Batch Flow shop scheduling using Camel Optimization Algorithm for minimization energy consumption

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**Abstract.**  The main problem in batch flow shop production scheduling is minimizing energy consumption while considering the machine capacity and the optimal number of batches. This research aims to implement the Camel Algorithm to address this problem and evaluate its effectiveness in reducing energy consumption. The method involves parameterizing the Camel Algorithm, including determining temperature and visibility and iterative iteration to find the optimal solution. The results showed that the Camel Algorithm with a population of 200 and 200 iterations resulted in the lowest total energy consumption of 1063.6, with the optimal number of batches varying from 7 to 13, depending on the applied machine capacity. This finding indicates that the Camel Algorithm effectively reduces energy consumption in production scheduling. The implications of this research are essential for industries focusing on energy efficiency, especially in the context of batch production, with wide applicability potential to improve operational sustainability and energy cost reduction.

**Keywords:** Batch Scheduling, Flow shop, Camel Algorithm, Energy Consumption

# INTRODUCTION

In the current industrial era, energy demand in various industrial sectors is increasing and diversifying, significantly impacting the environment. Energy use in the industrial sector includes various energy sources, such as natural gas and petroleum, the primary raw materials in production. The industrial sector is the largest energy consumer globally, absorbing about half of the world's total energy consumption. [1]. In Europe, energy use in some building’s accounts for up to 40% of total energy consumption. It contributes 36% to total carbon dioxide (CO2) emissions. Therefore, improving energy use efficiency is essential to achieve energy savings and reduce negative environmental impacts. [2]. Countries like Germany have pioneered energy transformation policies with stringent standards that reduced heating fuel consumption by 15% between 2002 and 2010. [3]. It demonstrates the urgency to prioritize energy efficiency across all sectors, including manufacturing, where energy consumption significantly impacts the economy, environment, and operational performance [4].

Innovation in energy efficiency is also increasing, especially in the manufacturing industry. Data shows that in 2012, the industrial sector absorbed 31% of total global electricity consumption, with the manufacturing industry accounting for 90% of that described [5]. This significant energy consumption highlights the importance of introducing new technologies and methodologies to reduce energy consumption significantly [6]. One of the main challenges in production scheduling is optimizing factors such as turnaround time, cost, and quality. However, environmental factors like energy consumption are often overlooked [7]. Therefore, innovations incorporating energy optimization in batch scheduling in flow shop production systems have become urgent. In this regard, the Camel Optimization Algorithm (COA) method offers an innovative solution, mimicking camels' adaptability in dealing with extreme environmental conditions, to maximize energy efficiency in production scheduling.

Previous research has examined batch flow shop scheduling with various energy optimization approaches. For example, the two-mixed integer method solves batch-scheduling problems in flow shops [8]. In addition, other approaches include the capacitated lot-sizing problem in flow shop systems with energy considerations. [9], as well as energy-aware batch scheduling using an ant colony optimization algorithm [9]. [10]. Other research also includes lot-sizing in multi-stage flow line production systems with energy considerations. [11], as well as batch scheduling for energy consumption minimization in heat treatment applications [11]. [12]. Meanwhile, some research focuses on the dual-objective optimization of single-machine batch scheduling with energy cost considerations. [13], and energy-efficient scheduling of batch processing machines with dynamic job arrival times [13]. [14]. Although these studies make significant contributions, most only focus on the energy minimization aspect without considering other factors such as batch demand and machine capacity. [15].

Although various approaches have been proposed for batch flow shop scheduling with energy considerations, shortcomings have not been optimally addressed. Most studies only consider energy minimization without considering the complex interaction between batch demand and machine capacity, which can affect the system's overall performance. In addition, the optimization approaches used are still less effective in handling scenarios with many variables and uncertainties. It is where the Camel Optimization Algorithm (COA) makes a significant contribution [16]. By mimicking camels' adaptive behavior in extreme conditions [17], COA is expected to provide a more flexible and efficient solution to flow shop scheduling problems. This research aims to fill the gap by applying COA to batch flow shop scheduling to minimize energy consumption while improving previous approaches' shortcomings in flexibility and efficiency. The main contribution of this research is to provide an innovative and more adaptive optimization solution to reduce energy consumption in manufacturing processes.

