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USING HARMONY SEARCH FOR OPTIMISING UNIVERSITY SHUTTLE BUS DRIVER SCHEDULING FOR BETTER OPERATIONAL MANAGEMENT

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ABSTRACT
Managing human resource to achieve specific goal in an organisation is a crucial task. One of various aspects in managing human resource is preparing optimum scheduling to perform certain tasks. The main objective of this paper is to illustrate the preparation and the work of optimum scheduling for university shuttle bus driver using a recently develop meta-heuristic technique known as Harmony Search. A mathematical formulation for the university shuttle bus driver scheduling problem based on the requirement and the preference of the university is illustrated. The optimum schedule is generated using Harmony Search, an optimisation approach inspired by the processes in music improvisation with less mathematical computation. It can be seen that the result produced using harmony search approach to automate the optimum university shuttle bus driver scheduling is quite promising because it yield better value of objective function compared with the one being done manually. Automation of the optimum university bus driver scheduling certainly can enhanced the operational management processes. This work can be regarded as a multidisciplinary work which several domains such as computer science, mathematics, operational research and management are involved.

Keywords: Harmony Search, Scheduling, Driver, Operational Research, Management.

1. INTRODUCTION

Scheduling is one of operational research application domain being applied in various aspects. An optimum schedule will leads to better management of resources. In certain universities, managing the operational of university buses to deliver transportation services to the students is one of many responsibilities that need to be taken care of. The management needs to produce monthly bus driver schedule based on certain policies and requirements. Therefore, the management need to carefully assign the tasks of delivering transportation services to the university bus driver which is being translated into a fair and optimum bus driver schedule.

Considering some constraints with certain criteria such as total overtime, multiple shifts, maximum daily work hours and mandatory rest periods contributes to the complexity of optimum schedule (M. Chen & Niu, 2012; Rodrigues et al., 2006). There are various techniques to generate optimum driver or crew schedule. There is a work that set the bus driver scheduling according to Phase Scheduling Mode which decides driver scheduling based on identified trips plan (Chen & Li, 2010). Valouxis & Housos (2002) illustrated a quick search approach which utilise cost matching, shortest path and set partitioning as the main algorithm. M. Chen & Niu (2012) translated bus driver scheduling problem into 0-1 integer programming considering early, day and late duty modes as well as time shift and work intensity constraints and finally solves it using tabu search algorithm.

Some works presented a way to solve bus driver scheduling problem with genetic algorithm using real life data in Shijiazhuang, China and Portuguese urban bus companies (Q. Chen & Li, 2010; Dias et al., 2002). Lourenço (2005) presented a multi objective driver scheduling model and solve it using tabu search technique, meta heuristics and genetic algorithm. Li & Kwan (2003) hybrid genetic algorithm and fuzzy set theory in their work. Vaquerizo et al. (2012) solved driver scheduling using Grasp algorithm and scatter search algorithm.

In this study, Harmony Search (HS) which has been developed by Geem et al. (2001) as a population-based meta heuristic optimisation is used to produce an optimum university shuttle bus driver scheduling. This paper is organized as follows: Section Mathematical Model for University Bus Driver Schedule presents the mathematical formulation for the university shuttle bus driver scheduling problem based on the requirement and the preference of the university. The proposed harmony search algorithm for university bus driver scheduling is presented in Section Harmony Search Approach for University Shuttle Bus Driver Scheduling Problem. Section Result and Discussion presents the results and finally concluding remarks are presented in the last section.

2. MATHEMATICAL MODEL FOR UNIVERSITY BUS DRIVER SCHEDULE

Since the university has a scattered campus and student accommodations, the management level has determined a set of route for their transportation services covered by shuttle buses. This service must be delivered to the students covering two shifts, morning and evening. According to the university management level, each driver must be covering one route only in a day. Besides that, according to the university policy, a worker can only work within 7 to 11 hours in a day. It must be noted that the assignment of the driver, route and shift must fulfil the weekly university demand. The management level also prefers each driver receives two morning shifts and two evening shifts in a month. They also prefer if the driver cover different route every week in a month.

Based on the requirement and the preferences of the university, a mathematical model has been formulated to produce university bus driver scheduling. A set of hard constraints which need to be fulfilled and a set of soft constraints have been structured as in Table 1. It must be noted that in order to produce an optimum schedule, soft constraints violation need to be minimized.

Table 1: DSP Constraints

Hard Constraints (HC)	1) Assign one type of shift and route per week for each driver.
	2) Weekly coverage demand of each shift type and route needs to be fulfilled.
Soft Constraints (SC)	1) Assigns each driver two weeks for morning shift and two weeks for evening shift in a month.
	2) Assigns each driver with different routes for every week in a month.

