution construction. In this case, it shows that incorrect assignment can possibly be made and affects the searching for a good solution quality of an examination timetable.

Thus, this study proposed a nonlinear heuristic modifier as to resolve the problem related with bad solution construction when ordering the examinations by using the heuristic modifier. The ordering using nonlinear heuristic modifier can give benefit especially by decreasing some difficulty values of certain examinations for giving a better examination ordering. This study also explores the variations of nonlinear in calculating the difficulty value in order to see the improvement of solution search when compared with a linear increment of the difficulty value of an examination. This nonlinear heuristic modifier is combined with graph coloring heuristics to construct the examination timetable. It is hoped that when the difficulty of an examination is varied within a nonlinear arrangement, the proposed approach can give a good estimation of the difficulty of an examination so that a good examination timetable could be obtained.

This study begins with introducing a nonlinear heuristic modifier as a new approach to calculate the difficulty value of an examination instead of using a linear increment as proposed by previous studies. Two graph coloring heuristics which are (1) largest degree and (2) saturation degree are combined within nonlinear heuristic modifier in constructing solution for examination timetabling problem. Three variations of nonlinear methodology are presented in calculating the difficulty values and comparison with some previous studies is also obtained in order to see the performance of the proposed method. This study proposed a good estimation of examination orderings when the difficulty of an examination is estimated by using a nonlinear arrangement and good examination timetable is produced.

Section 2 provides a review on the heuristic modifier and nonlinear heuristic modifier approaches. Section 3 describes the nonlinear heuristic modifier and its implementation. Next, the discussion of the result and comparison with previous studies are presented in Section 4. Finally, Section 5 gives the conclusion of the study.

2 LITERATURE REVIEW

2.1 Examination timetabling problem

Carter and Laporte [28] defined the examination timetabling problem as:

"The assigning of examinations to a limited number of available time periods in such a way that there are no conflicts or clashes"

The aim of the examination timetabling problem is to assign examinations into time slots without having conflict among examinations and at the same time fulfilling some other preferences. There are many techniques in solving examination timetabling problems. These techniques can be classified into two which are constructive and improvement heuristic techniques.

The constructive heuristic technique is the process of building an initial solution from scratch and repeatedly extend the solution until a complete solution is constructed [29]. Examples of techniques classified under constructive heuristic are graph-based heuristic [18, 26, 30] and fuzzy-based heuristics [4, 32], decomposition [5, 6] and heuristic modifier [7, 8].

On the other hand, improvement heuristic technique started from complete solutions that have been made randomly or by using constructive heuristic. Then by using another method such as meta-heuristic or hyper-heuristic, one would try to get a better solution by improving the objective function. Improvement heuristic can be found using a continuous process such as a step-by-step process until it reached the best solution or until runtime is expired [33, 34, 35, 36] Local-search based [11, 37, 38] and population-based search [13, 39] are considered as improvement heuristic technique. This paper concentrates on timetabling construction using graph-based heuristics.

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2.2 Graph-based Heuristics

Carter et al. [28] focused on a graph coloring approach by comparing five Algorithmic Rules. The five types of Algorithmic Rules are Largest Degree (LD), Saturation Degree (SD), Largest Weighted Degree (LWD), Largest Enrolment (LE) and Random Ordering (RO). Carter et al. (1996) found that LD strategy produces a better solution most of the time when compared with other algorithmic rules. However, SD provides a better sequence ordering of the examination compared to LD on all measures: solves quality, backtracking and CPU time.

Abdul-Rahman et al. [18] investigated the use of adaptive strategies for examination timetabling problems within constructive approach using graph coloring heuristic. In the process of assigning examination to time slot, they combined a stochastic component with graph coloring heuristic and produce a comparable solution compared with others constructive approaches. The difficulty value was identified by increasing the difficulty in certain ways. Thus, a good approximate solution could be obtained. This research found that the saturation degree produced most of the best results as compared to the largest degree heuristic.

Hussin, Basari, Shibghatullah, Asmai, and Othman [30] used graph coloring approach in order to guarantee that all exams are scheduled and students can sit all exams that they required. After producing the examination timetabling, distribution of students among the rooms was conducted using selection heuristic which is equivalent to the knapsack filling problem.

