



## Production Scheduling Optimization Using The Campbell Dudek Smith (CDS) Method to Minimize Makespan in A Flow Shop Manufacturing System

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### Abstract:

**Background:** Production scheduling plays a crucial role in improving manufacturing system efficiency, particularly in flow shop environments where jobs must follow the same processing sequence across multiple machines. At CV. Sinar Surya, the production scheduling for lathe machines is still conducted manually based on operator experience, resulting in high machine idle time, low machine utilization, and prolonged makespan. This condition causes inefficiencies in production processes and delays in order completion. Therefore, an effective scheduling method is required to optimize the production sequence and improve operational efficiency.

**Aim:** This study aims to optimize production scheduling in a flow shop manufacturing system by applying the Campbell-Dudek-Smith (CDS) method to minimize makespan and reduce lathe machine idle time.

**Methods:** The research was conducted at CV. Sinar Surya Palembang uses a quantitative approach. Data were collected through direct observation, interviews with production staff, and company documentation. The collected data include processing time for each job, production sequences, machine working hours, and existing production schedules. The CDS heuristic method was applied by transforming the multi-machine flow shop problem into several two-machine subproblems, which were then solved using Johnson's rule to determine the optimal job sequence.

**Results:** The existing production schedule yielded a makespan of 163 minutes and a total machine idle time of 140 minutes. After applying the CDS method, the optimal job sequence obtained was J4 - J5 - J3 - J1 - J2, which reduced the makespan to 147 minutes and decreased total idle time to 95 minutes. This represents a 16-minute reduction in makespan (approximately 9.8%), indicating improved production efficiency.

**Conclusion:** The implementation of the CDS method improves production scheduling efficiency in a flow shop manufacturing system by generating a more optimal job sequence, reducing makespan, and machine idle time.

**Implication:** The findings suggest that the CDS method can be an effective scheduling approach for manufacturing companies using flow shop systems, particularly for improving machine utilization, reducing production delays, and supporting better production planning and decision-making.

**Keywords:** Production scheduling, CDS method, flow shop, Makespan optimization, idle time



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## INTRODUCTION

In modern manufacturing environments, companies are required to maintain high levels of productivity, efficiency, and responsiveness to customer demands. Increasing market competition forces manufacturing firms not only to produce high-quality products but also to deliver them in shorter lead times while minimizing operational costs. One of the key factors that determines production efficiency is the effectiveness of production scheduling. Production scheduling refers to the process of determining the order and timing of jobs processed through machines or workstations to ensure the optimal utilization of available resources (Geurtsen *et al.*, 2023; Shim, Park and Choi, 2017). Effective scheduling can improve throughput, reduce idle time, and minimize the overall production completion time (makespan).

In many manufacturing systems, particularly those adopting a flow shop production system, each job must pass through several machines in the same processing sequence. Although this system simplifies workflow management, it often creates scheduling challenges when multiple jobs compete for the same machines. Poor scheduling decisions can lead to imbalanced workloads across machines, resulting in idle time, bottlenecks, and longer production completion times. These inefficiencies can negatively affect productivity and customer satisfaction due to delays in order fulfillment (Asawawibul *et al.*, 2025; Khedr and S, 2024).

CV. Sinar Surya, a metal fabrication company located in Palembang, Indonesia, faces similar challenges in its production process, particularly in the lathe machine workstation. The company produces various precision components, including shafts, bolts, and threaded pipes, for the automotive and heavy equipment industries. However, the company's production scheduling system is still performed manually, based on operator experience rather than systematic calculations. As a result, machines frequently experience idle time due to waiting for materials or preceding processes. In some cases, idle time reaches 30-40% of the total daily shift, significantly reducing machine utilization and increasing production makespan.

Machine idle time represents a form of production waste because operational costs such as electricity, machine depreciation, and labor continue even when machines are not producing output. In addition, inefficient scheduling may delay production completion, leading to a longer makespan and reduced manufacturing capacity. Therefore, implementing

an effective scheduling method becomes essential to improve resource utilization and streamline production flow.

