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Energy-Efficient No-Idle Flowshop Scheduling Optimization Using African Vultures Algorithm

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ABSTRACT

The issue of energy consumption is currently a major concern globally, especially in the industrial sector, where most of the energy demand comes from the manufacturing sector. To reduce energy consumption, one of the proposed strategies is to reduce the idle time between jobs on machines during the production process, known as No-Idle Permutation Flowshop Scheduling (NIPFSP). This research proposes the application of the African Vultures Optimization Algorithm (AVOA) as a solution to the energy consumption challenge in the case of production scheduling. The algorithm is examined in detail through a series of trials to obtain the most efficient work order in the production schedule, subject to careful setting of iteration and population parameters. The result of implementing the AVOA algorithm is then compared with the method used by the company in a scheduling case. The research findings show that AVOA significantly outperforms the method commonly used by the company, confirming its performance advantage in optimizing energy consumption in the context of production scheduling.

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1. INTRODUCTION

In the last 10 years, energy demand in the world has increased rapidly. On the other hand, current energy resources are still dominated by fossil fuels (Wu & Che, 2019). The industrial sector has a major contribution to the use of global energy consumption (Ding *et al.*, 2016). Half of the total energy used comes from this sector, especially in the manufacturing industry sector, one of which is the convection industry. One strategy to be able to reduce energy consumption is to carry out efficient scheduling, to reduce unnecessary costs. Scheduling has a very important role in the problem of energy consumption in manufacturing companies (Utama, 2019). This indicates that production scheduling that focuses on structuring machine resources must be implemented immediately in manufacturing companies (Surjandari *et al.*, 2015; Nasution *et al.*, 2017). One of the scheduling problems that focuses on minimizing energy consumption is the No-Ilde Permutation Flowshop Problem (NIPFSP).

NIPFSP is a type of flowshop scheduling that does not allow machines to be idle during the production process (Zhao, Zhou, & Liu, 2021). In general, large energy consumption is generated during the production process. However, most of the energy is also generated when the machine is idle (Mouzon *et al.*, 2007). In this problem, the turn-off strategy cannot be used because if the machine turns off, it is necessary to start setting it again from the beginning, which is quite time-consuming. So, when done repeatedly, it will have an impact on the effectiveness and productivity of the machine (Tampubolon, 2018). Several previous studies have examined the NIPFSP problem with the aim of minimizing makespan, including Zhou *et al.* (2014) which used the invasive weed optimization algorithm, Shen *et al.* (2019) which used the General Variable Neighborhood Search (GVNS) algorithm, Rui & Xingsheng (2020) which used the discrete sine optimization algorithm, and Zhao *et al.* (2021) which used a cooperative water wave optimization algorithm. Meanwhile, there were studies that focus on minimizing tardiness, such as Tasgetiren *et al.* (2013) which used a discrete artificial bee colony and Nagano *et al.* (2017) which used the NEH method. Furthermore, for studies that focus on minimizing energy consumption, namely Chen *et al.* (2019) which used the Collaborative Optimization Algorithm, Cheng *et al.* (2021) which used Mixed-Integer Programming, and Al-Imron *et al.* (2022) which used the Grey Wolf Optimizer algorithm.

The goal of prior research on the NIPFSP problem has been to minimize energy consumption while employing multiple algorithms to solve it. Nevertheless, no study has been conducted that looks at NIPFSP issues with the goal of reducing energy usage by utilizing the African Vultures Optimization Algorithm (AVOA). In order to address the NIPFSP problem, which focuses on minimizing energy consumption, research suggests AVOA. One of the newest metaheuristic algorithms, AVOA, was developed by Abdollahzadeh *et al.* (2021) and is based on African vultures' hunting. The efficacy of this algorithm in resolving various optimization issues, including fuzzy controller optimization for two-link gripping mechanism trajectory tracking Jovanović *et al.* (2022), as well as optimization of distributed generation and capacitor banks in radial distribution systems (Biswal & Shankar, 2022) and also optimization of lithium-ion battery parameter (Fahmy *et al.*, 2023).

