Minimizing Makespan In Flow Shop Scheduling: The CDS Method with Overlapping

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ABSTRACT

This study implements The Campbell, Dudek, and Smith (CDS) scheduling method with overlapping to enhance production efficiency, with the primary objective of minimizing makespan through strategic job overlapping. The overlapping technique divides the selected job into two batches, where the first batch, upon completing Machine 1, immediately proceeds to Machine 2, while the second batch undergoes Machine 1. Once the second batch completes Machine 1, it is transferred to Machine 2. Machine setup is only performed upon job arrival. The results indicate a lead time saving of 83 minutes, reflecting a significant reduction in total processing time. This corresponds to a 4.69% decrease in makespan, suggesting the efficiency of the CDS method's overlapping approach in optimizing scheduling performance and resource utilization.

Keywords: *Scheduling, CDS, multi-machine flow shop, Overlapping*

Introduction

Production scheduling, a strategic planning activity, involves the allocation of resources such as machinery and manpower to execute a sequence of tasks within a specified [1]. This process significantly impacts the satisfaction of consumer demand, which can be measured by comparing the total production time with the deadline. If the production time is within or less than the due date, consumer demand can be met on time. However, if the production time exceeds the due date, consumer demand fulfillment will be delayed, leading to potential customer dissatisfaction. Resource constraints often lead to scheduling issues. Therefore, effective scheduling is not just important, but crucial for maximizing resource usage and meeting consumer demand in the right quantity and at the right time. Increasing a company's competitiveness and productivity in manufacturing requires effective production scheduling. A popular production technique called flow shop scheduling requires that several operations be completed in a predefined order using a particular set of equipment or production steps. In flow shop scheduling, reducing the makespan—the time needed to finish all jobs—is the main problem. This optimization depends on a more successful and efficient production process.

The heuristic approach is one of the strategies developed to optimize scheduling in flow shops. Compared to exact optimization techniques, the heuristic approach is quicker and more useful, particularly for large-scale, complex issues [2] This approach can produce near-optimal answers in less time by applying straightforward but efficient decision rules.

Aside from the heuristic method, the overlapping strategy presents a valuable tool for enhancing scheduling efficiency. This approach allows a job to progress to the next stage before the previous one is fully completed, thereby reducing waiting time between processes and accelerating the overall completion [3]. When integrated with the heuristic method, the overlapping strategy is anticipated to further optimize the scheduling system, leading to a reduction in makespan and an enhancement in production efficiency.

Numerous studies have examined flow shop scheduling to reduce makespan through heuristic techniques. The backward scheduling model in a two-stage hybrid flow shop system seeks to minimize mean flowtime . While this study does not explicitly address batch overlapping, the proposed model may enhance scheduling efficiency within the production system [2]. The dynamic batch scheduling model uses a backward scheduling approach and heuristic methods to minimize the average tardiness of order completion and scrap quantity in the flow shop production system; however, this study does not apply batch overlapping [4]. Furthermore, the Cross Entropy-Genetic Algorithm (CEGA) has been developed to optimize makespan in flow shop scheduling [5].

The Campbell, Dudek, and Smith (CDS) scheduling method is among the most frequently utilized methods in flow shop scheduling to minimize makespan. It is commonly employed as a benchmark for comparing various heuristic approaches within the domain. Numerous studies have implemented CDS Method and evaluated its performance relative to other heuristic techniques. One such study examined the effectiveness of both the Genetic Algorithm and CDS method in addressing flow shop scheduling problems based on makespan criteria. The findings indicated that both methods were capable of generating near-optimal solutions for complex scheduling scenarios [6].

Another study introduced a modified version of CDS Method tailored for flow shop environments involving parallel machines, batch processors, and assembly stations. The results demonstrated that this adaptation produced efficient scheduling outcomes for the given case [7]. Additionally, a comparative analysis involving CDS method, Bat Algorithm, and Tabu Search was conducted, revealing that CDS method achieved a shorter makespan than the alternative approaches [8]. Moreover, a hybrid scheduling technique that integrates elements from both the NEH and CDS method was developed to further minimize makespan. The study concluded that this combined approach resulted in more efficient scheduling compared to the First Come First Serve (FCFS) method [9]. Based on several previous studies, CDS method was selected because it offers a more straightforward and more computationally efficient approach compared to methods such as NEH or Genetic Algorithm (GA). CDS Method is capable of producing reasonably good solutions in a shorter amount of time and does not require complex parameter settings or configurations, unlike GA. Furthermore, CDS method is more straightforward to implement in production systems with a fixed number of machines and a linear processing sequence, making it well-suited for this study, which focuses on makespan optimization within a clearly defined flow shop structure.