One widely used heuristic method for flow shop scheduling problems is the Campbell, Dudek, and Smith (CDS) method. The CDS method is an extension of Johnson's rule for solving scheduling problems involving more than two machines. It works by transforming the multi-machine scheduling problem into several two-machine subproblems, each of which is solved using Johnson's rule to obtain candidate job sequences. Among these sequences, the one producing the smallest makespan is selected as the optimal schedule (Prasetyo and Heryati, 2024; Sauvey and Sauer, 2020; Mashuri *et al.*, 2019). Due to its relatively simple computational procedure and good performance, the CDS method has been widely applied in industrial scheduling problems to reduce makespan and improve production efficiency.

Previous studies have demonstrated the effectiveness of the CDS method in optimizing production scheduling. CDS can produce smaller makespan values than other heuristic methods, such as Gupta's. The CDS method significantly reduces waiting time and machine idle time. These findings indicate that the CDS method remains a reliable heuristic approach for solving multi-machine flow shop scheduling problems in manufacturing systems (Prasetyo and Heryati, 2024; Mashuri *et al.*, 2019).

Based on these considerations, this research focuses on optimizing production scheduling in a flow shop manufacturing system using the Campbell-Dudek-Smith (CDS) method. The study aims to determine an optimal job sequence that minimizes makespan and reduces machine idle time at CV. Sinar Surya. By implementing a systematic scheduling approach, the company is expected to improve production efficiency, enhance machine utilization, and support better production planning and decision-making processes.

Production scheduling optimization has become a critical issue in modern manufacturing systems due to increasing demands for productivity, efficiency, and shorter production lead times. Scheduling determines the sequence and timing of jobs processed on machines to ensure optimal utilization of production resources and minimize delays in order completion. Inefficient scheduling often leads to high machine idle time, production bottlenecks, and increased makespan, thereby negatively affecting operational performance and customer satisfaction.

In flow shop manufacturing systems, each job follows the same processing sequence across multiple machines. Although this structure simplifies routing, determining the optimal

job sequence becomes increasingly complex as the number of jobs and machines increases. Consequently, many studies have explored optimization approaches, including heuristic algorithms, metaheuristic methods, and simulation-based scheduling techniques, to improve production performance.

One widely used heuristic approach for solving multi-machine flow shop scheduling problems is the Campbell–Dudek–Smith (CDS) method. This method extends Johnson’s rule for two-machine scheduling problems by transforming a multi-machine problem into a set of two-machine subproblems. Each subproblem generates candidate job sequences, and the sequence with the minimum makespan is selected as the optimal schedule. Because of its computational simplicity and relatively good performance, the CDS method has been widely applied in industrial production systems

Previous studies have demonstrated the effectiveness of the CDS algorithm in improving scheduling efficiency. Research comparing CDS with other heuristic approaches, such as the Gupta method, found that CDS often produces shorter makespan values and more efficient job sequences. Other studies that combine CDS with heuristic or evolutionary algorithms have shown improvements in machine utilization, reduced waiting times, and enhanced production efficiency in multi-machine manufacturing environments.

Furthermore, recent literature on production scheduling emphasizes integrating computational algorithms and optimization techniques into manufacturing systems to support Industry 4.0 practices. These approaches aim to improve production planning accuracy, reduce operational waste, and increase system responsiveness in complex manufacturing environments.

## **LITERATURE REVIEW**

### **Production Scheduling in Manufacturing Systems**

Production scheduling is a fundamental activity in manufacturing management that determines the sequence and timing of job processing across available resources such as machines, labor, and materials. Efficient scheduling plays a significant role in improving operational performance, reducing production delays, and ensuring optimal utilization of production resources. Production scheduling aims to determine the order and timing of operations to achieve production objectives such as minimizing completion time, reducing machine idle time, and increasing overall productivity (Ghasemi *et al.*, 2024).

In modern manufacturing systems, scheduling complexity increases as the number of jobs, machines, and operational constraints grows. Inefficient scheduling often results in excessive machine idle time, longer production completion time, and reduced production capacity. Therefore, many studies have focused on developing optimization techniques and algorithms that can generate efficient production schedules.