# METHODS

## ASSUMPTIONS AND PROBLEM DEFINITION

The batch flow shop scheduling problem discussed in this study is based on several crucial assumptions. First, the production process consists of two stages, namely machine 1 and machine 2. Machine 1 is the initial stage in the production process, while machine 2 is used at the final stage. Second, the capacity of machine 1 is assumed to be smaller than the capacity of machine 2, which can affect the production flow and efficiency of completion time. Third, multiple jobs can be grouped into a single batch, which enables process optimization based on similar or matching job characteristics. Finally, the processing time for each batch is calculated as the accumulation of the processing time of each job contained in the batch. Thus, the duration of batch completion is highly influenced by the number and complexity of jobs. A further illustration of this problem is shown in **FIGURE 1**, which depicts the process flow of batch flow shop scheduling on the two machines used.



**FIGURE 1.** Illustration of batch flow shop scheduling problem

## CAMEL ALGORITHM

In this research, the Camel Algorithm is applied to solve batch flow shop scheduling problems to minimize energy consumption. The Camel Algorithm implementation procedure consists of several critical steps. First, the parameters of the algorithm are determined, which include the number of camel deployments (N), number of iterations, upper and lower bounds, maximum temperature (Tmax), minimum temperature (Tmin), and visibility values. These parameters are essential in optimizing and influencing how the algorithm explores the solution space and adapts the camel locations. The next step is to initialize the camels' initial locations distribution. At this stage, the camel herd is randomly initialized within the predefined solution space using equation (1). where and are the upper and lower bounds of the solution space, and are random values.

(1)

Once the initial location is determined, the Large Rank Value (LRV) method converts the camel position to permutation order. This procedure is an effective and easy for convert positions to permutation sequences [18-22]. Next, the fitness value is calculated based on the energy consumption of the camel's initial location. The process of updating the ambient temperature includes updating the temperature based on equation (2).

(2)

Next, the latest camel location is determined using equation (3):

(3)

The latest camel location is then compared with the visibility threshold value. Suppose the random visibility value at each camel location is greater than or equal to the visibility threshold. In that case, the location is updated using the above equation (3). Otherwise, the camel locations are fixed using the initialization equation (1). This process is followed by sorting the latest location updates using the LRV method and calculating the fitness value for the latest camel location.

These steps are repeated at each iteration until it reaches a predetermined iteration limit. Finally, the best fitness value of each updated camel location is evaluated to obtain the optimal solution for minimizing energy consumption. This pseudo-code of the Camel Optimization algorithm directs the process of calculating and updating camel locations with high efficiency, ensuring optimal results in the context of batch flow shop scheduling. The pseudo-code of the Camel Optimization algorithm for minimizing energy consumption of batch flow shop scheduling problem is as follows:

**Algorithm: Modified COA**

**Begin**

**Step 1**: **Initialization**:

Set the temperature range and the location range Tmin and Tmax ; set the camel caravan size and the dimension; set the visibility threshold; initialize the location of each camel from Eq.(1).

Determine permutation job using **LRV.**

**Step 2:** Subject the locations to a certain fitness function for energy consumption; determine the current best location; randomly assign a visibility (v) for each camel.

**Step 3: While** (iter<itermax) **do**

**For** i=1: Camel Caravan Size

Compute the temperature T from Eq. (2)

Compute the endurance E from Eq. (3)

If v < visibility threshold, then

Update the camel location from Eq. (3)

**Else**

Update the camel location from Eq. (1)

**End If**

**End For**

LRV Location & Energy Consumption Update

**If the** new best location is better than the older one

The new best is the global best

**End If**

Assign new visibility for each camel

**Step 4: End While**

**Step 5:** Output the best solution

**End**

## DATA

At this stage, collecting the data required for data processing is crucial in solving flow shop batch scheduling problems by considering machine capacity constraints. The data collected includes processing time and demand information for each job and each machine's capacity and energy consumption. **TABLE 1** presents the processing time and demand for each job in the system, which includes the estimated duration of time required to complete each batch and the number of units to be produced. **TABLE 2** provides information on the capacity and energy consumption of each machine in the system, detailing the maximum capacity that can be processed by each machine and the amount of energy consumed during the production process. This data is essential for scheduling analysis and optimization, as it allows an accurate assessment of the efficiency of energy use and the fulfillment of machine capacity during the production process.

