Modified Parameters of Harmony Search Algorithm for Better Searching

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Abstract. The scheduling and rostering problems are deliberated as integrated due to they depend on each other whereby the input of rostering problems is a scheduling problems. In this research, the integrated scheduling and rostering bus driver problems are defined as maximising the balance of the assignment of tasks in term of distribution of shifts and routes. It is essential to achieve is fairer among driver because this can bring to increase in driver levels of satisfaction. The latest approaches still unable to address the fairness problem that has emerged, thus this research proposes a strategy to adopt an amendment of a harmony search algorithm in order to address the fairness issue and thus the level of fairness will be escalate.

The harmony search algorithm is classified as a meta-heuristics algorithm that is capable of solving hard and combinatorial or discrete optimisation problems. In this respect, the three main operators in HS, namely the Harmony Memory Consideration Rate (HMCR), Pitch Adjustment Rate (PAR) and Bandwidth (BW) play a vital role in balancing local exploitation and global exploration. These parameters influence the overall performance of the HS algorithm, and therefore it is crucial to fine-tune them. The contributions to this research are the HMCR parameter using step function while the fret spacing concept on guitars that is associated with mathematical formulae is also applied in the BW parameter. The model of constant step function is introduced in the alteration of HMCR parameter. The experimental results revealed that our proposed approach is superior than parameter adaptive harmony search algorithm. In conclusion, this proposed approach managed to generate a fairer roster and was thus capable of maximising the balancing distribution of shifts and routes among drivers, which contributed to the lowering of illness, incidents, absenteeism and accidents.

1. Introduction
Public transport can be considered an important backbone in developing cities; because of that, movement in cities must be handled efficiently [1]. At the same time, public transport systems are always trying to provide a quality service at a reasonable price in terms of public administration and the user. Public transport is also facing problems in terms of optimisation problems; as a result, operational research has become a choice for solving this for a few decades now [2]. Several software
systems have been identified by researchers which could be integrated into the operational research area, thus assisting in the planning and execution of operations. Transportation planning can be divided into several sub-problems according to their complexity, such as timetabling, vehicle scheduling, driver scheduling and roster scheduling [3]. The transport service corresponds to buses travelling between two points or two cities which indicates a set of lines, and can also be represented as numbers; therefore, timetables can be created. Each line has its own frequency and is determined according to demand. The vehicle schedules aim to minimise the number of vehicles needed; the daily work of each vehicle is called a piece of work that must start and finish at the same point with a set start and completion time. When dealing with scheduling, there is compulsory term known as constraint that refers to the feasibility of a duty. If a set of feasible duties is distributed evenly, covering all vehicle trips scheduled for a route or a small set of routes, this provides a solution to the bus driver scheduling problem. Rosters are created monthly, which consist of daily routines, days off and holidays for each driver. The above explanations show the relationship between timetabling, vehicle scheduling, crew scheduling and roster scheduling; how they are related to each other is shown in Figure 2.1. Each of these phases can be considered an independent problem.

![Diagram](image.png)

Figure 1: Overview of the operational planning process in public transport [4]

In the driver scheduling problem (DSP), there are several objective functions that are commonly considered, such as reducing the number of duties, reducing idle times, reducing the penalties for constraint violation, reducing the number of uncovered shifts, and reducing the cost of potential disruptions [1]. Also, driver scheduling is not only concerned with those aspects that have been reported previously for objective functions, but is also interested in managerial issues such as the fairness of assignments. The issue of fairness should be addressed due to the significant impact which improving fairness in a schedule will have on the productivity and engagement of an employee [5]. The objective in bus driver rostering problem (BDRP) is to reduce costs or the number of staff. Also, friendly employee rosters can attract bus drivers, train drivers, cabin crew and pilots [6]. Preferences and fairness are also key criteria that become an objective in construction crew rostering. Driver scheduling and driver rostering are the phase of operative planning transportation which is the main concern of this thesis. Maximising the balancing distribution of an assignment of tasks fairly has become a focus of this research.

