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A Novel Hybrid Multi-Verse Optimizer Algorithm for Energy-Efficient Permutation Flow Shop Scheduling Problem

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Abstract. Recently, The issue of energy consumption has become an issue that is often considered, and the manufacturing sector contributes to the most significant proportion of this problem. Energy-Efficient Permutation Flow Shop Scheduling Problem (EEPFSP) is an effective way to solve this problem. This research offers a new algorithm Hybrid Multi-Verse Optimizer Algorithm (HMVO). Siz experiments are presented to minimize total energy consumption. In addition, the Genetic algorithm (GA) and Ant Colony Optimization (ACO) algorithms were used as comparison algorithms. The experimental results show that HMVO requires low iterations to solve small and medium EEPFSP cases. However, the proposed algorithm requires large iterations to solve large case problems. In addition, the HMVO algorithm is more effective than GA and ACO in solving EEPFSP problems.

Keywords: Energy-efficient; flow shop; Multi-Verse Optimizer; Algorithm

1. Introduction

In manufacturing, electrical energy becomes an essential resource [1]. The electrical energy needs in the manufacturing sector have continued to increase in recent decades [2]. In Germany, this sector consumes more than forty-seven percent of the total domestic electrical energy [3]. Furthermore, manufacturing companies in China required almost half of the domestic electrical energy [4]. Moreover, electrical energy is generated from fossil fuels in power plants [5, 6]. Therefore, the manufacturing sector must contribute to minimizing this problem. One effective way to solve this issue is energy-efficient scheduling [7]. One of the energy-efficient scheduling issues is in the flow shop problem. This issue is called the Energy-Efficient Permutation Flow Shop Scheduling Problem (EEPFSP) [8]. Flow shop scheduling has job characteristics that are processed in the same order [9-11]. Researchers have published several EEPFSP studies. Several exact, heuristics, and metaheuristics procedures have been proposed. In the exact procedure, the branch and bound procedure were offered by Liu, Zhang, Yang, Chen and Huang [12], and Mixed Integer Linear Programming (MILP) was proposed by Fazli Khalaf and Wang [13]. One of the heuristic procedures proposed was Novel NEH [14]. In addition, Several metaheuristics and hybrid procedures have been proposed, such as ant colony optimization (ACO) (ACO) [15], Genetic Algorithm (GA) [16], A Modified Imunne Clone [17], Hybrid Whale Optimization [18]. The metaheuristic algorithm has high popularity from several procedures proposed in the EEPFSP problem compared to other procedures. One of the interesting new metaheuristic algorithms is the Multi-Verse Optimizer (MVO) algorithm [19]. This algorithm is inspired by the displacement of the position of the universe. The MVO algorithm has been applied in various engineering fields. However, to the best of our knowledge, the MVO algorithm was never applied in the EEPFSP problem. Therefore, this study proposes an MVO algorithm integrated with a tabu search procedure to solve the EEPFSP problem. We call this algorithm as hybrid MVO (HMVO). In the EEPFSP issue, this research concentrates on reducing energy consumption which concerns a sequence-dependent setup time.

2. Methods

2.1 Assumptions, notations, and mathematical models

One of the scheduling problems is EEPFSP which requires jobs to be completed in the same order on a series of machines. In this EEPFSP problem, this research involves setup time which depends on the sequence job. The assumptions used in this study are: (1) on all l machines, the start time is 0; (2) The setup time for each job on the machine depends on the job sequence; (3) machine finish time is defined as the time when the final work on each machine l is completed. Furthermore, (4) setup time should be separated from processing time, (5) no work should be interrupted. The following is a notation in the problem of minimizing total electricity energy consumption in the EEPFSP problem:

$\boldsymbol{l}$	list of machines, $l = 1,2 \dots q$
$\boldsymbol{k}$	list of jobs, $k = 1,2 \dots p$
$\boldsymbol{q}$	number of machines total
$\boldsymbol{p}$	number of jobs
$\boldsymbol{Sk}$	Setup time k job each machine in the first sequence (hour)
$\boldsymbol{S_{k,k+1}}$	setup time for moving sequence k to $k+1$ on all machines (hours)
$\boldsymbol{Tk,l}$	processing time for a job k to be processed on machines l (hour)
$\boldsymbol{Pel}$	index of machine electricity consumption l (watt/hour)
$\boldsymbol{Iel}$	electricity consumption index of machine l when idle (watt/hour)
$\boldsymbol{Sel}$	electricity consumption Setup index of machine l (watt/hour)
$\boldsymbol{Ck,l}$	completion time of job sequence k at on machines l
$\boldsymbol{Bl}$	total busy time of machines l (hour)
$\boldsymbol{Tl}$	completion time of machines l (hour)
$\boldsymbol{Sl}$	total setup time of machinesi$j$ (hour)
$\boldsymbol{Il}$	total machinery idle time l (hour)
$\boldsymbol{TEC}$	use of total energy (watt)

