



Bus Driver Scheduling and Rostering: Maximise Fairness using Enhanced Harmony Search Algorithm with Varieties of Step Functions and Fret Spacing Formula

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Abstract

This research proposes an adjustment of harmony search algorithm as a strategy to achieve a superior performance by manipulate three key operators in harmony search known as the Harmony Memory Consideration Rate (HMCR), Pitch Adjustment Rate (PAR) and Bandwidth (BW) that lead harmony search to accomplish a balancing between local exploitation and global exploration. The first contribution is having HMCR parameter using step function, while the second is applying the fret spacing concept on guitars toward BW parameter. There are three proposed models on the alteration of HMCR parameters based on the use of the fundamental step function; the constant interval of step function, dynamic increase and decrease interval functions. From an observation result, our proposed technique is superior adopted by using a second model that contrast to parameter adaptive harmony search (PAHS). In brief, this proposed technique magnificently to construct a fairer roster among drivers.

Keywords: meta-heuristics; fairness; harmony search; scheduling, rostering.

1. Introduction

Optimisation is described as the accumulation of mathematical algorithms, where various engineering applications are succeed. Conventional mathematical approaches cannot cope with some of the recent applications that are extremely complicated. This has led to the development of a new mechanism for new design solution in accordance with the field of general nature-inspired algorithms known as metaheuristics. This method was developed in the past years based on collective behaviour of natural or artificial decentralised self-organised systems [1-3]. The sophisticated collective intelligence tactics are exploited to be adopted in algorithms and it has been illustrated as powerful problem-solving features as asserted in the study of [4]. It comprises an easy interaction agent that refers to intelligence rests in the networks of interaction between individuals as well as among individuals and the environment. Evolutionary or swarmed based algorithms indicate a generic population founded by metaheuristic optimisation algorithms. These metaheuristics are typically inspired on metaphors expressing natural process or social phenomena. The harmony search (HS) algorithm is among the freshest metaheuristic algorithms.

The harmony search (HS) algorithm is initiated by [5] in year 2001. HS algorithm is categorised as novel population according to literature survey on metaheuristics. The HS algorithm is devised from the domain of music. In its foundation or root theory of HS, the approaches inspired by the musical performance steps participate when a group of musicians hunt for a harmonious symphony

and continue to polish their tune to reach an escalation pleasant harmonies. Harmonising musical harmony is corresponding to an optimisation solution whereas in optimisation technique, improvisation of music is corresponding to the local and global searching mechanism to a problem. From this view, the aesthetic quality referring to the combination of each pitch generated by musical instruments is equivalent to the objective function value. Various variables allotted a set of values defined as an objective to a problem. As a matter of facts, the total number of publications in connection of harmony search has rapidly grown. In 2010, Google Scholar has recorded 500 searches for harmony search including the quotation mark [6]. The same search has showed about 3000 results in 2012. Whereas, by the end of 2014, the result was further increased to a number greater than 9000. Some of the areas with a highest rate of request to be put into practise of HS are power flow problem [7], flow shop problem [8], water design distribution networks [9], truss structures optimisation [10], problems of orienteering [11], solving sudoku [12], steel sway frames design [13] and transportation scheduling [14].

The HS was opted and being the focus of this research due to several remarkable advantages over other metaheuristic approaches. For instance, the HS algorithm implements stochastic random searches instead of requiring a derivative information in which HMCR and PAR are responsible to obviate the requirement in adopted derivative information [15]. Secondly, HS imposes a small amount of mathematical prerequisite that is effortless to overcome various problems merged in engineering optimisation problems and also entail a few parameters [16-17]. Thirdly, HS is efficient in conducting continuous and discrete variables [18] as

well as unnecessary for decision variables to assign an initial value setting. Fourthly, HS possesses a high potential region of the solution space within practical computational time [19]. Finally, HS algorithm can undergo fast search besides being efficient. These characteristics have made the HS more flexible and yield a good result with chances to attain near global solutions [19-20].