One of the most widely used performance indicators in production scheduling is makespan, the total time required to complete all jobs in a production system. Minimizing makespan is considered an important objective because it directly affects production throughput, machine utilization, and delivery performance.

### **Flow Shop Scheduling Problem**

A flow shop scheduling system is a production configuration in which each job follows the same processing sequence across multiple machines. This system is commonly applied in manufacturing industries where products must undergo standardized processes such as cutting, machining, and finishing.

Although the flow shop structure simplifies routing decisions, scheduling problems arise due to variations in processing time among jobs. These variations may cause imbalanced workloads among machines, leading to bottlenecks and machine idle time. Determining the optimal sequence of jobs in flow shop systems is computationally difficult when the number of machines exceeds two, making heuristic algorithms an effective alternative for solving such problems (Ghasemi *et al.*, 2024; Neufeld, Schulz and Buscher, 2023).

### **Campbell, Dudek, and Smith (CDS) Method**

The Campbell, Dudek, and Smith (CDS) method is a heuristic algorithm for solving multi-machine flow shop scheduling problems. The CDS method extends Johnson's rule, which originally applies to two-machine scheduling problems. The algorithm converts a multi-machine scheduling problem into several two-machine subproblems, each solved using Johnson's rule to generate candidate job sequences (Setiawan, Susanto, Rinamurti, Chen, *et al.*, 2025).

The CDS procedure involves constructing  $m-1$  subproblems, where  $m$  represents the number of machines. Each subproblem combines the processing times of the first  $k$  machines with those of the remaining machines, yielding a simplified two-machine scheduling

problem. After obtaining candidate job sequences from each subproblem, the sequence with the smallest makespan is selected as the optimal schedule. The CDS method has several advantages, including its relatively simple computation process, low computational cost, and ability to produce near-optimal scheduling solutions. Because of these characteristics, the CDS method has been widely implemented in industrial scheduling applications, particularly in flow-shop production environments.

### **Previous Studies on CDS Scheduling**

Numerous studies have examined the application of heuristic scheduling methods, including the CDS algorithm, in manufacturing systems. Comparative study between the CDS method and the Gupta method for multi-product scheduling problems. Their results showed that the CDS method consistently generated smaller makespan values, indicating better scheduling performance compared to the Gupta algorithm (Fang, Cheang and Lim, 2023).

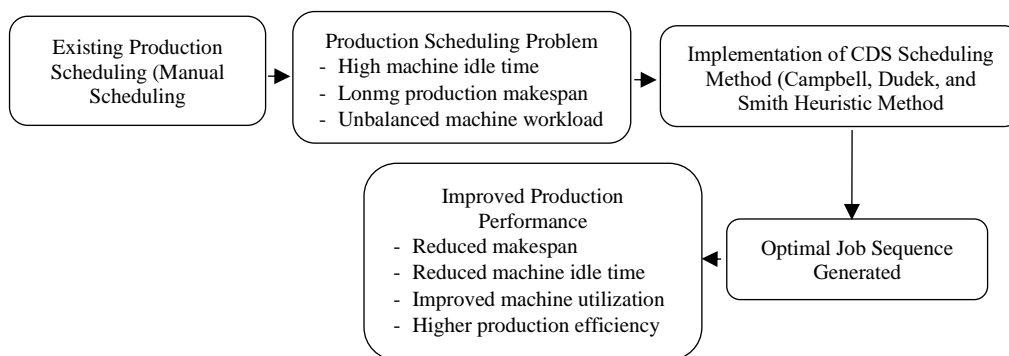
The CDS method is used with other heuristic scheduling approaches, such as NEH and the Palmer methods. The study found that the CDS method significantly reduced machine waiting and idle times, improving overall production efficiency. The CDS method with Genetic Algorithms in multi-stage scheduling problems. Although genetic algorithms provide flexible optimization capabilities, the CDS method demonstrated stable performance and faster computation, making it suitable for industrial applications that require quick scheduling decisions. Additionally, several studies in manufacturing industries have reported that applying heuristic scheduling algorithms can reduce production completion time by approximately 10-30%, depending on system complexity and job characteristics (Setiawan, Susanto, Rinamurti, Alfian, *et al.*, 2025; Fang, Cheang and Lim, 2023).