Figure 1. Notation in the problem of minimizing total electricity energy consumption in the EEPFSP problem

The mathematical model for the EEPFSP problem is as follows:

Goal function $Zmin = \min TEC$ (1)

Constraint :

$$C_{1,1} = S_1 + P_{1,1} \quad (2)$$

$$C_{1,l} = \max(C_{1,l-1}, S_1) + P_{1,l} \ , \qquad l = 2..q \quad (3)$$

$$C_{k,1} = C_{k-1,1} + S_{k-1,k} + P_{k,1} + \ , \qquad k = 2..p \quad (4)$$

$$C_{k,l} = \max(C_{k,l-1},\ S_{k-1,k} + C_{k-1,l}) + P_{k,l} + ,k = 2..p, l = 2..q \quad (5)$$

$$Bl = \sum_{k=1}^{p} P_{k,l} \ , \quad \forall\, l = 1..q \quad (6)$$

$$Sl = \sum_{k=2}^{p} S_{k-1,k} + S_1 \,, \qquad \forall\, l = 1..q \tag{7}$$

$$Tl = \max\,(C_{k,l}) \;,\; \forall\, k = 1..p,\; l = 1..q \tag{8}$$

$$Il = Tl - Bl - Sl \;, \qquad \forall\, l = 1..q \tag{9}$$

$$TEC = \sum_{l=1}^{q}(Bl.Pel + Il.Iel + Sl.Sel) \tag{10}$$

The objective function of reducing the energy electricity consumption of the EEPFSP issue is modeled in Equation (1). finish time on the first sequence job on machine 1 is formulated in the Constraints (2). Constraints (3) describes the finish time of the first sequence job on machines 2 to q. The finish time of k sequence jobs on machine 1 is modeled on the Constraints (4). Constraints (5) formulates the finish time of k job sequences on machine l. The busy time of each machine l is shown in Constraint (6). Constraints (7) describe the setup time. The machine completion time l is presented in Constraint (8). Constraint (9) shows the machine idle time l. The objective function TEC formula is presented in Equation (10).

2.2 Proposed Hybrid Multi-Verse Optimizer Algorithm

The Multi-Verse Optimizer (MVO) algorithm is motivated by events in nature, namely the displacement of the position of the universe. This inspiration originates in the theory of the presence of several universes and their interactions via white, black, and wormholes. In the Hybrid Multi-Verse Optimizer (HMVO) algorithm, three main stages are proposed: exploration, exploitation, and improving solutions with tabu search. In the exploration phase, to explore the search space, the MVO algorithm employs the concept of white holes and black holes. The roulette wheel mechanism is applied to the white holes choice and determination based on the normalization inflation rate. This mechanism is modeled in Equation (11). Where, x_j^i denotes the jth parameter on universes i-th, and Ui denotes universes i-th. $NI(Ui)$ is the normalization of the inflation rate universe i-th, and $r1$ indicates a random number [0 1]. x_k^j is the j-th parameter of the k-th universes choose by the roulette wheels mechanism.

$$x_i^j = \begin{cases} x_k^j \; r1 < NI(Ui) \\ x_i^j \; r1 \geq NI(Ui) \end{cases} \tag{11}$$

In each iteration, 2 MVO parameters must be updated, namely Traveling Distance Rate (TDR) and Wormhole Existence Probability (WEP). These parameters are modeled in equations (12) and (13). Where, l describes the present iteration, L shows the maximum iteration. min indicates the minimum value (0.2), and max describes the maximum value (1). In the TDR parameter, this parameter depends on the P value. The P value is 6, which indicates the exploitation of iterations. MVO algorithm exploitation formula is shown in Equation (14). Where, Lb denotes Lower bound, and Ub is Upper bound. $r2$, $r3$, and $r4$ are random values $[0, 1]$. In evaluating the fitness universe, this study proposes a large rank value (LRV) procedure to convert the vector position of the universes to job permutations [9-11].

$$WEP = min + l \times \left(\frac{max - min}{L}\right) \tag{12}$$

$$TDR = 1 - \frac{l^{1/P}}{L^{1/P}} \tag{13}$$

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$$x_i^j = \begin{cases} \begin{cases} X_j + TDR \times \left((ub_j - lb_j) \times r4 + lb_j \right) & r3 < 0,5 \\ X_i - TDR \times \left((ub_i - lb_i) \times r4 + lb_i \right) & r3 \geq 0,5 \end{cases} & r2 < WEP \\ x_i^j & r2 \geq WEP \end{cases} \quad (14)$$