In addition, research on batch overlapping has also been conducted to improve the efficiency of flow shop scheduling. The implementation of batch overlapping can reduce machine idle time and increase production throughput [10]. The integration of heuristic methods with batch overlapping in flow shops has been found to significantly optimize production performance [11]. However, most previous studies have applied either CDS method or overlapping separately. Research that explicitly integrates both approaches, particularly within small-scale real-world production systems, remains very limited. This gap forms the primary focus of the present study, which aims to evaluate the effectiveness of integrating CDS method and batch overlapping in improving scheduling efficiency.

This study aims to analyze and evaluate the application of CDS method combined with overlapping techniques in flow shop scheduling to minimize makespan. With the potential to inspire positive change in the manufacturing industry, this research could motivate the development of more optimal scheduling strategies and the improvement of overall productivity.

Research Methods

This research employs a quantitative approach by integrating CDS method with the overlapping technique within a flow shop scheduling system. The primary objective of this study is to minimize the makespan and assess the enhancement of scheduling efficiency compared to the conventional implementation of the CDS method. This study addresses the issue of prolonged makespan resulting from suboptimal job sequencing in a multi-machine production environment. To mitigate this problem, the classical CDS method is enhanced by integrating an overlapping technique to accelerate the overall production flow.

In flow shop scheduling, CDS approach establishes the ideal job sequence that minimizes overall completion time. The dataset used in this study contains the number of machines, jobs, and processing times for each task on each computer. The CDS approach determines an efficient job sequence based on these processing times. When CDS method is used with the overlapping technique, activities on the next machine can begin before the prior machine's entire batch of work is completed, speeding up the overall production flow. However, two critical variables must be considered in this case: waiting time (w_{ij}) and machine setup time (s_m).

Waiting time (w_{ij}) refers to the time a task must wait before being processed on the next machine, which is usually caused by the machine continuing to process previous jobs or gaps between processes. Machine setup time (s_m) refers to the time required to prepare the machine for a new job, such as tool adjustments or calibration. Both variables must be considered in the scheduling design to ensure a more accurate estimation of work durations and a smooth production flow with minimal delays. By including waiting and setup time into the overlapping technique, scheduling may be optimized to eliminate idle time between machines and considerably reduce makespan. This strategy improves production efficiency and speeds up the completion of all jobs in the flow shop system. Figure 1 illustrates CDS method with overlapping.

A comparative evaluation was conducted between the standard CDS method and the modified CDS approach incorporating the overlapping technique based on three key performance indicators: makespan *(Fmax),* total flow time *(Fij),* and. As illustrated in Figure 1, this Gantt Chart illustrates three jobs (Job 1, Job 2, and Job 3) processed sequentially through three machines, namely Machine 1 (M1), Machine 2 (M2), and Machine 3 (M3). Each job is represented by differently colored blocks—blue for Job 1, red for Job 2, and green for Job 3—indicating the processing duration on each machine. Before processing begins on each machine, a small orange block signifies the setup time, which is the time required to prepare the machine before processing a new job. Meanwhile, the gray striped areas represent waiting time, the duration a job must wait because the next machine is not yet ready to receive the process.

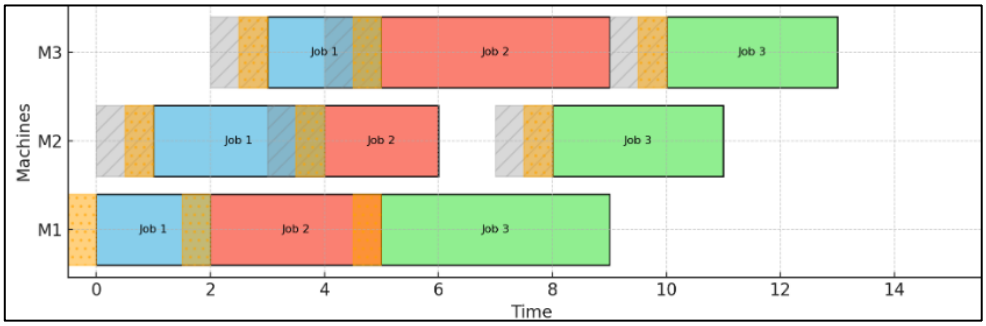

Figure 1. CDS Method with Overlapping (with wait and setup times)