### **Research Gap**

Although many studies have demonstrated the effectiveness of heuristic scheduling algorithms such as CDS, many manufacturing companies still rely on manual scheduling practices. Manual scheduling is typically based on operator experience rather than systematic calculations, which often leads to inefficient job sequences, higher machine idle time, and longer production completion times. In small and medium-sized manufacturing industries, the lack of computerized scheduling systems further complicates production

planning (Goyal *et al.*, 2026). As a result, there is a need for practical and computationally efficient scheduling methods that can be implemented in real production environments.

This research addresses the gap by applying the Campbell, Dudek, and Smith (CDS) method to optimize production scheduling in a real flow-shop manufacturing system at CV. Sinar Surya. The study aims to demonstrate how the CDS algorithm can improve scheduling efficiency by minimizing makespan and reducing machine idle time in practical manufacturing operations. Conceptual framework - research model shown in Figure 1.



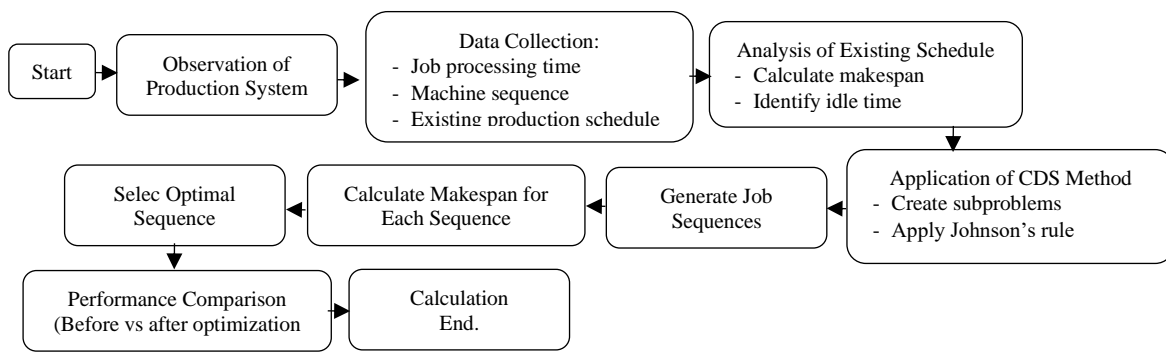
**Figure 1. Conceptual framework of production scheduling optimization using the CDS method**

Figure 1 illustrates the conceptual framework of this study. The research begins with the existing production scheduling system, which is performed manually and often results in high machine idle time and longer makespan. To overcome these issues, the Campbell, Dudek, and Smith (CDS) method is applied to determine an optimal job sequence in the flow shop production system. The implementation of the CDS method is expected to reduce makespan, decrease machine idle time, and improve overall production efficiency.

## METHODS

### Research Design

This study employs a quantitative research approach to evaluate the effectiveness of the Campbell, Dudek, and Smith (CDS) method in optimizing production scheduling within a flow shop manufacturing system. The research compares the performance of the existing production schedule with the optimized schedule generated using the CDS algorithm, focusing on minimizing makespan and reducing machine idle time (Setiawan, Budiyanto, and Rinamurti, 2025; Mustajab, 2023). The research procedure used in this study is illustrated in the following steps (Figure 2):



**Figure 2. The research procedure used in this study**

### Production System and Mathematical Model

The production system analyzed in this study consists of 5 jobs and 3 machines. Machine sequence: M1= Cutting, M2= Lathe Machine, and M3= Finishing. All jobs follow the same machine sequence, which represents a flow shop scheduling system (Wei *et al.*, 2025). The CDS method constructs two-machine subproblems based on the following equations:

For each job *i*:

$$P_{i1}^{(k)} = \sum_{j=1}^k t_{ij} \tag{1}$$

$$P_{i2}^{(k)} = \sum_{j=k+1}^m t_{ij} \tag{2}$$

Where:

$P_{i1}^{(k)}$  = processing time of job *i* on machine group 1;  $P_{i2}^{(k)}$  = processing time of job *i* on machine group 2

$t_{ij}$  = processing time of job *i* on machine *j*; *m* = number of machines; *k* = subproblem index.