The rule of HS encounter amendment by producing a new solution and another adjustment take part after new solutions are generated. These strengthen the search process and allow the algorithm to generate more refine solutions. This research emphasises the proposed method in aspect of improvisation process refined by modifying the main parameters noted as Harmony Memory Consideration Rate (HMCR) and Bandwidth (BW) using certain concepts deviated from the original concept. In this research, a new approach was proposed that employs HS to solve scheduling and rostering problems. This approach aims at constructing a better solution while applying the step function, linear function and guitar fret spacing within a reasonable period. Driver scheduling also concern with management issues like fairness of assignment. Fairness issue needs to be overcome because significant impact that raises fairness level in a schedule will surge productivity and involvement of an employee [21]. Scheduling and rostering categorized as separate problems which can be resolved individually, however it is assume to be mutually depend on each other when aspect of fairness is adopted. In this study particularly, modified harmony search algorithm which is classified as metaheuristic approach is preferred to overwhelm these issues. The demand receive by a university which is described as balancing the allocation of shifts and routes represent a fairness aspect in this research. The contributions in this paper are summarized as follows:

- The idea of step function being embedded in the Harmony Memory Consideration Rate (HMCR) parameter in which HMCR is one of the main parameter in HS. With that, three variants of model were suggested. These three models were namely constant, dynamic increase and dynamic decrease of step function. Each of these models has their own features in terms of how each interval of group iteration is allocated when looking for global optimum solutions.
- The second contribution is a new constructed formula for distance bandwidth (also main parameter in HS), whereby the knowledge of fret spacing is imitated. By adopting that principle, this work enable the small distance until the greatest distance of bandwidth being covered. In other words, every decision variable can be changed to any value within the permissible range of solutions together with the assistance of random numbers that has defined a sequence number every time it is generated.

The remainder of the study will be organised as follows. In Section one, the problem statement will be described. Section three discusses approached of the study, while Section III.I presents the problem formulation. In Section III.II, the formulation of constraint and objective function is presented. Section four, five and its subsection performed the proposed of the study, Section six discussed the experiment, Section seven explained the observation from the experiment and finally Section eight conclude and give some recommendation.

2. Problem Statement

The features of HS algorithm including easiness and effectiveness in obtaining a near global solution within an acceptable time allow it to be applied in various applications. When it comes to handling diverse cases, the HS remained unsatisfactory even though many variants of the HS algorithm have been suggested [22]. Similar to other metaheuristic methods, the HS also suffers from significant issue of sensitive parameter setting. Therefore, a strategy is needed to fine adjustment of parameters that can assist to retain a trade-off between diversification and diversification. According to [23], harmony search has a drawback particularly with regard to parameter settings, which are quite sensitive despite managing to solve

several real-world optimisation problems [24]. In previous studies, HS were developed in different variants in a new way by updating a set of parameters to dynamic value to gain optimisation ability. In other studies, hybridisation by combining other metaheuristic algorithms or self - adaptively parameters tuning that select the best control parameters during evolutionary steps are an attempt to improve the performance of HS. According to [23], harmony search has a drawback, particularly with regard to parameter settings, which are quite sensitive despite managing to solve several real-world optimisation problems [24].