On the other hand, Burke, Pham, Qu, and Yellen [26] introduced the heuristic combination with a linear approach. Weightage were given to the heuristic combinations so that each simple heuristic can contribute to the process of ordering vertices. Therefore, new best results have been obtained as compared to other constructive methods that has been applied to this benchmark dataset. A study by Rahim, Nor, Bargiela and Qu [31] introduced a new optimization method for the examinations scheduling problem. In this method, permutations of slots and assignments of exams were conducted upon the feasible schedules obtained by the standard graph coloring methods with largest degree ordering.

2.3 Heuristic Modifier Within Examination Timetabling

Heuristic modifier within examination timetabling was introduced by Burke and Newall [7]. This parameter was used to in express the priority of difficulty of certain examinations based on the concept of Squeaky Wheel Optimization [19]. The difficulty of an examination is shown by the increment of the heuristic modifier and it is determined at each iteration whenever that examination cannot be assigned to any time-slot due to conflicting with other examinations. The higher the value of the heuristic modifier means that the examination cannot be assigned to any of time-slots many times in the earlier iterations. Since the examination is difficult to be scheduled then it is supposed be given priority to be assigned first in the next iteration.

Studies in Abdul-Rahman et al. [18] and Abdul-Rahman et al. [8] employed the concept of heuristic modifier with some adjustments. Abdul-Rahman et al. [18] extended the study on heuristic modifier of Burke and Newall [7] by presenting more schemes in selecting an examination to be assigned to a time-slot. Graph coloring heuristics which are largest degree and saturation degree were combined with heuristic modifiers to solve examination timetabling on a benchmark problem. The approach is able to construct good solution quality and comparable to other previous constructive approaches

An investigation on linear combinations of heuristic modifier with graph coloring heuristics for solving two benchmarks datasets of examination timetabling was done by Abdul-Rahman et al. [8]. For simplifying the exact problem data, each of the graph coloring heuristic parameter was invoked through a normalization strategy. The two graph coloring heuristics of largest degree and saturation degree were used to estimate the difficulty of an examination when combining with heuristic modifier. Therefore, in determining the arrangement of the examinations, a concept of difficulty score was employed by combining information from heuristic modifier and graph coloring heuristic(s) with some parameter settings for each variable. The study found that by combining information from a number of graph coloring heuristics together with a heuristic modifier, huge advantages could be obtained especially in pertaining good solution quality.

2.4 Nonlinear Approach within Timetabling

The nonlinear approach was introduced in a number of researches related with timetabling field. In a study by Landa-Silva and Obit [20], a nonlinear decay rate was proposed to solve course timetabling problems. The standard great deluge algorithm [21] was modified by introducing a nonlinear decay rate to change the solution acceptance nonlinearly based on the current solution improvement. The experimental results illustrated that the nonlinear great deluge is better than the previous results reported in the literature.

An extension of the study on the nonlinear great deluge algorithm also was reported in Landa-Silva and Obit [22] with a hybridization of evolutionary algorithm in solving the problem related to university course timetabling. In another study, Obit and Landa-Silva [23] obtained a computational research of the nonlinear great deluge algorithm applied on two benchmark datasets of university course timetabling. The study showed promising solutions for both problems.

A hybridization of reinforcement learning method with nonlinear great deluge hyper heuristic was presented in Obit et al. [24] in solving a problem related to university course timetabling. The strategy was to choose low-level heuristics and the acceptance criteria was determined by the nonlinear great deluge. The proposed approach is capable to obtain a new best solution when compared to other solutions reported in the literature.

3 PROPOSED ALGORITHM

Heuristic modifier is performed as a penalty modifier to calculate the difficulty of an examination that cannot be arranged in the previous iteration. Based on a previous study [18], the heuristic modifier sometimes does not reflect the actual difficulty of an examination because even though the value is increased but still infeasible assignments are occurred. Due to the reason, this research embarks on modifying the heuristic modifier by introducing a nonlinear strategy in order to assign new difficulty value for an examination in constructing an examination timetable. The calculation of the difficulty of examination i at iteration t, *difficultyi(t)* using heuristic modifier was adopted from Burke and Newall [7] and is presented in Equation (1). The *heuristic(t)* is a heuristic value of examination i at iteration t based on the chosen graph coloring heuristic, while the $HMi(t)$ for examination i at iteration t is a heuristic modifier value. At each iteration, the $HMi(t)$ is increased by an adjust function whenever examination i cannot be assigned to any time-slot. In this study, each time an examination cannot be assigned to any time-slot then the modifier is increased by one in every iteration.