In order to ease the scheduling process, a set of pattern by combining a set of route and a set of shift is produced as in Table 2. For the purpose of this study, there are 7 different routes and 2 shifts (morning and evening) to be covered. The demands for every combination pattern are set by the university. For mathematical formulation purposes, we denote i, j, k, l and x as driver, shift, route, week and a schedule solution respectively. We denote c, f_c, $f_c(X)$ and m_c as soft constraints, value to the soft constraint c, value given by the soft constraint c applied to the solution X and threshold for the minimum tolerated weight respectively. The goal is to find a solution X that satisfies $f_c(X) > m_c$ for every soft constraint c.

Table 2: Combined Pattern of Route and Shift

Patterns	**Combination of Route and Shift**	Demand
0	Route 1 Shift M	5
1	Route 1 Shift E	2
2	Route 2 Shift M	3
3	Route 2 Shift E	2
4	Route 3 Shift M	2
5	Route 3 Shift E	2
6	Route 4 Shift M	1
7	Route 4 Shift E	1
8	Route 5 Shift M	1
9	Route 6 Shift M	3
10	Route 7 Shift M	2
11	Route 7 Shift E	1

The mathematical formulations for the hard and soft constraints are as follows:

$$\text{Min } c_{soft} = \sum_{c \in C} \left(x_{ijkl}\right) f_c\left(X\right) \qquad (1)$$

Subject to:

$$\sum_{j \in J} \sum_{k \in K} x_{ijkl} = 1 \quad ; \quad \forall i \in I, \forall l \in L \qquad (2)$$

$$\sum_{i \in I} x_{ijkl} = d_{jk} \quad ; \quad \forall l \in L \qquad (3)$$

$$\sum_{j \in J} \sum_{l \in L} x_{ijkl} = 2 \quad ; \quad \forall i \in I \qquad (4)$$

$$\sum_{k \in K} \sum_{l \in L} x_{ijkl} = 1 \quad ; \quad \forall i \in I \qquad (5)$$

Equation (2) and (3) is hard constraint 1 and 2 respectively while equation (4) and (5) is soft constraint 3 and 4 respectively.

3. HARMONY SEARCH APPROACH FOR UNIVERSITY SHUTTLE BUS DRIVER SCHEDULING PROBLEM

HS is inspired by mimicking the improvisation process of music players (Diao & Shen, 2012; Geem et al, 2001; Geem, 2008; Lee & Geem, 2005). In the performance of music, each musician will play one musical note at a time, and these note will be combined together to form a harmony which is measured by aesthetic standards (Geem et al., 2001; Hadwan, Ayob, Sabar, & Qu, 2013). According to (Geem et al., 2001; Geem, 2008) HS has the following characteristics: fewer mathematical requirements and generates a new solution iteratively after considering all the existing solutions; it has a novel stochastic derivative which reduces the number of iterations that are required to converge towards local minima; able to handle both discrete and continuous variables and finally proved to have simplicity, flexibility, adaptability, generality, and scalability. Various real world problems has been solved using HS as optimisation problem solution and it yield excellent result as well as outperform other techniques (Geem, 2010; Manjarres et al., 2013).

As a rule of thumb, a group of musician will keep on playing the note until harmonies are achieved. Same thing goes to HS whereby it improves the solution iteratively based on good candidate solutions originated from the initial population known as "harmony memory"

(Hadwan et al., 2013). A new solution known as "new memory" will be produced after each iteration (Al-Betar et al., 2012). The new memory will be compared with the existing one in harmony memory; the worst harmony in harmony memory will be deleted and being replaced with the new memory. This will be repeated until acceptable solution is obtained. It must be noted that the new harmony will be produced based on these operators: HMCR (harmony memory consideration rate (accumulative search)), random consideration (diversify the new harmony), pitch adjustment rate (PAR, analogous to local search) and bandwidth (BW). The pseudo code of HSA for university bus driver scheduling is shown in Table 3. This pseudo code is coded with C++ programming for automation purposes.

Table 3: The pseudo code of HSA for university bus driver scheduling

Step	Process	Description
1	HS parameter initialization	Define objective function, initialize HMCR, PAR and BW which is very important for producing new value during improvisation

2	HM initialization:
	-Initialize random pattern based on demand and assign it to drivers.
	-Evaluate soft constrains and calculate objective function.
		begin
		for i = (1 to WEEK) **do** /* WEEK is the number of weeks */
		for j = (1 to HMS) **do**
		$x^j = ø$;
		for k = (1 to n) **do** /* n is the number of drivers */
		choose one pattern randomly for driver *k* based on demands
		endfor
		evaluate the soft constraints
		calculate the objective function value $f(x^j)$
		add x^j to HM
		endfor
		endfor
		end