Musical improvisation analogy in HS is relatively appealing and straight forward as compared to other meta - heuristic algorithms. However, the setting of parameter can be an issue. According to [25], parameters are set to invariant values for HMCR, PAR and BW parameters in standard HS causing poor accuracy and convergence rate. Indirectly, the task of finding optimal solutions lies in the total number of iteration [26]. Thus, it is difficult to suggest an appropriate value to work well when dealing with different situations [27]. Due to this, the optimisation process has fall into the local optima solutions [28]. Thus, to intensify the presentation of the harmony search, both parameters of PAR and BW were transformed into irregular values where dynamic values are established [25]. This is in accordance with the HMCR parameters; in maintaining a small constant value, the algorithm missed the local search capabilities or inadequate local search power while retaining a constant large value of HMCR parameters leading to results being easily trapped in the local optimum [29]. The parameter setting is important to improve performance such as fixing certain values at the beginning of executing an experiment. In the improved harmony search, the new additional parameters, PAR_{min} , PAR_{max} , bw_{min} , and bw_{max} , should be fine-tuned depending on the types of problem and difficulty to determine the ranges to be specified [26]. According to [12, 30] that emphasised parameter setting, the results shown by harmony search were not rigorous. These restrictions have led to the motivation of the present study where the proposed approach is inspired by the Parameter Adaptive Harmony Search Algorithm (PAHS). The parameters of HMCR in this research were specified within the range starting at small values and approached the end of the maximum number of iterations with increasing values. The upgrading strategy for HMCR was carried out in such a manner that balances between exploration and exploitation. This is because the global exploration occurred at the initiation of iteration and local searching was managed at a high number of iterations to obtain a global optimum.

3. Approaches of the Study

To overcome the fairness issues in this work, the problem is formulated into a set of mathematical equation with multi-constraints. The constraints are subjected to all regulations and laws that have been enforced by the company and government respectively. To obtain a maximum balancing of tasks, both problems of driver scheduling and driver rostering are integrated, leading to increased fairness among the drivers. The harmony search (HS) algorithm is chosen as a tool to solve fairness, where the best solution is obtained through the search within the space in which searching process is carried out by three major parameters found in HS. The HS algorithm is one of the most recent meta-heuristic algorithms suggested by [5] which imitates musician experiments and better harmonies by keeping changes in pitches through improvisation. The algorithm is successfully applied in the optimisation of heat exchangers, pipe network design, vehicle routing [31-32], telecommunications and many more [33-39]. The achievement of HS can be boosted in two approaches either hybridizing [40-42] it with other meta-heuristics or adjusting a few parameters [43-45, 38, 29]. Majority improvement in HS associates in parameters setting, such as the harmony memory consideration rate (HMCR), pitch adjustment rate (PAR) and step size or bandwidth (BW). Motivated by the facts that HMCR parameter assists the algorithm

to exploit and explore the solutions, the rate of HMCR is setting at a small rate at preliminary phase and increase gradually at the end of the optimization process. Meanwhile, the BW parameter is problem- dependent as well as it provides the significant effect toward the performance of the algorithm. It must be noted that this study modified these two parameters and becomes a key point that will be focused in detail.

3.1. Problem Formulation for Bus Driver Scheduling and Rostering

Problem formulation is a very significant and critical process in any kind of problems [46-54]. The task plan for each university bus driver is to assign a series of routes and shifts in this scheduling and rostering problem. The demand determined the construction of driver schedule that rely on company's rules and guideline. The details of the problems are as follows: Given a set of M drivers P_i for $i=1,2,3,\dots,M$, in what way can N shifts S_j for $j=1,2,\dots,N$ be allocated to the drivers in order to include set of O routes R_k for $k=1,2,\dots,O$ according to demand set D in entire cycle, W_l for $l=1,2,\dots,Q$. It must be noted that these assignment must be fair among the drivers. This section present mathematical model to the DSP and DRP that is subjected to a set of constraints delineated and the solutions obtained from these models are reliable to be practised in real situations and thus could become a generic model. Constraint could be separated into two, known as hard and soft constraints. It is needed to put an attention that the selections of the constraints are relying on the particular problem and on the guideline of the company. The hard constraint is essential to fulfill and it represented the sort of problem being looking at, meanwhile soft constraint has some relaxation that can be violated. If so, every violated of soft constraint is penalized according to the violation level. However, to obtain excellent solutions, soft constraint violation should be minimized. In this research, both types of constraints are employed. The constraints applied in this work are problem specific to the university bus driver and can be amended to transform into a generic model.