According to the above description, the research objectives of this study are as follows: 1) creating the AVOA algorithm to solve the NIPFSP problem, which tries to minimize energy consumption; and 2) contrasting the AVOA algorithm's output with the company's approach. The remainder of this article is summarized below. In Section 1, the research background is explained, in Section 2 a literature review on no idle flowshop scheduling is presented, the proposed method and algorithm are explained in Section 3, data on production process time, machine energy consumption, and machine specifications, altogether with research results are presented in Section 4, and conclusions from the research results are presented in Section 5.

2. LITERATURE REVIEW

The literature review on NIPFSP plays a crucial role in identifying, evaluating, and summarizing previous studies related to production scheduling in a flowshop environment without idle time between operations, conducted by a number of researchers with various objective functions. Table 1 displays some of the previous studies that used NIPFSP with various objective functions. The review's results indicate that the goal of makespan minimization dominates NIPFSP research, with only a few studies concentrating on efforts to minimize energy consumption. Therefore, in this study, researchers are interested in exploring the NIPFSP problem with a focus on the objective of minimizing energy consumption. This study proposes using the AVOA algorithm as a solution to the NIPFSP problem with the goal of minimizing energy consumption.

3. METHOD

According to research conducted by Zhao *et al.* (2021), the Permutation Flowshop Scheduling Problem (PFSP) is a type of scheduling that considers permutation constraints, where the order of job processing must be uniform on each machine. The PFSP can be classified into several categories, including the following:

(1) Permutation Flowshop Scheduling Problem (PFSP): PFSP is considered as a special form of flowshop scheduling problem, where jobs must follow a fixed and ordered production process path.
(2) No-Wait Flowshop Scheduling Problem (WFSP): WFSP plans the sequence of jobs without waiting. Once a job begins processing on the first machine, the system allows no waiting time between two consecutive machines until the last machine completes its processing.
(3) No-Idle Flowshop Scheduling Problem (NIPFSP): NIFPSP is the scheduling of work on machines without idle time, where each machine must complete work without interruption from the first job on the first machine to the completion of the last job on the last machine.

Figures 1–3 describe the differences among these three categories of PFSP.

Several presumptions are made in the context of NIPFSP, including the following:

(1) Every job set of size n must be performed on machine sets of size m in the same order.
(2) All jobs arrive and are prepared for processing when the job arrival time value is 0.
(3) The processing start time of the first job on the second machine to the m-th machine needs to be delayed in order to meet the no-idle requirement.
(4) Every machine is limited to processing a single job at a time, and every job can only be processed once on a single machine.
(5) The machine cannot be stopped until the last job is completed once the first job process has begun.
(6) Job processing time includes machine setup time.
(7) No idle machines are permitted while a job is being processed.

In recent years, high energy consumption has become a critical issue in the world (Koomey, 2011). The industrial sector is one of the largest energy-consuming sectors, accounting for one-half of the world's total energy (Fang et al., 2011). High energy use can affect the productivity of the company's production system itself. Thus, companies in the industrial sector are required to reduce their energy consumption. Usually, waste of energy consumption occurs when the machine is idle. Thus, companies, especially in the industrial sector, need proper production scheduling in order to minimize energy consumption.

To find out the total energy that has been consumed, it can be calculated using the mathematical formulation, i.e. proposed by Öztop *et al.* (2022). The objective function in this formulation is to minimize total energy consumption. The decision variables are the job sequence