The application of the overlapping technique is visible in this gantt chart, where a portion of a job batch can be processed immediately on the next machine, even though processing on the previous machine has not been fully completed. For example, Job 1 begins processing on Machine 2 before the entire batch finishes on Machine 1 and proceeds to Machine 3 even though processing of Job 1 on Machine 2 is ongoing. This approach allows parallel processing between machines and between batches, thus reducing machine idle time and accelerating the completion of all jobs (makespan). Scheduling, considering waiting and setup time, results in more realistic and efficient outcomes. This graphic shows how properly developed overlapping techniques can dramatically increase production system efficiency in a flow shop setting.

In the overlapping technique, the selected job is divided into two batches. Once the first batch completes machine 1, it immediately proceeds to machine 2, while the second batch undergoes operation 1. When the second batch finishes machine 1, the first batch is already in machine 2, and the second batch is promptly transferred to Machine 2 upon completion. Machine setup is performed only when a job arrives.

Indices, parameters, variables, and notations used in this paper are shown as follows.

Indicies :

i = index of jobs, $i = 1,2, \dots, n$

j = index of machines, $j = 1,2, \dots, m$

k = index of position in job sequence, $k = 1,2, \dots, n$

Parameters :

n = total number of jobs

m = total number of machines

N = total number of batches

tij = processing time of job i on machine j

w = Waiting time

s_m = Set up time

r_{ij} = start time of job i on machine j

F_{ij} = completion time of job i on machine j

Decision Variables :

$\chi_{ik} \in \{0,1\}$ = 1 if job i is assigned to position k in the sequence, 0 otherwise

$r_{ij} \geq 0$ = Start time of job i on machine j

$F_{ij} \geq 0$ = Completion time of job i on machine j

$Fmax \geq 0$ = Makespan (completion time of the last job on the last machine)

The CDS method, proposed in 1965, is an extension of the well-known Johnson's Rule. Johnson's Rule is commonly applied to determine the optimal job sequence for two-machine flow shop problems by dividing a production process into two distinct machine groups [12]. The CDS method generalizes this approach to accommodate flow shop scheduling involving more than two machines by constructing a series of hypothetical two-machine problems based on the original system.

The procedural steps of The CDS method are as follows:

1. Calculate $t^*_{i,1}$ dan $t^*_{i,2}$ for each *job* i.
   - $t^*_{i,1}$ represents the cumulative processing time of job i across the first k machines.
   - $t^*_{i,2}$ denotes the cumulative processing time of job i across the remaining $m-k$ machines. These computations are performed for each iteration, where $k = 1,2,\dots,m-1$
2. Identify the minimum value between $t^*_{i,1}$ and $t^*_{i,2}$ for each job.
3. If the minimum value occurs in $t^*_{i,1}$, the job is scheduled as early as possible in the sequence. Conversely, if the minimum occurs in $t^*_{i,2}$, the job is scheduled as late as possible.
4. Remove the scheduled job from the job list. If there are remaining unscheduled jobs, return to Step 2. The process continues until all jobs are scheduled, completing a total of $m-1$ iterations.

The CDS method involves transforming a flow shop problem with more than two machines into multiple two-machine problems. Each transformation is associated with a specific iteration k and the cumulative processing times for each job are computed as follows:

$$t *_{i,j} = \sum_{j=1}^{k} t_{i,j} \tag{1}$$

$$t *_{i,2} = \sum_{j=k+1}^{m} t_{i,j} \tag{2}$$

To evaluate machine utilization and efficiency, the calculation of idle time is essential. The modified start time on machine $j-1$ for job i, considering the idle time, is given by: [13]:

$$t_{[i],\ j-1\ New} = t_{[i],\ j-1} + I_{[i],\ j-1} \tag{3}$$

The idle time on machine j job i is defined as:

$$I_{[i],j} = \max\{0, (\textstyle\sum_{k=1}^{i} t_{[k],j-1\ New} - \sum_{k=1}^{i} t_{[k],j} - \sum_{k=1}^{i-1} I_{[k],j})\} \tag{4}$$

Where:
$I_{[i],j}$ *denotes the idle time of machine* machine j before processing job i