$$difficulty_i(t) = heuristic_i(t) + HM_i(t) \qquad (1)$$

where,

$$HM_i(t+1) = \begin{cases} modify(HM_i(t)), & \text{if examination } i \text{ cannot be assigned to any time-slot} \\ HM_i(t), & \text{otherwise} \end{cases}$$

This study introduced a nonlinear heuristic modifier, $HM_{NLi}(t)$ where the penalty is given to examination i at iteration t and the value is modified nonlinearly. Equation (2) presents the calculation of $difficulty_i(t)$ by using nonlinear heuristic modifier.

$$difficulty_{ei}(t) = heuristic_{ei}(t) + HM_{NLei}(t) \qquad (2)$$

In this study, the nonlinear heuristic modifier is integrated with two graph colouring heuristics which are known as largest degree and saturation degree. These two heuristics are used for measuring the difficulty of an examination when combined with the nonlinear heuristic modifier. These two heuristics were used in this study for comparison purposes.

Besides, this study employed the concept of nonlinear introduced by Obit *et al.* [24] to calculate the difficulty of an examination in a nonlinear fashion. The nonlinear heuristic modifier approach proposed in this paper is formulated as in Equation (3).

$$HM_{NLi}=HM_i \times (exp^{\,\delta(rnd[min,max])}) \qquad (3)$$

Where,
$HMNLi$ = a modified nonlinear heuristic modifier value of examination i
$HMei$ = a heuristic modifier value of examination i
δ = nonlinear parameter
min = minimum value of heuristic modifier of examination i
max = maximum value of heuristic modifier of examination i

1) The effectiveness of the proposed approach of nonlinear was tested using three pairs of minimum and maximum values. The three pairs of minimum and maximum are: *Nonlinear1*: the minimum is a current negative value of heuristic modifier of an examination *i* and the maximum value is a current positive value of heuristic modifier of an examination *i*.
2) *Nonlinear2:* a minimum value is equal to zero '0' and maximum value is the current value of the heuristic modifier.
3) *Nonlinear3*: the minimum is the minimum value of the heuristic modifier of all exams and the maximum is the maximum value of the heuristic modifier of all exams.

Besides, the proposed approach is also tested with three difference delta values which are 0, 0.01 and 0.1. Comparison is obtained in order to choose the most suitable delta value to calculate the difficulty value of the nonlinear approach. Preliminary test shows that delta value of 0.1 performed the best when compared with other delta values. Algorithm 1 shows the pseudo-code of the proposed nonlinear heuristic modifier approach.

Algorithm 1 Construction of examination timetable based on the nonlinear heuristic modifier

```
Choose a graph coloring heuristic and do the initial ordering
Identify minimum, min and maximum, max value of the HM based on the chosen test
for t = 1 to maximum number of iterations, n
      order examinations based on difficulty
   for i= 1 to number of examinations i
      assign examination i to a timeslot
      if examination i cannot be arranged
            calculate the difficulty of examination i using HM_NL approach
            if Nonlinear1 ; min = -max, where max is the current value of a heuristic modifier of an examination i
            else if Nonlinear2 ; min = 0, max = current value of the heuristic modifier for examination i
            else if Nonlinear3 ; min = minimum value of heuristic modifier of all examination i, max = maximum value of the heuristic modifier of all examination i
            end if
      end if
   end for
   Evaluate solution, keep the solution if it is the best found so far
end for
```

Figure 1 illustrates the implementations of the nonlinear heuristic modifier in constructing examination timetable. Assume that there are five examinations which are e_1, e_2, e_3, e_4 and e_5 that need to be arranged in one set of timeslots. Figure 1(a) shows the number of examinations in clash of each examination. Then, the examinations are ordered based on the number of clashes (as shown in Figure 1(b)) and examination with the highest number of clashes is arranged first.

Initially, the first iteration follows the ordering of graph coloring heuristic. Assume that this assignment is performed for 50 iterations. At each iteration, if an examination cannot be assigned to any of timeslot then the heuristic modifier of that examination is increased by one. At iteration ten, assume that examination e_3 and e_5 cannot be arranged to timeslots for a number of times in the previous iterations. Say, e_3 cannot be arranged for five times and e_5 cannot be arranged for three times.