The makespan is calculated as:  $C_{ij} = \max(C_{i-1j}, C_{ij-1}) + t_{ij}$

Where:  $C_{ij}$  = completion time of job *i* on machine *j*

The objective of scheduling optimization is:  $C_{max} = \max(C_{ij})$ , which represents the total production completion time (makespan).

### CDS Algorithm Procedure

The CDS scheduling algorithm is implemented using the following steps: 1) Determine the number of machines *m*, 2) Generate *m-1* two-machine subproblems, 3) Combine processing times according to CDS transformation, 4) Apply Johnson's rule to each subproblem, 5) Generate job sequences for each subproblem, 6) Calculate the makespan of each sequence, and 7) Select the sequence with the minimum makespan as the optimal schedule (Pt *et al.*, 2027).

## CDS Algorithm Pseudocode

Input:

Processing time matrix  $t(i,j)$   
 Number of jobs  $n$   
 Number of machines  $m$

For  $k = 1$  to  $m-1$

Calculate  $P1(i) = \text{sum of } t(i,1..k)$   
 Calculate  $P2(i) = \text{sum of } t(i,k+1..m)$

Apply the Johnson Rule:

If  $P1(i) < P2(i)$   
 Schedule a job at the beginning  
 Else  
 Schedule the job at the end

End

For each sequence generated

Calculate makespan

Select a sequence with the minimum makespan

Output:

Optimal job sequence

## Performance Evaluation Metrics

The performance of the scheduling system is evaluated using the following indicators: *Makespan*. Makespan represents the total time required to complete all jobs in the production system. *Machine Idle Time*. Idle time refers to the period during which machines remain inactive while waiting for jobs. *Production Efficiency*. Production efficiency is evaluated by comparing the existing scheduling system with the optimized CDS scheduling results (Setiawan, Susanto, Rinamurti, Alfian, *et al.*, 2025b).

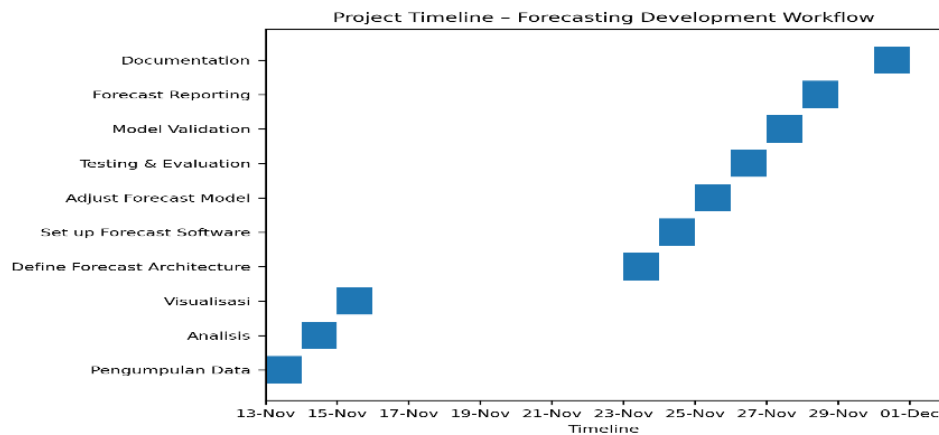
## DISCUSSION

Figure 3 shows the main production machines used in the manufacturing workshop, including the CNC plasma cutting machine, vertical milling machine, and conventional lathe. The CNC cutting machine is used in the initial stage to cut raw materials into the required dimensions. Milling and lathe machines are subsequently used for machining and shaping operations to achieve the desired geometry and surface quality. These machines form a sequential production flow that supports the manufacturing process analyzed in this study.