Table 1. Literature review no-idle flow shop

No	Author	Method	Manufacturing system type	Objective function	Algorithm
1	Nagano *et al.* (2017)	Heuristic	No-idle flow shop	Minimize Tardiness	Insertion Constructive Heuristic (ICH)
2	Shao *et al.* (2017)	Heuristic	No-idle flow shop	Minimize Makespan	Memetic Algorithm with hybrid Node and Edge Histogram (MANEH)
3	Ying *et al.* (2017)	Heuristic	Distributed Assembly No-idle flow shop	Minimize Makespan	Iterated Reference Greedy (IRG) Algorithm
4	Liu *et al.* (2018)	Heuristic	No-idle flow shop	Minimize Energy Consumption	Nawaz Dudek Enscore Ham (NEH)
5	Shen *et al.* (2019)	Heuristic	No-idle flow shop	Minimize Makespan	General Variable Neighborhood Search (GVNS) Algorithm
6	Nagano *et al.* (2019)	Heuristic	No-idle flow shop	Minimize Makespan	Insertion constructive heuristic (ICH)
7	Öztop *et al.* (2020)	Heuristic	No-idle flow shop	Minimize Makespan	General Variable Neighborhood Search (GVNS) Algorithm
8	Rui & Xingsheng (2020)	Heuristic	No-idle flow shop	Minimize Makespan	Discrete Sine Optimization Algorithm
9	Della Croce *et al.* (2021)	Meta-heuristic	No-idle flow shop	Minimize Makespan	Integer Linear Programming (ILP)
10	Cheng *et al.* (2021)	Meta-heuristic	No-idle flow shop	Minimize Energy Consumption	Mixed-Integer Programming (MIP)
11	Zhao *et al.* (2021)	Meta-heuristic	Distributed Assembly No-idle flow shop	Minimize Makespan	Cooperative water wave optimization algorithm
12	Balogh *et al.* (2022)	Meta-heuristic	No-idle flow shop	Minimize Tardiness	Mixed Integer Linear Programming
13	Al-Imron *et al.* (2022)	Meta-heuristic	No-idle flow shop	Minimize Energy Consumption	Grey Wolf Optimizer Algorithm
14	Öztop *et al.* (2022)	Meta-heuristic	No-idle flow shop	Minimize Makespan	mixed-integer linear programming (MILP) and constraint programming (CP) model
15	Agnetis & Pranzo (2023)	Heuristic	No-idle flow shop	Minimize Makespan	Mixed-Integer Programming (MIP)
16	This research (2023)	Meta-heuristic	No-idle flow shop	Minimize Energy Consumption	African Vultures Optimization Algorithm (AVOA)

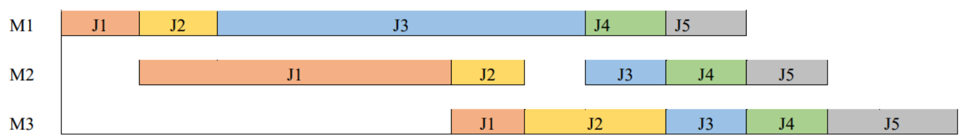

Figure 1. Pure flowshop

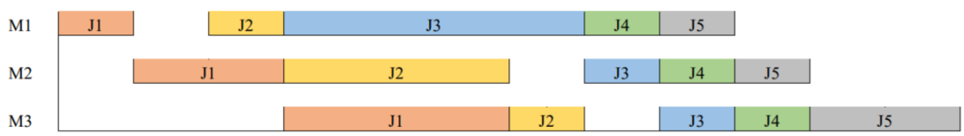

Figure 2. No-wait flowshop

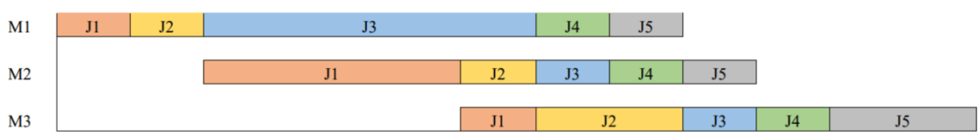

Figure 3. No-idle flowshop

in terms of binary variables and the speed of the job to be processed in each machine. The details of mathematical formulation are found in Risma & Utama (2023).

In the following paragraph, we describe the AVOA algorithm for minimizing energy consumption in the case of NIPFSP. In this study, the Large Ranked Value (LRV) is a simple, effective operation to convert the position of a batch into a sequential order of jobs, starting from the largest value to the smallest (Utama, 2018; Utama & Widodo, 2021). Figure 4 illustrates the LRV method in