3.2. Formulation of Constraints and Objective Function

In (1) is the first hard constraint in this study in which it assign for every driver is one kind of shift and route per week. The assignment of shift and route is given either per week or daily basis which relies on the cycle that has been fixed.

$$\sum_{s=1}^N \sum_{r=1}^O x_{psrw} = 1 \quad \forall p \in P, \forall w \in W \tag{1}$$

In (2) is the second hard constraint in which it fulfills the weekly coverage demand of each shift type and route. In a bus driver scheduling problem (BDSP), need to be reminded that company should be finalize the demand. Demand modeling is referring to the procedure of interpreting several predicted pattern of organization into related tasks and the demand for staff is depend on the construction task utilities.

$$\sum_{p=1}^M X_{psrw} = D_{sr}; \forall s \in S, \forall r \in R, \forall w \in W \tag{2}$$

The first soft constraint which is governed in (3) concentrates on the frequency of every shift that should be given to all the drivers. The company is responsible to construct the frequency for each shift and this perhaps one of the conditions for evaluation of fairness. The second soft constraint which is governed in (4) is to

designate dissimilar routes for each week in a month. For each week the driver cannot have the repeated route.

$$\sum_{w=1}^Q \sum_{r=1}^O x_{p,s=j,r,w} = u_j \quad \forall p \in P, \forall s \in S \tag{3}$$

$$\sum_{w=1}^Q \sum_{s=1}^N x_{psrw} \leq 1 \quad \forall p \in P, \forall r \in R \tag{4}$$

In this study, the fairness is measured among drivers is soft constraint. After schedule is constructed, an objective function can be assessed.

The objective function used in this research is to minimise the soft constraint violation as illustrated in (5).

$$\text{Minimize } 1 - \left[\frac{\left(\frac{\sum_{i=1}^M f_1(i)}{M} + \frac{\sum_{i=1}^M f_2(i)}{M} \right)}{\left(\frac{\sum_{i=1}^M F_1(i)}{M} + \frac{\sum_{i=1}^M F_2(i)}{M} \right)} \right] \tag{5}$$

In (5), $f_1(i)$ illustrates the value designates to driver i for soft constraint 1 while $f_2(i)$ denotes the value assigned to driver i for soft constraint 2. $f_1(i) = 0.50$ if the soft constraint is breach while $f_1(i) = 1.0$ if the soft constraint is satisfied. The same is true for soft constraint 2, where $f_2(i) = 0.50$ if the soft constraint is violated and $f_2(i) = 1.0$ if it is satisfied. $F_1(i)$ and $F_2(i)$ represents the ideal or recommended solution where it satisfy soft constraint 1 and soft constraint 2 correspondingly in which its value is 1.

4. Proposed Approach for Enhancement of HMCR

The goal of this research is to examine the outcome of tuning the selected main parameters of harmony search towards the overall performance while maintaining both an exploitation and exploration of solution populations. In metaheuristic algorithm, the searching strategy consists of two pillars known as exploitation and exploration. The trade – off must be accomplished between these two elements. A careful concern, consequently, should be put forth in deciding the rules of updating mechanisms to carry out a delicate trade – off among these two search strategies. Apart from using a fixed value parameter for whole iteration, dynamic parameter was suggested to manage local and global search in the entire search space. The dynamic parameter adjustment was brought up as an alternative to the standard, which is a fixed value. There are two suggested approaches to alter the HMCR and BW parameters in dynamic manner. The dynamic changes in the value of HMCR begin with small value and as the number of iteration approaches maximum number of iteration, the value of HMCR increased. The HMCR values behave based on the justification that if HMCR retains a small static value with escalating of itera-

tions, the algorithm could defeat local search capability and thus cannot obtain global optimum. Otherwise, the high static value of HMCR retained in final iterations would encourage the algorithm to be trapped in local optima. Thus, to enhance global exploratory, HMCR value was forced to begin at small value in early generations. With small HMCR value, the searching was randomised, which is still in a permissible range. Therefore, the produced solution was diversified and led to a better exploration. It must be noted that the HMCR value must be increased gradually in the form of linear or step function. Once it reaches certain higher value at maximum number of iteration, the local search ability is strengthened to gain the global optimum.