**Figure 3. Production machines used in the flow shop manufacturing process**

Figure 4 illustrates the project timeline for developing the forecasting model. The visualization presents the sequence of project activities, including data collection, analysis, visualization, forecasting model design, testing, validation, and documentation. Each task is scheduled within a defined timeframe, illustrating the project's chronological workflow. The timeline provides a clear overview of task dependencies and project progress, allowing better monitoring and coordination throughout the forecasting model development process.



**Figure 4. Project timeline for forecasting model development**

### Existing Production Scheduling Performance

The initial analysis evaluated the performance of the company's existing production scheduling system. The current scheduling process is performed manually based on operator experience without a structured optimization method. As a result, the job sequence applied in the existing schedule is J2 - J1 - J4 - J5 - J3.

Based on the production schedule analysis, the total makespan generated by the existing scheduling system is 163 minutes. In addition, the production system also experiences significant machine idle time. The idle time recorded for each machine is **35** minutes for Machine 1 (cutting), 48 minutes for Machine 2 (lathe), and 57 minutes for Machine 3 (finishing), for a total of 140 minutes.

These results indicate that the current scheduling system is inefficient, as the high idle time suggests an imbalance in machine workload distribution (Setiawan, Susanto, Rinamurti, Alfian, *et al.*, 2025a). The finishing machine has the highest idle time, indicating a potential bottleneck in the production flow. Such inefficiencies increase the overall production completion time and reduce machine utilization.

### Scheduling Optimization Using the CDS Method

To improve the efficiency of the production scheduling system, the Campbell, Dudek, and Smith (CDS) heuristic method was applied. The CDS method generates several candidate job sequences by transforming the multi-machine scheduling problem into multiple two-machine subproblems and solving them using Johnson’s rule. After applying the CDS algorithm, the optimal job sequence obtained is: J4 - J5 - J3 - J1 - J2. The optimized sequence yields a makespan of 147 minutes, which is shorter than that of the existing scheduling system. This result demonstrates that the CDS method successfully improves the job sequencing process and creates a more balanced production flow (Based *et al.*, 2025).

### Comparison of Scheduling Performance

A comparison between the existing scheduling system and the CDS optimized scheduling system is presented in Table 1.

**Table 1. Comparison of Production Scheduling Performance**

Scheduling Method	Job Sequence	Makespan (minutes)	Total Idle Time (minutes)
Existing Schedule	J2 - J1 - J4 - J5 - J3	163	140
CDS Method	J4 - J5 - J3 - J1 - J2	147	95

The results show that the implementation of the CDS method reduces the production makespan by 16 minutes, which represents an efficiency improvement of approximately 9.8% compared to the existing scheduling system.

Furthermore, the total machine idle time decreases significantly from 140 minutes to 95 minutes, indicating improved machine utilization and a more balanced production workflow.

### **Analysis of Machine Idle Time**

Machine idle time is an important indicator of production efficiency as it reflects machine utilization. In the existing schedule, Machine 3 (finishing) experienced the highest idle time, indicating an unbalanced job sequence that caused waiting between processes. After applying the CDS method, idle time decreased on all machines: Machine 1 from 35 to 22 minutes, Machine 2 from 48 to 31 minutes, and Machine 3 from 57 to 42 minutes, showing improved production synchronization.

### **Scheduling Efficiency**

Heuristic scheduling methods such as the Campbell, Dudek, and Smith (CDS) algorithm can significantly improve production efficiency in flow shop manufacturing systems by optimizing job sequences based on processing time combinations. In this study, the existing scheduling system produced a makespan of 163 minutes, while the CDS method reduced it to 147 minutes, representing a 16-minute reduction (9.8%). This improvement indicates that the CDS algorithm generates a more efficient production sequence and enhances workflow synchronization.

The Gantt chart analysis shows that the existing job sequence J2-J1-J4-J5-J3 created several idle intervals between processes due to manually determined scheduling. These idle periods resulted in unbalanced machine workloads and inefficient resource utilization, particularly on the finishing machine. By optimizing the job sequence, the CDS method reduces idle time and improves overall production flow.