The makespan, a critical performance metric in scheduling, is defined as the completion time of the last job on the final machine. It can be calculated using the following equations:

$$Makespan = F_{[n],m} \tag{5}$$

$$F_{[n],m} = \textstyle\sum_{i=1}^{n} t_{[i],m} + \sum_{i=1}^{n} I_{[i],m}$$

Where
$F_{[n],m}$ denotes the finish time of the last job on the last machine,
$t_{i,m}$ is the processing time of job i on machine m
$I_{[i],m}$ is the idle time on machine mmm before processing job i

The overlapping method is a production scheduling strategy designed to minimize the total production time, or makespan, by enabling concurrent processing of job batches across sequential stages. This approach involves partitioning the total number of units in a job into multiple batches, thereby allowing downstream operations to commence processing prior to the full completion of upstream operations [14]. By facilitating partial job transfers between production stages, this method effectively reduces machine idle time and enhances overall workflow efficiency.

The key principles underlying the overlapping method are as follows [15]

1. The total number of parts to be processed is divided into at least two batches.
2. Upon the completion of the first batch at the initial stage, it is immediately transferred to the subsequent stage for further processing.
3. While the first stage processes the second batch, the second stage begins processing the first batch concurrently, resulting in overlapping operations.
4. If the processing time at the second stage is shorter than that at the first stage, the size of the first batch must be sufficiently large to ensure continuous operation and prevent idle time on the second stage.

The mathematical formulation for the number of parts and batches is defined as follows:

$$Q_i = \frac{n}{N} + \frac{s_1(N+1-2i)}{2\left(t_1 + 2\sum_{k=2}^{m} t_k\right)} \qquad i = 1,\ldots, N. \tag{6}$$

Where
Q_1 = Minimum size of the first batch
Q_2 = Minimum size of the second batch
S_1 = Setup time on the first machine
t_k = Processing time on machine k

Results and Discussion

A sample dataset related to jersey production was utilized to evaluate the effectiveness of The CDS method integrated with the overlapping technique in flow shop scheduling. The dataset was obtained from a small manufacturing enterprise in Bandung, Indonesia. The key data required for this evaluation are as follows:

1. Machine Processing Times

Table 1. Machine Processing Times

Job	Machine Processing Time (min)					Total (Min)
	1	2	3	4	5	
1	38	8	15	12	6	79
2	72	8	20	22	32	154
3	81	8	20	33	47	189
4	87	8	20	36	45	196
5	96	8	20	31	43	198
6	102	8	20	29	41	200

2. *Job Data*

Table 2. Job Data

Job	Demand	Due Date (Days)
1	50	4
2	12	2
3	22	3
4	24	3
5	15	2
6	30	4

3. Machine Data

Table 3. Machine Data

Machine	Number of Machines	Setup Time (min)
M1	1	2
M2	2	5
M3	2	8
M4	5	2
M5	5	8

Another issue addressed in this study is the lateness penalty cost, which is the cost incurred by the company due to finishing projects after the set deadline. This penalty is calculated using the number of tardy jobs and the product category. Late penalties are applied at 10% of the total order cost.

The CDS method uses Johnson's rule to sequence the jobs. Number of iterations (k) is 5 machine – 1 = 4 iterations. According to the CDS procedure, the first step is to calculate $t^*_{i,1}$ and $t^*_{i,2}$ using the CDS method, as shown in Table 4.

Table 4. Machine Data

Iteration	Equaation	*Job*	$t^*_{i,1}$	$t^*_{i,2}$
1	$t^*_{i,1} = t_i$ on machine 1 $t^*_{i,2} = t_i$ on machine 5	1	40	68
		2	74	84,8
		3	83	214,8
		4	89	224
		5	98	137

		6	104	254
2	$t^*_{i,1} = t_i$ is the sum of t_i on machines 1 and 2 $t^*_{i,2} = t_i$ is the sum of t_i on machines 4 and 5	1	245	190
		2	127	139,6
		3	176	362
		4	190	398,8
		5	163	232
		6	229	430
3	$t^*_{i,1} = t_i$ is the sum of t_i on machines 1, 2 and 3 $t^*_{i,2} = t_i$ is the sum of t_i on machines 3, 4 and 5	1	628	573
		2	255	267,6
		3	404	590
		4	438	646,8
		5	321	390
		6	537	738
4	$t^*_{i,1} = t_i$ is the sum of t_i on machines 1, 2, 3, and 4 $t^*_{i,2} = t_i$ is the sum of t_i on machines 2, 3, 4 and 5	1	750	778
		2	309,8	320,6
		3	551,2	683
		4	612,8	747,8
		5	416	455
		6	713	863

Job sequence based on CDS method using Johnson's rule for each iteration. The job sequences for iterations 1, 2, 3, and 4 are shown in Table 5.