Scheduling and rostering for drivers are separate problems that can be solved independently, but when dealing with the aspect of fairness, driver scheduling and rostering are interdependent on each other. To achieve fair schedules, a meta-heuristic approach known as the modified harmony search algorithm is selected as a tool to directly address these issues. The fairness aspect in this research is interpreted as balanced the allocation of shifts and routes selection based on demand received by a university. A reduction level of maximization toward shifts and route distribution, can result lower satisfaction achieve by drivers and thus causes in a lower quality of work and poor job performance. The remainder of the dissertation will be organised as follows. In Section 2, the literature review will be described. Section 3 discusses the research methodology, while Section 4 presents the result and analysis and the last Section 8 conclude of the research.
2.0 Literature Review

Recent approaches used in driver scheduling is categorised into two general groups solved by a computer: heuristic algorithms and exact algorithms but most on the basis of mathematical programming methods [7][8]. Heuristic and meta-heuristic techniques adopt intuitive approaches to solve the driver scheduling problem, where the structure of the problem is interpreted, analysed, and exploited intelligently to obtain a “reasonable” solution with some justification [9]. Heuristic is primarily applied in driver scheduling problems in the beginning of 1960s and end of 1970s (Elias, 1964; Wren, 1971). Currently, meta-heuristic approach is widely used to substitute heuristic terms and is broadly applied to address driver scheduling problems. Constraint programming and integer programming are examples of exact methods [12]. The branch-and-bound algorithm is the best known exact algorithm that solved linear integer programs [13]. Constraint programming is one of the latest techniques blended in mathematical programming to decrease the difficulty of scheduling problems (Desrochers, Gilbert, Sauvé, 1992; Falkner, 1992; Fores et al., 1999; Smith, 1988). Mathematical programming techniques solved the scheduling and rostering problems by formulating them into linear programs; the most famous model applied is the Dantzig set covering formulation [18]. The set covering problem (SCP) is categorised into NP-hard problems and well-defined mathematical problems in computational complexity theory [19][20]. Set covering problems act as a model for real world problems and are categorised as one of the most important discrete optimisations. Set covering comprises of m-row and n-zero column one-zero matrix at a minimal cost, representing a subset of columns [21].

Based on the case study for bus driver scheduling in Beijing [22], the issues arising are producing and selecting of a set of legal duties (shifts or workdays) to include all vehicle blocks. The aim of the study is to reduce the total operational costs for a transit agency. The set portioning/covering problem (SPP/SCP) is adopted in modelling the problem into a mathematical formula. Tabu search is one of the earlier forms of meta-heuristic algorithms; attempts were made by Cavique et al. (1999) who introduced driver scheduling issues in Lisbon Underground proposed minimum number of duties governed by a set contractual rules. De Leone et al. (2011) integrated the GRASP algorithm into the bus driver scheduling problem, which was tied to the constraint outlined by Italian transportation legislation. The driver scheduling problems deal with the allocation of piece-of-work to shifts where supposed the each piece-of-work is delegate to only one driver, the shifts are feasible and minimise both total cost of operation and amount of shifts required. The paper entitled “Workload Balancing in Transportation Crew Rostering” showed that fairness is measured in terms of workload of drivers so that the workload balancing problem in crew scheduling could be achieved [24]. The problem is described in the form of a network flow based on the space-time network. Xie and Suhl (2015) assessed driver scheduling problems and driver rostering problems that integrated cyclic and non-cyclic rosters using one network model known as commercial solvers.

In the last decade, the fairness problem has received ample consideration, nevertheless, the fairness issue included in the rosters frequently ignored in the research. Currently, the fairness concern has become one of the main problem present in transportation scheduling that there is a room need to be improve. In this research, fairness criteria is analyse to be integrate into bus driver scheduling and rostering problem. The fairness is perceived to fulfil all the constraints construct by a company where it is established based on the needs. An allocation of shifts and routes given to the drivers are the characteristics which determines the degree of fairness is achieved that this assignment of the shift and route must be distributed an evenly among drivers. The modified harmony search algorithm is employed to solve those problems. HS is imitate an improvisation of pitches in searching of pleasing harmony that analogous to seeking an optimum solution that refer to fairness schedule in this research. Therefore, this research is focus on bus university. The interviews collected the data regarding bus drivers’ scheduling and rostering. As a problem domain, much information that has been recognised needs to be found. In this research, the interview is held with Bahagian Hal Ehwal Pelajar & Alumni (HEPA). The interview was conducted with the Bahagian Pengurusan Kenderaan Universiti (BPKU),
which has information on the daily operations of bus scheduling and is also appointed to plan the driver scheduling for every month. There are a few pieces of important information that need to be gathered when dealing with bus university data, such as the amounts of drivers, buses provided, students, hostels and the students for each hostel.