The purpose of using step function is to control the parameters that can be changed to the desired value. In this study, the maximum and minimum ranges of HMCR parameter gains lie between 0.10 and 0.99. The dynamic parameter made the value of HMCR parameter to be changed during various phases known as starting, intermediate and termination in the searching process. A deep exploration on the entire solution space occurred during starting and intermediate process of searching a solution and hence, a wide range of solutions were gained. During the intermediate phase, a steady improvement in the aspect of quality solutions was gathered. Lastly, during the termination phase, as fine – tuning of better solution has been achieved, the global optimum solution was turned up within harmony memory. Further explanation on behavior of stepwise function correlated with the HMCR parameter is further explained in the subsequent subsection. As for BW parameter, a mathematical formula that mimics fret spacing is applied. The implementation of how fret spacing is related to the construction formula of bandwidth is also discussed further.

4.1. Constant Interval of Step Function for HMCR

The main idea for this first model is to have a group of iterations where each group has its own HMCR value. The unique characteristic of this model is that the number of iterations is constant for all groups. For example, group 1 has five iterations (iteration 1 until iteration 5) in which all this five iteration has the same HMCR value. Figure 1 illustrates all the groups and its corresponding HMCR values for every group of iteration. The y-axis represents HMCR value while the x-axis represents the interval of iteration respectively. The increment in the HMCR value is represented by $HMCR_{interval}$. The model work by initially determined the number of interval group K , by using the following equation:

$$K = \frac{NI}{b} \tag{6}$$

In (6), NI denotes the total number of iteration and b denotes the number of iteration in each group. For instance, let us say that NI is equal to 900, and b is 180. Therefore:

$$K = \frac{900}{180} = 5 \text{ (Interval groups of iteration)}$$

Once the value K is obtained, then $HMCR_{interval}$ is generated as follows:

$$HMCR_{interval} = \frac{HMCR_{max} - HMCR_{min}}{K - 1} \tag{7}$$

In (7), $HMCR_{max}$ is the maximum value of HMCR and $HMCR_{min}$ is the minimum value of HMCR. For example, let us

say that K equals 5, $HMCR_{max} = 0.90$, $HMCR_{min} = 0.10$, then:

$$HMCR_{interval} = \frac{0.90 - 0.10}{5 - 1} \tag{8}$$

From the above example as well as illustrated in Figure 1, it is visible that there are five groups of interval iterations. Each group contains 180 iterations, while the increment, $HMCR_{interval}$ is 0.20. Hence, the experiment is conducted by using various rates of HMCR obtained from the step function. Then, HMCR at 0.1 will be run at iterations from 1 until 180. This will be followed by the value of HMCR at 0.3, which is executed at iterations 181 until 360. The following value of HMCR is at 0.5, which performed at iteration 361 until 540. This experiment is extended until HMCR value reach es 0.9.

In other words, the research employed a step function approach to specify the set of HMCR values covered at certain ranges of iteration. In (8) represents the details of HMCR values for this example.

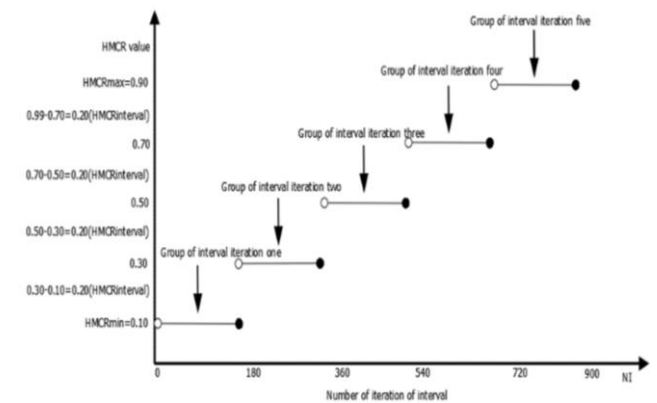


Fig. 1: Illustration of constant interval of step function for HMCR.