Table 5. Summary of Job Sequences for Each CDS Iteration

Iteration	Job Sequence
1	*Job* 1 – *Job* 2 – *Job* 3 – *Job* 4 – *Job* 5 – *Job* 6
2	*Job* 2 – *Job* 5 – *Job* 3 – *Job* 4 – *Job* 6 – *Job* 1
3	*Job* 2 – *Job* 5 – *Job* 3 – *Job* 4 – *Job* 6 – *Job* 1
4	*Job* 2 – *Job* 5 – *Job* 3 – *Job* 4 – *Job* 6 – *Job* 1

Calculate the total completion time (Fmax) and the minimal makespan. The completion time and makespan are shown in Table 6.

Table 6. Completion Time and Makespan Calculation

Iteration	*Job*	M1	M2	M3	M4	M5
1	1	40	245	628	750	818
	2	114	298	756	810,8	902,8
	3	197	391	984	1131,2	1346
	4	286	492	1232	1406,8	1630,8
	5	384	557	1390	1501,8	1767,8
	6	488	682	1698	1874	2128
2,3,4	2	74	127	255	309,8	394,6
	5	172	237	413	508	645
	3	255	348	641	788,2	1003
	4	344	449	889	1063,8	1287,8
	6	448	573	1197	1373	1627
	1	488	778	1580	1702	1770

Based on the CDS method calculations, the summary of makespan is as follows.

Table 7. Makespan for Each Iteration

Iterations	Job Sequence	*Makespan*
1	*job* 1 – *job* 2 – *job* 3 – *job* 4 – *job* 5 – *job* 6	2128
2	*job* 2 – *job* 5 – *job* 3 – *job* 4 – *job* 6 – *job* 1	1770
3	*job* 2 – *job* 5 – *job* 3 – *job* 4 – *job* 6 – *job* 1	1770
4	*job* 2 – *job* 5 – *job* 3 – *job* 4 – *job* 6 – *job* 1	1770

The optimal job sequence corresponding to the minimum makespan was obtained in iterations 2, 3, and 4, with the sequence: job 2 – job 5 – job 3 – job 4 – job 6 – job 1, yielding a makespan of 1770 minutes. Detailed calculations of the makespan, daily completion times, and tardiness are presented in Table 8.

Table 8. Makespan, completion time, and tardiness calculations

Job	*Completion Time* (min)	*Completion Time* (Days)	*Due Date* (Days)	*Tardiness* (Days)
1	394,6	1	2	0
2	645	2	2	0

3	1003	3	3	0
4	1287,8	3	3	0
5	1627	4	4	0
6	1770	4	4	0

CDS scheduling Gantt chart is in Figure 2.

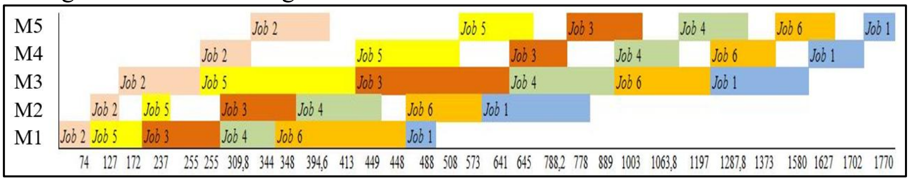

Figure 2. CDS Scheduling Gantt Chart

The calculated makespan is 1770 minutes with the job sequence: job 2 – job 5 – job 3 – job 4 – job 6 – job 1. Since there are no delayed jobs, the tardiness cost is 0.

The subsequent step involves determining the job overlapping. The first overlapping will be applied to the last task in the schedule through a local left shift on the Gantt chart. As a result, Job 1 is selected as the task to be overlapped. Job 1 was selected for overlapping because it is the last job in the schedule, which directly affects the makespan. Overlapping this job helps reduce the total completion time by accelerating the final process steps and minimizing idle time at the end of the production flow. Subsequently, calculate the total batch size (lot size) for Job 1.

$$Q_i = \frac{50}{2} + \frac{2(2+1-2(1))}{2(40+2(40+205+383+122+68))} = 25$$

$Q_2 = n - Q_1$

$= 50 - 25 = 25$

Processing times per machine, based on batch count and size, are shown in Table 9.