HS is categorised as a meta-heuristic algorithm whereby its design impersonates the concept of music improvisation and continues to polish pitches in order to attain better harmony. According to [26], the standard HS algorithm involves five basic parameters, which are the harmony memory size (HMS), the harmony memory consideration rate (HMCR), the pitch adjustment rate (PAR), the distance bandwidth (BW) and the number of improvisations (NI). In this respect, the three main operators in HS, namely the Harmony Memory Consideration Rate (HMCR), the Pitch Adjustment Rate (PAR) and Bandwidth (BW) play a vital role in seeking excellent outcomes. HMS is the representation of the number of the solution vector in harmony memory, while HMCR indicates the balancing between the value of exploration and exploitation, which ranges from zero to one. The PAR is a parameter which determines the requirements for further alteration, whether it is necessary or not, according to BW parameters. The termination criterion is NI, while BW is the step size of the PAR parameter. This research focuses on the HMCR and BW parameters.

3.0 Research Methodology
The contribution of this research is in terms of enhancements toward HMCR and BW parameters in the HS technique, while the driver scheduling and rostering problems will be the application domain in this research. The purpose of this study is to examine the effect of tuning the main parameters of harmony search that consist of HMCR, PAR and BW, towards the overall performance while maintaining both an exploitation and exploration of populations. To obtain good solutions, step function and fret spacing formulae are employed in this study. An adjusted HMCR with step function and as well as fret spacing of BW parameters are the methods proposed in problem solving. The scheduling and rostering problem of university bus driver in this study is to assign the task plan for the crews where the task plan for each driver include a series of routes and shifts. The construction of driver schedule is subjected to the rules and guideline of a company where it is highly depending on the demand. The problem can be defined as follows:

Given a set of $M$ drivers $P_i$ for $i = 1, 2, 3, ..., M$, in what way can the $N$ shifts $S_j$ for $j = 1, 2, ..., N$ be assigned to the drivers in order to cover a set of $O$ routes $R_k$ for $k = 1, 2, ..., O$ according to a set of demand $D$ in complete cycle, $W_l$ for $l = 1, 2, ..., Q$. It must be noted that these assignment must be fair among the drivers. The mathematical models to the BDSP and BDRP that subjected to a set of constraints delineated. It must be noted that the selection of the constraints are dependent on the specific problem and on the planning rules of the company or the problem owner. Constraint can be divided into two which are hard and soft constraints. The hard constraints is compulsory to satisfy and it is illustrated the type of problem being considered while soft constraint have some relaxation which could be violated. If such, each violation of a soft constraint is penalized according to the extent of that violation. Nevertheless, to achieve excellent solutions, soft constraint violation should be decreased. In this research, there are two kind of hard and soft constraints be employed respectively. The constraints applied in this research is a problem specific to the university bus driver.

Classification constraints can assist in the recognition and formulation of differences constraints that exist in scheduling problems. It must be noted that all hard constraints will be fulfilled, while the soft constraints are more flexible where it is acceptable to be violated. In this study, the soft constraints refer to the evaluation of the fairness among drivers. Once the schedule is obtained, an objective function can be evaluated. The first hard constraint in this study is assigned to one type of shift and a route per week for each driver. The shift and route designated can be either per week or daily, depending on the cycle that has been fixed.
\[
\sum_{s=1}^{N} \sum_{r=1}^{O} x_{psrw} = 1 \quad \forall p \in P, \forall w \in W
\]

The second hard constraint is weekly coverage demand of each shift type and route needs to be fulfilled. In a BDSP, it must be noted the company must finalized the demand. Demand modelling is the process of interpret several predicted pattern of organization into related tasks and then using the task utilities to determine a demand for staff.

\[
\sum_{p=1}^{M} X_{psrw} = D_{sr} ; \quad \forall s \in S, \forall r \in R, \forall w \in W
\]

The first soft constraint focus on the frequency of each shift that need to be assigned to all the drivers. In this case the frequency for each shift is created by the company and this might be one of the criteria for fairness evaluation.

\[
\sum_{w=1}^{Q} \sum_{r=1}^{O} x_{p,s=j,r,w} = u_{j} \quad \forall p \in P, \forall s \in S
\]

The second soft constraint is assigns each driver with different routes for every week in a month. Each driver cannot have the same repeated route for each week.