Thus, the formula of the nonlinear heuristic modifier is employed to calculate the new difficulty value of examination e_3. Assume that nonlinear1 with delta value 0.1 is used as for examples to calculate the new difficulty value of an examination. Therefore, the calculation of the new difficulty values for both e_3 and e_5 by using nonlinear heuristic modifier is shown below. The values -5 and 5 are the minimum and the maximum used in the calculation

$e_1 = 5$	$e_2 = 3$	$e_3 = 2$	$e_4 = 4$	$e_5 = 4$

(a)

Highest number of clashes will be arranged first

e_1	e_4	e_5	e_2	e_3

(b)

Figure 1: (a) Number of clashes for each of the examination, (b) Examinations ordering based on the largest degree graph coloring heuristic

$$HM_{NLe3} = 5 \times (\exp^{0.1(-5,5)}) = 6.75 \quad (4)$$

By using Equation 2, the new difficulty value of examination 3 is *difficultye3* = 8.75 where *heuristicei(t)*=2 and HM_{NLe3}=6.75.

After obtaining the new difficulty values of all examinations, the examinations are ordered decreasingly and are assigned to timeslot incrementally until a new complete solution is constructed, as illustrated in Figure 2. In this example, e3 is arranged first in the next iteration since it has the highest value of difficulty followed

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by other examinations with higher difficulty values. This procedure is repeated until it reached the final iteration.

e_3	e_5	e_1	e_4	e_2

(a)

8.75	7.66	5	4	3

(b)

Figure 2: (a) New arrangement of examinations based on the new difficulty value using nonlinear heuristic modifier (b) Difficulty value of each examination.

4 EXPERIMENTS

The proposed approach is experimented on an examination timetabling benchmark problem, using Visual Studio C++ 2008 on an Acer laptop Intel® Core ™ i7-4510U 2.0GHz with 8.00GB memory. The maximum number of iterations is set as fifty and the lowest penalty value is chosen as the best result. The Toronto benchmark dataset was presented by Carter *et al.* [25] and is used to experiment the proposed approach. The benchmark comprises of thirteen real world examination timetabling problem from several universities around the world. The objective of the Toronto benchmark problem is to produce a feasible timetable with no student has two examinations session at the same time and the spreading of conflicting students is maximized. Table 1 presents the characteristic of the Toronto benchmark problem.

Table 1: Characteristic of the Toronto Benchmark Problem

Problem	No. of Examinations	No. of Time slots	No. of Students	Conflict density
Car91	543	32	18 419	0.14
Car92	682	35	16 925	0.13
Ears83	190	24	1 125	0.27
Hec92	81	18	2 823	0.42
Kfu93	461	20	5 349	0.06
Lse91	381	18	2 726	0.06
Pur93	2 419	42	30 032	0.03
Rye93	486	23	11 483	0.08
Sta83	139	13	611	0.14
Uta92	622	35	21 266	0.18
Ute92	184	10	2 750	0.13
Tre92	261	23	4 360	0.08
Yor83	181	21	941	0.29

4.1 Parameter setup

A suitable parameter was set in calculating the difficulty value in the NLHM approach. Two graphs coloring heuristics which are largest degree (LD) and saturation degree (SD) are used to test three different values of minimum, min and maximum, max of nonlinear algorithm. The result of each set of minimum and maximum values tested with two graph coloring heuristics and $\delta=0.1$ is presented in Table 2 (refer to Appendix I). From the result, it presents that the best results are mostly gained from nonlinear 1 with six best results out of the thirteen problems. On the other hand, the nonlinear2 obtained five best results, while nonlinear3 obtained only two best results. The nonlinear3 does not perform well in constructing the solution and this is may be due to constructing too large range between the minimum and maximum value, thus higher penalty value is produced. Therefore, it is important for this study to identify the best configuration of nonlinear type in order to gain a suitable examination orderings. In terms of the types of graph coloring heuristic that have been used, the results show that the performance of both heuristics is about similar. The LD obtained six best results while the SD obtained seven best results out of the thirteen problems.