4.2. Dynamic Increased Interval of Step Function for HMCR

Dynamic increased intervals of step function will be used where the number of iterations for each interval group increased dynamically as illustrated in Figure 2. In other words, the number of iterations will be grouped according to arithmetic progression as shown in (9).

$$NI = \frac{K}{2} [2a + (K - 1)d] \tag{9}$$

Based on the above equation, the maximum number of iterations is indicated as NI and K is equal to the number of group interval of iterations. While, a is the number of iterations in the first group interval of iterations and the difference between successive groups is denoted by d . In order to describe in more detail the dynamic interval of step function, the following example is used to illustrate how the interval of step function in this work is dynamically increases. For example, the maximum number of iterations is 30 and both value of a and d are correspond to 2, thus:

$$30 = \frac{K}{2} [2(2) + (K - 1)2]$$

$$K = 5$$

Dynamic interval of iterations has a specific property where each group interval of iterations will be iterated dynamically; this high-

ly depends on the d value. If using the above example, there are five groups of interval of iterations where the first group interval of iterations consist of two iterations; this is continued by the second group where the interval of iterations has four iterations, then, six iterations are employed in the third group, the fourth group interval of iterations comprises eight iterations and the last group is the fifth group interval of iterations which contains ten iterations. In brief, it can be seen that there is an increase of about two iterations for each consecutive group interval of iterations.

As for the constant interval of iteration, once the K value is found, in (7) will be adopted in order to gain the $HMCR_{interval}$ value. When K values are obtained from Equation (9) and $HMCR_{max} = 0.99$, $HMCR_{min} = 0.10$, the interval is:

$$HMCR_{interval} = \frac{0.99 - 0.10}{5 - 1} = 0.2225$$

The following Figure 2 illustrates the above example, which could be used to assist in understanding clearly how the dynamic interval of iteration works. In (10) shows the interval of iteration.

$$HMCR = \begin{cases} 0.1; & 0 < NI \leq 2 \\ 0.3225; & 2 < NI \leq 6 \\ 0.545; & 6 < NI \leq 12 \\ 0.7675; & 12 < NI \leq 20 \\ 0.99; & 20 < NI \leq 30 \end{cases} \quad (10)$$

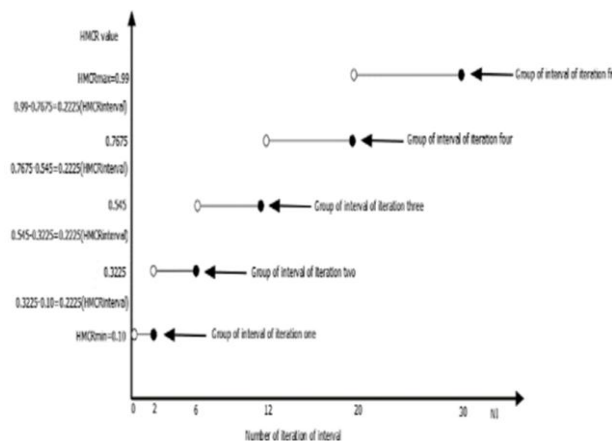


Fig. 2: Graphical interpretation of dynamic increase interval of step function

4.3 Dynamic Decreased Interval of Step Function for HMCR

The third model of step function introduced in this work is a dynamic decrease interval of step function for HMCR. It has the same characteristics as the dynamic increase interval of step function, but the difference is that the dynamic decrease interval begins with the group interval of iteration that has the higher number of iterations and decreases as the iteration increases. On the other hand, the group's interval of iteration starts at a lower interval of iteration for the dynamic increase interval of a step function. The concept of arithmetic progression still adopted so that the number of group interval of iterations, K , can be acquired.