**TABLE 1**. Process Time and demand table

|  |  |  |  |
| --- | --- | --- | --- |
| **Job** | **Demand (Kg)** | **M1 (Minute)** | **M2**  **(Minute)** |
| 1 | 250 | 75 | 225 |
| 2 | 50 | 15 | 45 |
| 3 | 175 | 52.5 | 157.5 |
| 4 | 275 | 82.5 | 247.5 |
| 5 | 125 | 37.5 | 112.5 |
| 6 | 50 | 15 | 45 |
| 7 | 150 | 45 | 135 |
| 8 | 275 | 82.5 | 247.5 |
| 9 | 225 | 67.5 | 202.5 |
| 10 | 125 | 37.5 | 112.5 |
| 11 | 275 | 82.5 | 247.5 |
| 12 | 125 | 37.5 | 112.5 |
| 13 | 50 | 15 | 45 |
| 14 | 275 | 82.5 | 247.5 |
| 15 | 100 | 30 | 90 |
| 16 | 150 | 45 | 135 |
| 17 | 175 | 52.5 | 157.5 |

**TABLE 2**. Capacity and Energy of Each Engine

|  |  |  |  |
| --- | --- | --- | --- |
| **Machine Name** | **Engine Capacity (Kg)** | **Process Energy (Kw/Min)** | **Idle Energy (Kw/Min)** |
| M1 | 500 | 0,03667 | 0,01333 |
| M2 | 600 | 0,4 | 0.08333 |

# RESULTS AND DISCUSSION

## OPTIMIZATION RESULTS

In this study, we applied the Camel Algorithm to a batch flow shop scheduling problem with 17 jobs and two machines. The calculation results using the MATLAB program show the performance of Camel Algorithm method in minimizing energy consumption. **TABLE 3** shows the calculation results, including the total energy consumption, process energy, idle energy, and number of batches for various combinations of population parameters and iterations.

The calculation results showed that the best energy consumption value was obtained in the configuration of population 200 and iterations 200. This configuration resulted in a total energy consumption of 1063.6, the lowest value compared to the other experiments. In this configuration, the process energy was recorded at 1057.4 and the idle energy at 6.25, with the most efficient number of batches at 7. **TABLE 3** presents the recapitulation of energy consumption for various parameter combinations, showing that while the total energy consumption remained consistent across all experiments, the number of batches varied.

The implications of this study show that the Camel Algorithm, with proper population and iteration parameters, can be effectively used to minimize energy consumption in batch flow shop scheduling systems. The success in achieving optimal total energy consumption at a population configuration of 200 and 200 iterations proves that this method is reliable for industrial applications that require efficient energy management.

**TABLE 3.** Recapitulation of Camel Algorithm Method energy consumption

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Population** | **Iterations** | **Total energy consumption** | **Energy Process** | **Energy Idle** | **Batch Quantity** |
| 50 | 50 | 1063.6 | 1057.4 | 6.25 | 8 |
| 200 | 1063.6 | 1057.4 | 6.25 | 8 |
| 500 | 1063.6 | 1057.4 | 6.25 | 8 |
| 200 | 50 | 1063.6 | 1057.4 | 6.25 | 8 |
| 200 | 1063.6 | 1057.4 | 6.25 | 7 |
| 500 | 1063.6 | 1057.4 | 6.25 | 8 |
| 500 | 50 | 1063.6 | 1057.4 | 6.25 | 8 |
| 200 | 1063.6 | 1057.4 | 6.25 | 9 |
| 500 | 1063.6 | 1057.4 | 6.25 | 8 |

## CAPACITY EFFECT SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to evaluate the effect of machine lot capacity variations on energy consumption in a batch flow shop scheduling system. The results of this sensitivity analysis are presented in **TABLE 4**, which shows how changes in machine capacity affect total energy consumption, process energy, idle energy, and the number of batches required. The table presents data for various machine capacities, ranging from 300 to 900, with consistent population and iteration configurations of 50, 200, and 500 iterations.