Table 9. Machine Processing Time by Batch

Job	Machine Processing Time (Min)				
	1	2	3	4	5
1	40	100	187,5	60	30
1b	[redacted]	100	187,5	60	30
2	74	53	128	54,8	84,8
3	83	93	228	147,2	214,8
4	89	101	248	174,8	224
5	98	65	158	95	137
6	104	125	308	176	254

Makespan calculations for Machines 1 to 5 are shown in Table 10.

Table 9. Makespan Overlapping

Job	Machine Processing Time (Min)				
	1	2	3	4	5
2	74	127	255	309,8	394,6
5	172	237	413	508	645
3	255	348	641	788,2	1003
4	344	449	889	1063,8	1287,8
6	448	574	1197	1373	1627
1a	488	674	1384,5	1444,5	1657
1b	[redacted]	774	1572	1632	1687

The scheduling Gantt chart based on the overlapping method is shown in Figure 3.

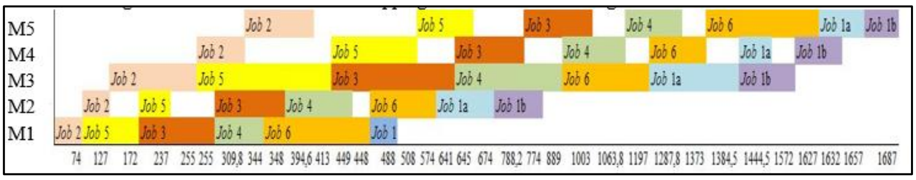

Figure 3. CDS Gantt Chart with Overlapping

The calculated makespan is 1687 minutes with the job sequence: job 2 – job 5 – job 3 – job 4 – job 6 – job 1. Since there are no delayed jobs, the tardiness cost is 0.

Lead time saving refers to the reduction in the total time required to complete a process compared to the original or baseline lead time. It is a key metric for evaluating improvements in production scheduling, as shorter lead times typically translate to increased responsiveness, higher throughput, and better resource utilization.

In this study, the CDS method was implemented both with and without overlapping to evaluate its impact on makespan. The following results were obtained:

- Initial makespan (without overlapping): 1770 minutes
- Improved makespan (with overlapping): 1687 minutes
- Lead time saving: 1770 − 1687 = 83 minutes

This reduction represents a 4.69% improvement in total completion time, which is a meaningful efficiency gain in a flow shop environment. By overlapping the last job in the schedule, the process on the final machine is accelerated, minimizing idle time and synchronizing job transitions more efficiently. Beyond just the makespan, such lead time savings can have broader implications:

- Improved machine utilization: Reduced idle times on downstream machines.
- Shorter total flow time: Jobs spend less time in the system overall.
- Delivery reliability: Reduced lead times contribute to improved on-time delivery performance.

However, it is important to note that while the overlapping technique yields measurable benefits, it also introduces potential trade-offs, such as increased complexity in coordination and possible risks of resource contention if not managed carefully. Additionally, overlapping was only applied to the last job in this scenario; applying it to multiple jobs could result in further improvements but would require more sophisticated scheduling logic and synchronization mechanisms.

To strengthen the validity of the observed improvement, further studies could incorporate statistical analysis or simulations across multiple job sequences and shop conditions.

Conclusion

This study demonstrates that integrating the CDS method with job overlapping significantly enhances scheduling efficiency by reducing total makespan. The results indicate that applying overlapping strategies can lead to substantial time savings without disrupting job sequences or incurring additional delay-related costs. This approach not only optimizes resource utilization but also accelerates overall production completion, making it highly relevant for modern manufacturing systems.

The practical implications suggest strong potential for adoption in real-world industrial settings, particularly in environments demanding high responsiveness and throughput. To expand its applicability, future research should explore the scalability of this method in more complex production scenarios, such as multi-machine or multi-stage systems. Furthermore, integrating dynamic scheduling elements and accounting for real-world uncertainties—such as machine breakdowns or variable processing times—will be crucial for developing a more resilient and adaptive scheduling framework.

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