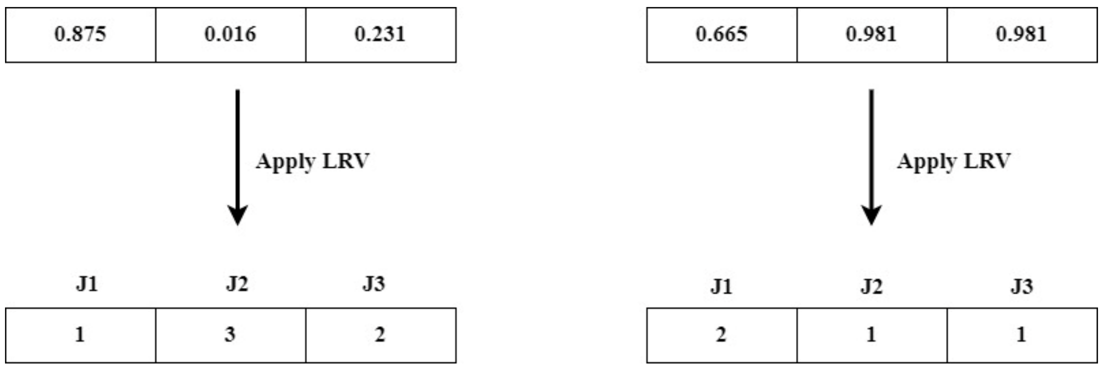

Figure 4. The LRV method

detail. LRV is a method that is effective for converting a continuous into a permutation work (Utama, 2021)

AVOA, a metaheuristic algorithm, divides vultures into groups led by the strongest vultures, mimicking the hunting behavior of African vultures. Since vultures can travel enormous distances in search of prey, a group of them will often search for prey when they are energetic and feel satisfied. Strong vultures can become aggressive when they are hungry, which can shift the hunting phase from exploration to exploitation. In this phase, African vultures avoid sharing food with other birds. Weak vultures, on the other hand, attempt to wear out strong vultures by congregating around healthy vultures and starting small fights. This study aims to resolve the energy consumption issue in the context of NIPFSP by utilizing AVOA. Risma & Utama (2023) provide the details of the AVOA solution for the NIPFSP.

4. RESULTS AND DISCUSSIONS

This research utilizes data from case study observations at a manufacturing company in Indonesia. The case study involved 27 tasks scheduled using the no idle flowshop scheduling method, with the process duration recorded in Table 2. Table 3 presents the idle energy consumption and process energy, while Table 4 displays the speed parameters. Furthermore, the research parameters include populations of 100, 300, and 500, with iterations of 100, 300, and 500, respectively. The output of each experiment is the total energy consumption.

The company applies the FCFS (First Come, First Served) method as an approach to scheduling production, which means that orders that arrive first will be processed first. The company operates the production process at normal machine speeds. The calculations conducted reveal a total energy consumption of 386.7503 KWh for the company's production schedule.

Table 2. Production process time

Job	M1	M2	M3	M4
1	0.75	0.00	5.01	150
2	1.50	37.50	10.02	450
3	11.40	285.00	76.15	3420
4	4.05	78.73	27.05	1620
5	3.60	59.04	0.00	840
6	7.35	120.54	49.10	1715
7	2.25	0.00	15.03	450
8	4.35	144.42	29.06	3480
9	1.05	0.00	7.01	210
10	2.10	0.00	14.03	560
11	11.40	285.00	76.15	3420
12	3.00	0.00	20.04	600
13	6.75	110.70	0.00	1575
14	19.50	319.80	130.26	4550
15	8.25	0.00	55.11	1650
16	8.40	210.00	0.00	2240
17	3.60	59.04	24.05	840
18	5.70	0.00	38.08	1140
19	7.50	123.00	0.00	6000
20	27.00	0.00	183.60	6300
21	24.30	398.52	0.00	7290
22	2.10	34.44	14.03	490
23	9.60	0.00	64.13	2240
24	6.90	113.16	0.00	1610
25	9.75	159.90	65.13	2275
26	0.45	7.38	3.01	105
27	1.80	29.52	12.02	420

Table 3. Energy consumption (KW)

Machine name	*Idle*	*Process*
Machine 1	0.333	0.750
Machine 2	0.685	1.500
Machine 3	0.490	0.900
Machine 4	0.170	0.250

Table 4. Speed parameters

Coefficient	Machine	Speed level normal
η	1	1
	2	1
	3	1
	4	1
λ	1	1
	2	1
	3	1
	4	1
φ	1	0.444
	2	0.457
	3	0.544
	4	0.678

The results of the calculation with iteration and population parameters using the AVOA algorithm have been presented in Table 5. From the calculation results, it can be concluded that the optimal performance lies at iteration 500 and population 500. In addition, the findings from the experiments show that increasing population and iteration result in lower Total Energy Consumption (TEC) values. Conversely, if the population and iterations are reduced, the resulting TEC tends to increase.