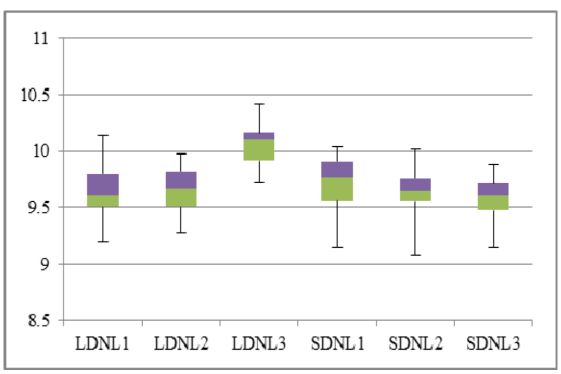
4.2 Result

Table 2 (refer to Appendix I) shows the results of three different nonlinear heuristic modifier approach with delta $\delta=0.1$ tested with two graph coloring heuristics. From the table it shows that saturation degree heuristic produced seven out of thirteen better results compared to largest degree heuristic for the Toronto datasets. Since that saturation degree is a dynamic graph coloring heuristic and this is may be the reason why it performed better than the largest degree heuristic. It has a high possibility to be a better solution as compared to other graph coloring heuristics generally

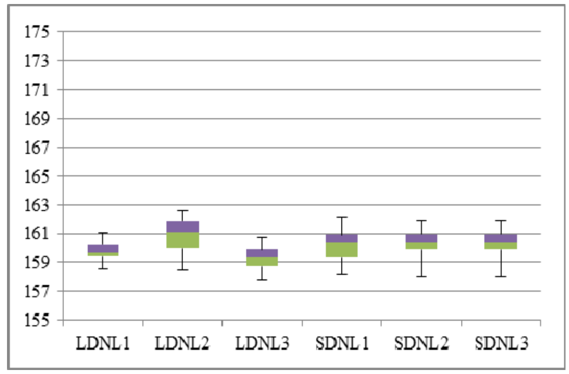
When using the given delta value, the result of the larger degree heuristic also shows competitive results when compared with saturation degree heuristic. This may be due to the chosen delta value that is suitable to be used with largest degree heuristic. In table 2 (refer to Appendix I), its shows that six of the thirteen results are from nonlinear1 five results are from nonlinear2 and two are from nonlinear3. The nonlinear3 does not produce a good result in calculating the penalty of the timetable because of the big range between the minimum and maximum value, thus higher penalty value is produced. Therefore, it is important for this study to identify the best configuration for the type of nonlinear approach.

Comparing the result from table 2 (refer to Appendix I) can be concluded that, most of the best results are obtained when tested the nonlinear approach with δ=0.1. This is may due to the increment and decrement of the difficulty value of examinations give, affect to the ordering of examinations. Thus, a good solution can be obtained from the proposed approach.

Figure 3 shows the boxplots of penalty value that has been gathered for Trent 92 and StAndrews83 with delta value of 0.1 tested with largest degree and saturation degree graph coloring heuristics. As shown in the figure (a), the nonlinear approach tested with saturation degree heuristic is better than the largest degree heuristic for Trent92, where nonlinear 3 shows good performance. On the other hand, the largest degree heuristic performed better than the saturation degree heuristic for the StAndrews83 as shown in figure (b). Among the nonlinear approaches of largest degree heuristic tested on StAndrews83, the nonlinear 3 performed the best. Note that both problems have some large differences in terms of problem size and conflict density. It can be concluded in this study that the problem size and the complexity of the tested problem plays important role in deciding which graph coloring heuristics and nonlinear approach should be used.



(a)



(b)

Figure 3: Result pattern of (a) Trent92 and (b) StAndrews83 by using Nonlinear Heuristic Modifier with delta (δ=0.1) tested with largest degree and saturation degree graph coloring heuristics (LDNL1=largest degree nonlinear1, LDNL2=largest degree nonlinear2, LDNL13=largest degree nonlinear3, SDNL1=saturation degree nonlinear1, SDNL2=saturation degree nonlinear2, SDNL3=saturation degree nonlinear3).

4.3 Comparison with other approaches

Table 3 (refer to Appendix II) presents the comparison of the results of our proposed approach with other constructive approaches with and without heuristic modifier that have been reported in the examination timetabling literature. The best result of each data is presented in bold font. The comparison was made between seven others studies related with constructive approaches which are Carter *et al.* [25], Burke and Newall [7], Asmuni, Burke, Garibaldi, McCollum, and Parkes [4], Burke, Pham, Qu, and Yellen [26], Pais, and Burke [27], Abdul-Rahman et al. [18] and Abdul-Rahman et al. [8]. Only the studies by Burke and Newall [7], Abdul-Rahman et al. [18] and Abdul-Rahman et al. [8] employed heuristic modifier and graph coloring.

As shown in the Table 3, it reveals that the result of NLHM does not obtained any best results when compared with other results from other constructive approaches.