In each iteration, the best solution is selected based on the fitness of the universe. Furthermore, it was improved using the Tabu Search Algorithm (TS). The five main stages of the TS algorithm are 1). Solution Representation, 2). Initial Solution based on the best universe in iterations l, 3). Neighborhood Solutions, 4). Tabu List, 5). Termination criteria [20]. Three neighborhood exchange rules are applied in the TS algorithm, such as swap, flip, and slide. Swapping two sequences is called as Swap rule. The Flip rule is carried out by reversing the order of the jobs. Further, shifting the order is referred to as a slide rule. Flip and swap in l iterations recur $p(p-1)/2$. Furthermore, the slide in iteration l recur p^2. The pseudocode of the proposed HMVO procedure demonstrates in algorithm 1.

```
Generate random universe (U)
Initialize TDR, WER, and Best fitness universes
while the final iteration is not met
    Apply LRV to convert position universes to job permutation
    Examine the fitness of all universes based on Equation (1)-(10)
    for each universe indexed by i
        Update TDR and WEP based on equation (12) and (13)
        For Black hole index = i;
        for each object index by j
            Exploration Phase
            r1 = Random([0, 1]);
            Apply equation (11)
            Explotitasion phases
            r2 = Random([0, 1])
            Apply equation (14)
        end For
    end For
    Improve solution in each iteration using tabu search
end while
```

Figure 2. Pseudocode Hybrid Multi-Verse Optimizier

2.3 Experiments

This study utilized Tk,l data from the research of Carlier [21] and Reeves [22]. The list of problems can be seen in table 1. Six cases were used with three data categories (small, medium, and large). Sk and $S_{k,k+1}$ data were generated from random numbers [1 10]. Pel, Iel, and Sel data were also randomly generated with values [5 10], [1 2], and [1 3], respectively. This EEPFSP experiment was conducted on 100 universes and two iteration variations (100 and 200). Each experiment was recorded to test the effect of TEC, energy setup, process energy, and energy idle. The HMVO algorithm was also compared with the ACO [15], GA [16] algorithm with 200 iteration parameters and a population of 100. This study was run using Matlab R2014a software on Windows 10 Intel (R) Core (TM) i5-4210U CPU @ 1.70. GHz 64-bit 4GB.

Table 1. EEPFSP problem case

Problem case	Familly case	Job	Machine	Refer from
Case 1 7/7	Small	7	7	Carlier [21]
Case 2 8/8	Small	8	8	Carlier [21]
Case 3 20/10	Medium	20	10	Reeves [22]
Case 4 20/5	Medium	20	5	Reeves [22]
Case 5 75/20	Large	75	20	Reeves [22]
Case 6 75/20	Large	75	20	Reeves [22]

3. Result and Discussions

The outcome of the experiment on the influence of iteration on electrical energy consumption are demonstrated in table 2. It shows that increasing iteration affects electricity energy consumption in the large case. However, increasing iterations did not affect the small and medium cases. These results indicate that solving small and medium cases requires low iterations. However, for the large case, the solution requires significant iterations. Other findings show that total energy consumption is influenced by setup and idle electricity energy consumption. In addition, the processing electricity energy consumption is fixed. Therefore, setup time and machine idle time need to be a concern in solving EEPFSP issues. The results of the comparison of the HMVO algorithm with ACO and GA are shown in Figure 1. It shows that in the small case, the three algorithms provide a similar result. Unfortunately, in medium and large, the HMVO algorithm provides a better solution than the GA and ACO algorithms. This research shows that the HMVO procedure is superior to the GA and ACO procedure for solving the EEPFSP problem.

Tabel 2. HMVO Experiment Results (watt)

Case	TEC		Energy setup		Energy Proses		Energy Idle	
	Iteration		Iteration		Iteration		Iteration	
	100	200	100	200	100	200	100	200
Case 1	97380	97380	364	364	75094	75094	21922	21922
Case 2	145351	145351	615	615	108777	108777	35959	35959
Case 3	39053	39053	1320	1320	32256	32256	5477	5477
Case 4	21220	21220	522	522	19206	19206	1492	1492
Case 5	258465	258256	8964	10008	218277	218277	31224	29971
Case 6	302922	303264	12831	13348	252507	252507	37584	37409

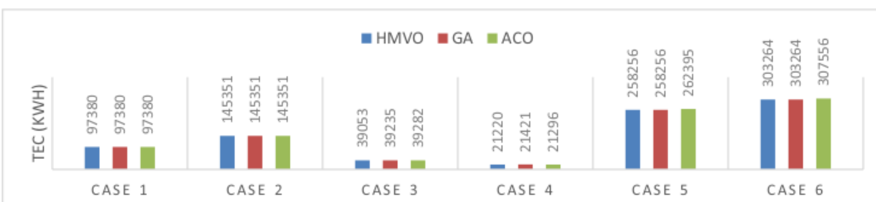

Figure 3. The results of the comparison of the HMVO algorithm with ACO and GA

4. Conclusion

This research proposes the HMVO procedure to solve the EEPFSP problem. Six cases were presented to test the effect of iteration on energy consumption. The results show that large iterations are effective for solving EEPFSP problems on large jobs. In addition, the HMVO algorithm provides a better solution than the GA and ACO algorithms. However, this study ignores the electricity tariffs that are generally used in the actual case. Therefore, in future research, it is necessary to consider energy tariffs in solving the EEPFSP problem.

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