The main finding of this analysis is that decreasing the machine capacity significantly affects the total energy consumption and the number of batches required. When the machine capacity was reduced from 900 to 300, the total energy consumption decreased consistently from 1073.6 to 1059.9. Simultaneously, the idle energy also decreased while the number of batches required increased. It shows that the smaller the machine capacity, the more efficient the system is in terms of energy consumption, but it requires more batches to complete the job. For a capacity of 300, for example, the total energy consumption reaches 1059.9 with 13 batches. In contrast, at a capacity of 900, it only requires four batches but with higher energy consumption.

The sensitivity analysis findings show that machine capacity variations significantly affect the total energy consumption and the number of batches required in the flow shop batch scheduling system. These results indicate that adjusting machine capacity can improve energy efficiency by reducing total energy consumption, even if it increases the number of batches. However, it should be noted that these findings apply in a context where the production process does not require a production setup.

This research deliberately ignores the production setup factor, an essential element in many production systems. Production setup, which includes the time and cost required to organize machines and tools before starting the production process, can significantly affect total costs and operational efficiency. If the production setup is considered, the results obtained may be different. For example, a reduced machine capacity leading to an increase in the number of batches may lead to a proportional increase in setup time, ultimately reducing the gains from the energy savings achieved.

In the context of production that requires setup, a smaller machine capacity may require more time for the preparation of each batch, which may add to the total production time and operating costs. Therefore, while this analysis shows that a smaller machine capacity can improve energy efficiency, it does not consider the additional setup time that may affect the overall results.

**TABLE 4** Recapitulation of the Effect of Capacity

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Capacity | Population | Iterations | **Total energy consumption** | **Energy Process** | **Energy Idle** | **Batch Quantity** |
| 900 | 500 | 50 | 1073.6 | 1057.4 | 16.25 | 4 |
| 200 | 1073.6 | 1057.4 | 16.25 | 4 |
| 500 | 1073.6 | 1057.4 | 16.25 | 4 |
| 800 | 500 | 50 | 1071.1 | 1057.4 | 13.75 | 4 |
| 200 | 1071.1 | 1057.4 | 13.75 | 4 |
| 500 | 1071.1 | 1057.4 | 13.75 | 4 |
| 700 | 500 | 50 | 1068.6 | 1057.4 | 11.25 | 5 |
| 200 | 1068.6 | 1057.4 | 11.25 | 5 |
| 500 | 1068.6 | 1057.4 | 11.25 | 5 |
| 600 | 500 | 50 | 1066.1 | 1057.4 | 8.75 | 6 |
| 200 | 1066.1 | 1057.4 | 8.75 | 6 |
| 500 | 1066.1 | 1057.4 | 8.75 | 6 |
| 500 | 500 | 50 | 1063.6 | 1057.4 | 6.25 | 8 |
| 200 | 1063.6 | 1057.4 | 6.25 | 8 |
| 500 | 1063.6 | 1057.4 | 6.25 | 8 |
| 400 | 500 | 50 | 1061.1 | 1057.4 | 3.75 | 11 |
| 200 | 1061.1 | 1057.4 | 3.75 | 10 |
| 500 | 1061.1 | 1057.4 | 3.75 | 10 |
| 300 | 500 | 50 | 1059.9 | 1057.4 | 2.50 | 12 |
| 200 | 1059.9 | 1057.4 | 2.50 | 13 |
| 500 | 1059.9 | 1057.4 | 2.50 | 13 |

# CONCLUSIONS

This study successfully applied the Camel Algorithm to minimize energy consumption in a batch flow shop production scheduling system with two machines. The analysis results show that using the Camel Algorithm with a population of 200 and 200 iterations results in the lowest total energy consumption, 1063.6, with the optimal number of batches. This finding confirms the effectiveness of the Camel Algorithm in optimizing energy consumption by considering machine capacity and batch variability. However, this study has some limitations. First, this study ignores the production setup factor, which is often essential in production processes. Without considering the setup time and cost, the results may not fully reflect operational efficiency and cost. Second, this research only uses one type of algorithm, the Camel Algorithm, without comparing it with other optimization methods that may provide better or different results. Suggestions for future research are to expand the scope of research by considering production setup factors in the scheduling model. It will provide a more accurate picture of energy efficiency and operational costs. In addition, research can compare the Camel Algorithm with other optimization algorithms, such as Genetic Algorithm or Simulated Annealing, to determine the most effective method. Future research can also extend the analysis by using data from different types of industries to test the generalizability of the findings and the method's effectiveness under various production conditions.

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