For instance, NI is equivalent to 30, the values of a and d are both set to 3 and again, Equation (9) is adopted to obtain the number of group iterations of intervals, K . Hence:

$$30 = \frac{K}{2} [2(3) + (K - 1)3]$$

$$K = 4$$

The next step is to apply in (7) in order to find the value of $HMCR_{interval}$ with value of $HMCR_{min}$ and $HMCR_{max}$ are 0.10 and 0.99 respectively. Through that equation, it produces 0.296667 for $HMCR_{interval}$ as shown below.

$$HMCR_{interval} = \frac{0.99 - 0.10}{4 - 1} = 0.296667$$

As indicated in the above example for K , there are four groups of iteration of intervals in which the first group iteration of interval has 12 iterations; next, the second group iteration of interval contains nine iteration, continue with the third group of iterations which consists of six iterations and the last group has three iterations. The reduction in number of iterations for each group is deducted at a constant number of three as the growth of the group interval is increased. Figure 3 illustrates the above example of dynamic decreased interval of step function for HMCR, and in (11) represents the HMCR value for each group of interval iterations.

$$HMCR = \begin{cases} 0.1; & 0 < NI \leq 12 \\ 0.396667; & 12 < NI \leq 21 \\ 0.693334; & 21 < NI \leq 27 \\ 0.99; & 27 < NI \leq 30 \end{cases} \quad (11)$$

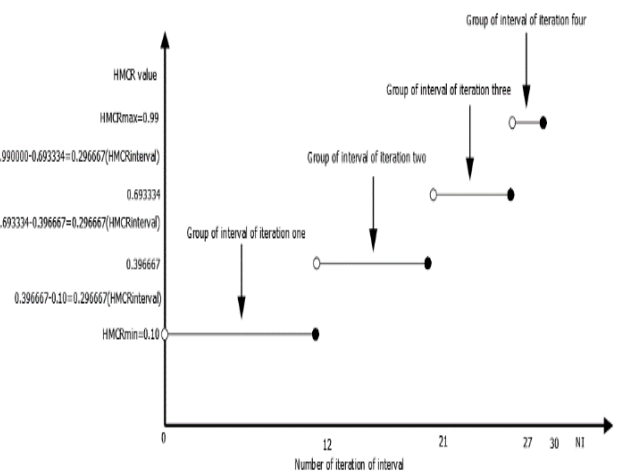


Fig. 3: Graphical representation of dynamic decrease interval of step function for HMCR.

5. Bandwidth

Bandwidth (BW) is a random distance parameter and is one of the crucial parameters found in the HS algorithm. As PAR governs the chance that chosen new harmony is further amended with a small distance bandwidth. The small step size is associated with an adjustment that corresponds to the local search, while global search corresponds to an amendment with larger step sizes. BW is responsible for moving the local search around the selected decision variable to form a new candidate harmony vector. The need to have BW dynamically at the initial stages favours exploration, while exploitation occurred in the final stages. By imitating the concept of the distance for each fret' position from the bridge, the formulation of bandwidth (BW) in this study is employed. In string instruments, the measurement taken is from the number of fret from the bridge, as in this research, it is a measurement of

how far the current solution can reach. As illustrated in (12), the value of 11 represents the distance from the first note until the last

note which starts at position zero until the 11th location. While, 12 indicates that there are 12 notes in one octave in a normal guitar.

Table2: The best optimisation result of proposed approach and PAHS.

	Constant of Step Function		Dynamic Increase of Step Function		Dynamic Decrease of Step Function		PAHS	
	Best	Mean	Best	Mean	Best	Mean	Best	Mean
Result at a and $b = 2$	0.12	0.167					0.12	0.158
Result at a and $b = 3$	0.12	0.157						
Result at a and $b = 4$	0.12	0.172						
Result at a and $b = 5$	0.12	0.159						
Result at a and $d = 2$			0.11	0.138	0.18	0.235		
Result at a and $d = 3$			0.11	0.142	0.17	0.229		
Result at a and $d = 4$			0.12	0.141	0.16	0.225		
Result at $a =$ and $d = 5$			0.11	0.133	0.13	0.218		