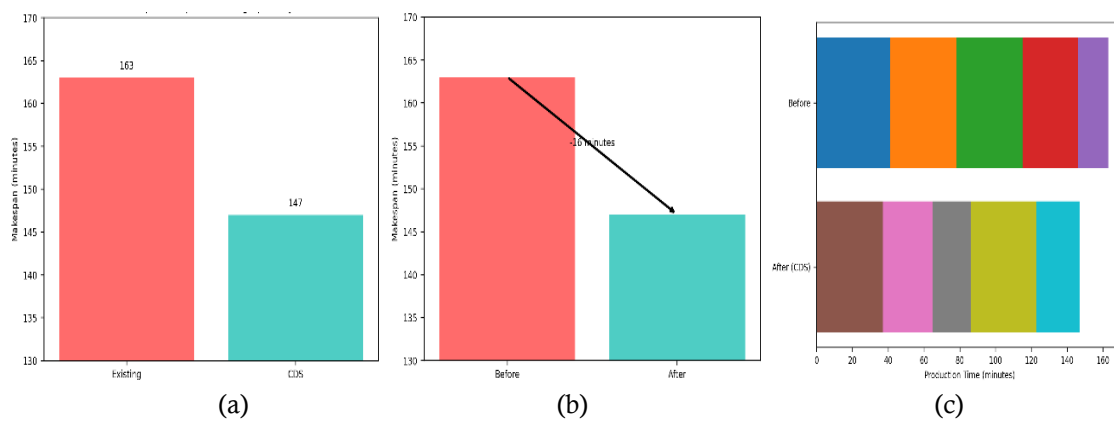
### **Gantt Chart After Optimization Using CDS**

After applying the CDS scheduling method, the optimal job sequence obtained is: J4 - J5 - J3 - J1 - J2. The Gantt chart of the optimized schedule shows a more compact arrangement of jobs across machines. The job processing intervals are closer together, indicating reduced waiting time between production stages. The improvements observed in the optimized schedule include: More balanced workload distribution among machines., Reduced idle time between job transitions, Shorter overall production completion time, and A more synchronized production flow across machines. As a result, the optimized schedule produces a shorter makespan and improves overall production efficiency (Yazdani and Haghani, 2024).

### Scheduling Improvement

The comparison between the Gantt charts before and after optimization demonstrates the effectiveness of the CDS method in improving scheduling performance. In the existing schedule, jobs are processed sequentially without considering optimal timing, resulting in longer waiting times and inefficient machine utilization.

In contrast, the CDS-based schedule arranges jobs according to combined processing times across machines. This approach reduces production gaps and ensures smoother transitions between machines. Consequently, the production system operates more efficiently with reduced idle time and improved throughput.



**Figure 5. (a) Makespan infographic comparison, (b) before-and-after makespan reduction chart, (c) Gantt chart of production scheduling.**

Figure 5 illustrates the integrated visualization of production scheduling performance before and after applying the Campbell, Dudek, and Smith (CDS) method. The first panel presents an infographic-style comparison of the makespan values, showing that the CDS method reduces the production completion time from 163 minutes to 147 minutes. The second panel displays a before-and-after comparison chart highlighting the decrease in makespan, emphasizing the improvement achieved through scheduling optimization. The third panel presents a Gantt chart comparison of the production flow across three machines—cutting, lathe machining, and finishing—before and after optimization. The optimized schedule shows a more compact job arrangement with reduced idle time and smoother production flow, indicating improved machine utilization and overall production efficiency. Table 2 shows that the Gantt Chart indicates the CDS method yields a more compact production flow. By prioritizing jobs with shorter initial processing times, "starvation" on

Machine 2 and Machine 3 is minimized. Table 1 shows the Gantt chart comparison before (existing) vs after (CDS).