Comparison of the results obtained in the calculation of production scheduling using the company method with the AVOA method in order to find out which scheduling is more efficient. Based on this, it is known that the scheduling results using the AVOA method have more efficient results compared to the scheduling results using the company method. Table 6 shows the comparative results of the total energy consumption generated from production scheduling using the two methods. The result shows that the TEC difference between the two methods is 9.5673, therefore, TEC is able to make a more efficient schedule with 2.47% efficiency.

5. CONCLUSION

This research proposes the application of the AVOA algorithm as an approach in dealing with the No Idle Flowshop scheduling problem with the main objective of minimizing energy consumption. Within the framework of this research, the AVOA algorithm has been successfully developed and applied as a solution to the

Table 5. Calculation results of AVOA method

Population	Iteration	Job Sequence	Energy Consumption
100	100	J3-J26-J12-J6-J15-J14-J24-J25-J5-J9-J21-J22-J16-J18-J7-J13-J2-J19-J17-J8-J10-J23-J4-J27-J20-J1-J11	378.2552
	300	J26-J16-J3-J6-J2-J8-J4-J5-J22-J19-J17-J10-J27-J12-J14-J20-J23-J21-J24-J7-J18-J15-J9-J13-J25-J1-J11	377.9153
	500	J5-J13-J23-J3-J21-J19-J7-J15-J10-J16-J12-J2-J8-J4-J6-J27-J14-J11-J26-J17-J22-J24-J18-J9-J20-J1-J25	377.8496
300	100	J15-J16-J17-J5-J10-J11-J18-J19-J3-J20-J21-J22-J23-J7-J8-J24-J25-J9-J26-J12-J4-J14-J13-J27-J6-J1-J2	377.7821
	300	J5-J23-J10-J2-J12--J22-J7-J6-J24-J26-J15-J3-J8-J20-J17-J19-J25-J11-J9-J21-J27-J16-J18-J4-J13-J1-J14	377.7716
	500	J8-J13-J6-J14-J20-J5--J25-J9-J17-J11-J16-J23-J15-J18-J7-J10-J26-J24-J27-J4-J21-J12-J22-J3-J19-J1-J2	377.4840
500	100	J6-J20-J26-J22-J8-J19-J10-J2-J25-J17-J24-J15-J3-J9-J16-J5-J12-J21-J4-J7-J14-J23-J11-J27-J13-J1-J18	377.3591
	300	J18-J19-J3-J11-J2-J22-J12-J4-J8-J24-J7-J5-J25-J20-J15-J23-J17-J26-J21-J13-J14-J9-J10-J27-J16-J1-J6	377.3093
	500	J22-J15-J5-J14-J13-J23-J19-J10-J2-J6-J12-J9-J26-J7-J24-J27-J8-J21-J4-J17-J11-J18-J16-J20-J3-J1-J25	377.1835

Table 6. Comparison of company method scheduling with AVOA method

Methods	Job Sequence	TEC
Company	J1-J2-J3-J4-J5-J6-J7-J8-J9-J10-J11-J12-J13-J14-J15-J16-J17-J18-J19-J20-J21-J22-J23-J24-J25-J26-J27	386.7503
AVOA	J22-J15-J5-J14-J13-J23-J19-J10-J2-J6-J12-J9-J26-J7-J24-J27-J8-J21-J4-J17-J11-J18-J16-J20-J3-J1-J25	377.1835

production scheduling problem. The findings of the study highlighted the significant impact of energy consumption arising when machines are idle. Based on the results of the research conducted, the AVOA algorithm is proven to be effective in addressing No Idle Flowshop scheduling challenges, with a focus on reducing energy consumption.

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