As can be seen, no best result is obtained from the proposed approach. Nevertheless, some of the results of our proposed approach are closed to the best results presented in Table 3, such as StAndrews83 and Purdue93. However, it can be seen that NLHM approach generates a better performance in eight out of thirteen, compared with previous approach proposed by Pais and Burke [27] for Earlhaig83, Edhec92, KingFahd93, Lse91, Ryerson92, StAndrews83, TorontoE92 and Yorkmill83.

Table 4 (refer to Appendix III) shows the comparison between NLHM with other heuristic modifier approaches tested on Toronto benchmark dataset. From the comparison, it shows that the result of NLHM approach tested on Toronto benchmark datasets is comparable when compared with other results from previous research with and without heuristic modifier. The result of NLHM is better than Burke and Newall [7] for three out of the thirteen problems, which are Edhec92, StAndrews83 and TorontoE92. Note that Burke and Newall [7] is the first study to employ the concept of heuristic modifier within examination timetabling problem. Moreover, the result of NLHM also is better than Abdul-Rahman et al. [18] for Edhec92 and StAndrews83 and better than Abdul-Rahman et al. [8] for TorontoAS92. However, Burke and Newall [7] does not provide the solutions for Purdue93 and Ryerson92, while Abdul-Rahman et al. [18] does not provide the solutions for Purdue93.

Based on the comparison with other constructive approaches shown in Table 5 (refer to Appendix IV). Carter *et al.* [25] used graph coloring in solving the problem, Asmuni *et al.* [4] and Pais, and Burke [27] combined fuzzy and heuristic in solving the problem, while Burke *et al.* [26] used liner combination graph coloring in solving the same problem. In terms of comparison with other approaches without heuristic modifier, the results of NLHM are also comparable with other constructive approaches and mostly better than other constructive approaches. It can be seen in Table 5 that StAndrews83 is best solution when compared with other approaches, while Edhec92. KingFahd93 and TorontoE92 are the second best approach out of all constructive approaches presented in Table 3. It is found that the existence of randomness in the proposed nonlinear function has affected the examination ordering by extremely change the difficulty of some examinations. Hence, this might affect the search for a better solution.

5 CONCLUSION

This paper introduces an enhanced method of heuristic modifier that incorporates nonlinear function in calculating the difficulty value of an examination for constructing examination timetable. The aim is to produce a clash free timetable with no students sitting two different examinations at one time and at the same time maximizing the spreading of students in the timetable. The nonlinear heuristic modifier aims to increase the difficulty value nonlinearly whenever an examination cannot be arranged into timetable. This study proposed three different strategies to change the difficulty values nonlinearly tested with two different graph coloring heuristics which are largest degree and saturation degree.

Testing on different types of nonlinear calculation i.e. nonlinear1, nonlinear2 and nonlinear3 found that different set of result combining with several values of delta (0.1, 0.01 and 0) were obtained. It is found that the best results were obtained when the nonlinear approach was tested with delta 0.1. From overall observation, nonlinear1 is better than the other types of nonlinear for both types of graph coloring heuristics i.e. LD and SD. Moreover, SD produces better solution compared to LD for most of the instances for all types of nonlinear approach. However, the proposed method does not perform well when compared with other best solutions proposed in the literature. This is because, in introducing the randomness in calculating the nonlinear heuristic modifier makes the chosen value varied too much and thus, produce not a good examination ordering that can minimize the penalty value. Nevertheless, in comparing with other constructive approaches, the proposed approach produced competitive results compared with several other approaches proposed by Asmuni et al. [4], Burke et al. [26], and Pais and Burke [27] when tested on Toronto benchmark dataset.

Based on comparison with other approaches in the literature, the proposed approach is comparable with other heuristic modifier approaches and some are closed to the best results. The solutions obtained from this study also can be improved by using other improvement methods such as hyper heuristic or metaheuristic.

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APPENDIX I:

Table 2: Computation results of Nonlinear Heuristic Modifier with delta (δ=0.1) for Toronto benchmark datasets (LD=largest degree, SD=saturation degree, NL1= nonlinear1, NL2= nonlinear2, NL3= nonlinear3).