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

### 3.1 Formulation of Objective Function

It must be noted that all hard constraints will be fulfilled, while the soft constraints are more flexible where it is acceptable to be violated. In this study, the soft constraints refer to the evaluation of the fairness among drivers. Once the schedule is obtained, an objective function can be evaluated. The objective function here is to minimise the soft constraint violation as illustrated in Equation (5).

\[
\text{Minimize } 1 - \frac{\left( \sum_{i=1}^{M} f_{1}(i) \right) + \left( \sum_{i=1}^{M} f_{2}(i) \right)}{2}
\]

\[f_{1}(i)\] denotes the value assigned to driver i for soft constraint 1 while \[f_{2}(i)\] denotes the value assigned to driver i for soft constraint 2. \[f_{1}(i)\] if the soft constraint is violated while \[f_{1}(i)\] if the soft
constraint is satisfied. The same is true for soft constraint 2, where \( f_2(i) \) if the soft constraint is violated and \( f_1(i) \) if it is satisfied. \( F_1(i) \) and \( F_2(i) \) denotes the ideal or preferred solution where it fulfils soft constraint 1 and soft constraint 2, respectively, in which its value is 1.

### 3.2 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 Equation (6).

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

Equation (6)

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 \( d \).

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 research dynamically increases. For example, the maximum number of iterations is 30 and both value of \( a \) and \( d \) are correspond to the two, 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 highly 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, Equation (7) will be adopted in order to gain the \( HMCR_{\text{interval}} \) value. When \( K \) values are obtained from Equation (6) and \( HMCR_{\text{max}} = 0.99, \; HMCR_{\text{min}} = 0.10 \), the interval is:

\[
HMCR_{\text{interval}} = \frac{HMCR_{\text{max}} - HMCR_{\text{min}}}{K - 1}
\]

Equation (7)

\[
HMCR_{\text{interval}} = \frac{0.99 - 0.10}{5 - 1} = 0.2225
\]

The following Figure 4.3 illustrates the above example which could be used to assist in understanding clearly how the dynamic interval of iteration works. Equation (8) deputises the interval of iteration.
3.3 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. If in string instruments, the measurement taken is from the number of fret from the bridge, as in my research, it is a measurement of how far the current solution can reach. As illustrated in Equation (9), 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.

\[
\text{BW} = \frac{11}{2^{\text{current solution}/12}}
\]

\text{(9)}

4.0 Result and Discussion

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 algorithm.
Table 1: The best optimisation result of proposed approach

|                | The best result at $a$ and $d=2$ | The best result at $a$ and $d=3$ | The best result at $a$ and $d=4$ | The best result at $a$ and $d=5$ |
|----------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| Dynamic interval of step of HMCR | 0.11                              | 0.11                              | 0.12                              | 0.11                              |
| Mean           | 0.138                             | 0.142                             | 0.141                             | 0.133333                          |

Table 2: The result of parameter adaptive harmony search (PAHS)

|                | The best result |
|----------------|----------------|
| PAHS           | 0.12           |
| Mean           | 0.158          |

The results are compared with existing approaches which are parameter adaptive harmony search (PAHS)[27]. For each technique, the best and mean are taken for the comparison of performance. The performance criteria are evaluated in terms of the objective function and mean value where both criteria must be obtained to minimise value. From the result above, experiments seen in Tables 1 and Table 2 exposed that the dynamic interval of step function offers a much superior performance compared to the parameter adaptive algorithm. Based on the above Table 2, the second model capable of accomplishing at 0.11 was the best objective function at $a$ and $d$ is fixed to two, three and five that often obtained 0.11 more than once while when $a$ and $d$ equal to four only managed to gain 0.12 and. The values $a$ and $d$ refer to the number of iterations in the first group of the interval of iteration and $d$ is the difference between the successive groups, respectively. As the number of $a$ and $d$ increase, the optimal solutions were found to be much better and proven through the mean value being fewer among others when $a$ and $d$ are equal to five.

5.0 Conclusion and Recommendation

In conclusion, this research managed to achieve all the aims that have been outlined. This objective managed to be achieved by regulating the main parameters of harmony search, which are HMCR and BW. For the HMCR parameter, a fundamental of step function is adopted while fret spacing theory is applied in the BW parameter. From the results demonstrated, the proposed approach managed to obtain a fairer rostering that illustrated an excellent objective function value. As for future work, I would like to suggest that this research be carried out at value $d$ was present in dynamic increase six and was discontinued until there were some available justifications that there was sufficient validation to stop an experiment. Furthermore, in a generic case the assumption made is not exactly fulfilled and, in order to achieve that assumption, an appropriate value of $a$ and $d$ must be obtained from the proper planning and construction of complexities that defined the number of variables involved.

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