3	Solution Improvisation
	-produce new pattern (NCHV) for drivers according to demand.
		begin
		for i = (1 to NI) do /* NI is the maximum number of improvisations*/
		$x^{new} = ø$
		for j = (1 to n) do /* n is the number of drivers */
		if (rand (0, 1) ≤ HMCR) then
		choose pattern randomly from the HM
		if (rand(0,1) ≤ PAR) then
		adjust the chosen pattern according to bandwidth (BW)
		/* BW = {1,-1}; is used to change the index of the selected shift pattern */
		else
		add the chosen shift pattern to solution x^{new} without changing
		endif
		else
		choose pattern randomly from the patterns pool
		endif
		repeat process until fulfilled the demand

		add the chosen shift pattern to solution x^{new} **endfor** **endfor** **end**

4	HM update -NCHV obtained in Step 3 will be compared with HM. If the NCHV is better, then HM will be updated.	**begin**
		for i = (1 to HMS) **do**
		find the highest value of objective function (the worst one) in HM
		compare the objective function of NCHV x^{new} with the worst one x^j
		endfor
		if ($x^j > x^{new}$)
		| **replace** x^j with x^{new}
		else
		| **remain** x^j in HM
		endif
		sort HM in ascending order based on f(x)
		end

5	Termination criteria checking	Step 3 and 4 will be iterated until it reaches the termination criteria.

4. RESULT AND DISCUSSION

An automated monthly schedule which is developed using C++ for university shuttle bus driver has been generated in this study. Figure 1 denotes the result of the driver schedule using harmony search for month duration. The first row of the table denotes schedule for driver 1 until driver 25. W1, W2, W3 and W4 denote week 1, week 2, week 3 and week 4 respectively. For example the set of pattern generated for driver 5 is 10-2-7-9, which means that the driver will be covering morning shift at route 1, evening shift at route 4, evening shift at route 7 and finally morning shift at route 6 for week 1, week 2, week 3 and week 4 respectively. The objective function produced for this automated schedule is 27. It is impossible for the value of objective function to reach 0 as the violation of the soft constraints could not be eliminated completely. For example, it can be seen that driver 1 receives pattern 2 twice in which soft constraint 1 and 2 are violated. However, it must be noted that all the hard constraints are fulfilled.

D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
W1	2	7	1	0	0	4	3	0	5	2	1	10	6	2	0	0	9	8	4	9	5	10	3	9	11
W2	2	8	9	3	7	6	0	4	2	5	1	2	0	0	5	3	0	9	0	1	11	4	10	10	9
W3	5	0	0	2	11	3	2	9	9	10	1	7	9	0	0	8	5	4	2	4	3	0	10	6	1
W4	4	0	0	1	9	0	1	4	6	9	0	9	5	10	7	5	10	3	8	3	0	2	11	2	2

Figure 1: An automatic driver bus schedule in terms of pattern for the best result produced (29th iteration)

In order to proof the effectiveness of the intelligent automation of the bus driver schedule, a comparison of the result is made between the automate schedules produced using HS and the existing schedule manually formed by one of the university management. We evaluated the objective function for both schedule as depicted in Table 4. It can be seen that the schedule produced using HS outperformed the manual schedule since it produce the minimum objective function compared to the others. Therefore, HS is successfully applied for optimising the university shuttle bus driver scheduling for better operational management.

T-test is also performed to compare the means between two samples. Table 5 depicts the result of t-test performed between the samples of existing manual schedule with the sample of automate schedule using HS. The mean calculated for both samples are 0.352 and 0.266 for manual schedule and automate schedule using HS respectively. P-value for two tail test is less than 0.05, therefore, there is a significant difference between the means of these two samples. Hence, the optimised and automated university shuttle bus driver scheduling produced using HS is different and better than the one generated manually by the management of the university.

Table 4: Comparison of existing manual schedule and automate schedule Produced Using HS

Schedule	Objective Function
Existing (March)	0.37
Existing (April)	0.41
Existing (May)	0.33
Existing (September)	0.33
Existing (October)	0.32
Schedule using HS	0.27

Table 5: T-Test of Real Schedule and Produced Schedule using HS

T-Test: Paired Two Sample for Means	Manual (Real Schedule)	Proposed Method (HS)
	0.37	0.3
	0.41	0.27
	0.33	0.23
	0.33	0.26
	0.32	0.27
	Variable 1	*Variable 2*
Mean	0.352	0.266
Variance	0.00142	0.00063
Observations	5	5
Pearson Correlation	0.433480344	
Hypothesized Mean Difference	0	
Df	4	
t Stat	5.483159732	
P(T<=t) one-tail	0.0026937	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.005387401	
t Critical two-tail	2.776445105	

5. CONCLUSION

In this paper, Harmony Search algorithm is proposed to solve the university driver scheduling problem. The schedule take into account all the hard and soft constraint posed by the university management in order to provide a desired service to the students. A slight modification has been made to accommodate these constraints so that the solution is feasible. This technique proved to be a promising one since it generates better results compared to the existing schedule generated manually by the management team. In future works, the hybridization with other techniques in this driver scheduling problem will be applied to get an excellent and better result.

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