Problem	LD			SD		
	NL1	NL2	NL3	NL1	NL2	NL3
Carleton91	5.56	5.43	**5.33**	5.37	5.43	5.46
Carleton92	4.79	4.64	4.80	**4.56**	4.66	4.66
Earlhaig83	**39.53**	39.96	41.49	40.60	40.42	40.61
Edhec92	12.00	**11.60**	12.18	12.08	12.23	12.18
KingFahd93	**15.31**	15.71	17.16	15.51	15.75	15.33
Lse91	12.17	12.13	13.25	11.97	**11.78**	12.36
Purdue93	6.16	6.57	6.13	**5.94**	6.20	6.13
Ryerson92	10.60	10.18	11.96	**9.89**	10.10	9.90
StAndrews83	**157.66**	158.28	159.87	158.17	158.01	158.31
TorontoAS92	3.93	3.77	3.80	3.76	**3.70**	3.72
TorontoE92	27.56	**27.12**	27.21	27.35	27.15	27.25
Trent92	9.19	9.28	9.72	9.14	**9.08**	9.15
Yorkmills83	41.93	43.65	43.67	41.84	42.35	**41.33**

APPENDIX II:

Table 3: Comparison of NLHM with other constructive approaches tested on Toronto benchmark datasets.

Data	NLHM	[25]	[7]	[4]	[26]	[27]	[18]	[8]
Carleton91	5.33	7.10	**4.97**	5.29	5.03	5.18	5.08	5.08
Carleton92	4.56	6.20	4.32	4.54	**4.22**	4.44	4.38	4.34
Earlhaig83	39.53	36.40	36.16	37.02	**36.06**	39.55	38.44	38.28
Edhec92	11.60	**10.80**	11.61	11.78	11.71	12.20	11.61	11.13
KingFahd93	15.31	**14.00**	15.02	15.80	16.02	15.46	14.67	14.42
Lse91	11.78	**10.50**	10.96	12.09	11.15	11.83	11.69	11.43
Purdue93	5.94	**3.90**	-	-	-	4.93	-	5.74
Ryerson92	9.89	**7.30**	-	10.38	9.42	10.04	9.49	9.37
StAndrews83	157.66	161.50	161.9	160.4	158.86	160.50	157.72	**157.34**
TorontoAS92	3.70	3.50	**3.36**	3.57	3.37	3.49	3.55	3.73
TorontoE92	27.12	**25.80**	27.41	28.07	27.99	29.44	26.63	26.24
Trent92	9.07	9.60	8.38	8.67	**8.37**	8.71	8.78	8.73
Yorkmills83	41.33	41.70	40.77	39.8	**39.53**	42.19	40.45	40.38

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APPENDIX III:

Table 4: Comparison of NLHM with other heuristic modifier approaches tested on Toronto benchmark datasets.

Data	NLHM	[7]	[18]	[8]
Carleton91	5.33	***4.97**	5.08	5.08
Carleton92	4.56	***4.32**	4.38	4.34
Earlhaig83	39.53	***36.16**	38.44	38.28
Edhec92	11.60	11.61	11.61	***11.13**
KingFahd93	15.31	15.02	14.67	***14.42**
Lse91	11.78	****10.96***	11.69	11.43
Purdue93	5.94	-	-	***5.74**
Ryerson92	9.89	-	9.49	***9.37**
StAndrews83	157.66	161.9	157.72	***157.34**
TorontoAS92	3.70	***3.36**	3.55	3.73
TorontoE92	27.12	27.41	26.63	***26.24**
Trent92	9.07	***8.38**	8.78	8.73
Yorkmills83	41.33	40.77	40.45	***40.38**

APPENDIX IV:

Table 5: Comparison of NLHM with other constructive approaches tested on Toronto benchmark datasets.

Data	NLHM	[25]	[4]	[26]	[27]
Carleton91	5.33	7.10	5.29	**5.03**	5.18
Carleton92	4.56	6.20	4.54	**4.22**	4.44
Earlhaig83	39.53	36.40	37.02	**36.06**	39.55
Edhec92	11.60	**10.80**	11.78	11.71	12.20
KingFahd93	15.31	**14.00**	15.80	16.02	15.46
Lse91	11.78	**10.50**	12.09	11.15	11.83
Purdue93	5.94	**3.90**	-	-	4.93
Ryerson92	9.89	**7.30**	10.38	9.42	10.04
StAndrews83	**157.66**	161.50	160.4	158.86	160.50
TorontoAS92	3.70	3.50	3.57	**3.37**	3.49
TorontoE92	27.12	**25.80**	28.07	27.99	29.44
Trent92	9.07	9.60	8.67	**8.37**	8.71
Yorkmills83	41.33	41.70	39.8	**39.53**	42.19