$$BW = \frac{11}{2 \frac{\text{current solution}}{12}} \tag{12}$$

6. The Experiment

The modelling of this study was implemented using a simulation of Dev and the code proposed was developed in C++ programming on a PC with 3.4 GHz Intel (R) core (TM) i7-6700 processor and 32 GB RAM. All proposed models were tested using the same optimisation problem where 30 independent runs for each model were executed on the same computer in order to ensure the reliability of the experimental results. The maximum number of iteration was set to 50,000 for each model. The maximum number of iteration was taken as 50,000 in order to ascertain whether all the techniques were given the same opportunity to grab the global optimum were not an obstacle to reach this [55]. Since the harmony search algorithm is a stochastic algorithm, different results would be generated at different times as it was executed. In this study, the statistical tools were employed to analyse the optimisation results produced. Table 1 indicated how the parameter fixing for every algorithm has been compared. The HMCR parameter that altered with step function has three models, which are constant, dynamic increase and dynamic decrease of step function. In constant step function, the experiment is run by setting the number of iterations in each group interval going from two until five, represented as $b = 2, 3, 4, 5$ while the dynamic increase and decrease of step function with experiments beginning at $d = 2,3,4,5$ respectively. Table 1 indicated how the parameter fixing for every algorithm has been compared.

Table 1: Parameter setting for experiment conducted.

	PAHS	Ours
HMS	4	4
HMCR _{min}	0.10	0.99
HMCR _{max}	0.10	0.99
PAR _{min}	0.01	0.99
PAR _{max}	0.01	0.99
BW		$\frac{11}{2 \frac{\text{current solution}}{12}}$
BW _{min}	0.001	

7. Experimental Observation

The results are compared with existing approach, which is PAHS in which one of the variants of HS. To compare the performance for each technique, the best value and mean are yield. The minimise value of objective function and mean value are becoming the performance criteria. In Tables 2 denotes the result that exposed the dynamic interval of step function (second model) leading the

performance compared to the PAHS and other both models. In this experiment, PAHS managed to gain 0.12 meanwhile the mean value hit 0.158. The second model capable of accomplishing minimum value at 0.11 when a and d is fixed to five. The value of a express to the number of iterations in the first group of the interval of iteration while value of d denotes the difference between the successive groups. The optimal solutions were discovered much superior as the number of a and d escalate. It is proven when a and d are equal to five reported that has fewer mean value.

For the first model, the best objective function is achieved at 0.12 for all value of b where represented the amount number of iteration in each group interval. The value of mean almost getting lesser as b value is escalated. The dynamic decrease interval of step function can be considered as the worst model due to merely obtained 0.13 as the best result it though indicates the reduction while d value is accelerated. To evaluate whether there is any significant difference between the performances of our proposed method and PAHS, statistical tool known as Wilcoxon Signed – Rank Test is used. The reason for employment of Wilcoxon Signed – Rank Test derived from aspect that the result achieved is not distributed normally, hence, non – parametric test is required. The significance value given by the statistical test is 0.004 and since it is less than alpha which is 0.05, the null hypothesis is rejected. Therefore, the proposed approach proposed in this paper shown a significant. In other words, the proposed approach proves to be better than the existing one.

8. Conclusion and Recommendations

In conclusion, all objectives in this research are managed to be achieved by adjusting the HMCR and BW which are known as a main parameter of harmony search. The concept of step function and fret spacing theory is adopted into HMCR and BW parameters respectively. The proposed technique succeeds to achieve a fairer scheduling and rostering that exhibited in obtaining superior objective function value. The performance of the suggested method in this research is highly dependent on the consolidations between the ideas of step function and linear increase function that have been manipulated in the main parameters of harmony search algorithm, which is HMCR. By varying the value of HMCR within certain range of minimum and maximum values which covers from 0.1 up to 0.99, this approach generated a superior outcome. High value of HMCR at the end of optimisation process helps the algorithm to seek the best solution retained in harmony memory. Therefore, a fairer bus driver scheduling and rostering is obtained.

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