**Table 2. Gantt Chart Comparison Before (existing) vs After (CDS)**

<b>Aspek</b>	<b><i>Before (Existing)</i></b>	<b><i>After (CDS)</i></b>
Job sequence	Manual	Otomated ( CDS )
Makespan	163 Minutes	147 Minutes
Idle time	High	Lower
Schedule density	Not Tight	More Compact
Visualization	Not Available	Gantt Chart
Production efficiency	Low	High

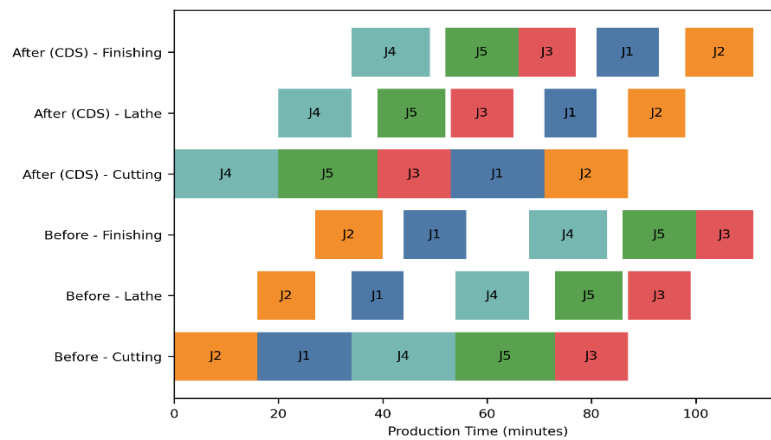
To analyze the impact of scheduling optimization on production flow, a Gantt chart comparison was developed to visualize the sequence and timing of job processing across the three machines in the production system, namely the cutting machine, lathe machine, and finishing machine. The visualization provides a detailed representation of how jobs are distributed over time before and after the application of the Campbell, Dudek, and Smith (CDS) scheduling method.

In the existing scheduling system, the job sequence is arranged manually without a systematic optimization approach. As illustrated in the Gantt chart, several idle intervals appear between consecutive job operations across machines. These idle periods indicate an imbalance in workload distribution and inefficient synchronization between processing stages. Consequently, the production system experiences longer waiting times between operations, which contributes to an increased overall production completion time (makespan).

After applying the CDS method, the optimized job sequence generates a more synchronized and compact production schedule. The Gantt chart clearly shows that job transitions between machines occur with fewer interruptions, reducing idle time and improving coordination among production stages. The improved scheduling structure enables machines to operate more continuously, thereby enhancing machine utilization and reducing the overall makespan.

Overall, the Gantt chart visualization demonstrates that implementing the CDS scheduling method significantly improves production flow efficiency in the flow shop manufacturing system. The optimized scheduling arrangement minimizes waiting time

between processes and supports a more balanced workload distribution across machines, ultimately improving production performance.



**Figure 6. Gantt Chart Comparison of Production Scheduling Before and After Applying the CDS Method in a Flow Shop Manufacturing System**

Figure 6 menyajikan perbandingan Gantt Chart penjadwalan produksi sebelum dan setelah penerapan metode Campbell, Dudek, and Smith (CDS) dalam sistem manufaktur flow shop. Diagram ini memperlihatkan perubahan urutan proses pekerjaan pada setiap mesin serta perbedaan alokasi waktu produksi yang dihasilkan dari penerapan metode CDS. Dengan membandingkan kedua Gantt Chart tersebut, dapat dianalisis bagaimana metode CDS mampu mengoptimalkan urutan pekerjaan sehingga berpotensi mengurangi waktu penyelesaian total (makespan) dan meningkatkan efisiensi proses produksi.

The novelty of this research lies in the practical implementation of the Campbell–Dudek–Smith (CDS) scheduling method in a real small-to-medium manufacturing environment, specifically at CV. Sinar Surya, which previously relied on manual production scheduling based on operator experience.

Several aspects highlight the contribution of this study:

1. Empirical Application in an SME Manufacturing Context. While many previous studies examine scheduling algorithms theoretically or through simulations, this research applies the CDS method directly to a real production system involving cutting, lathe, and finishing machines.
2. Integration of Scheduling Analysis with Machine Idle Time Evaluation. The study not only focuses on minimizing makespan but also analyzes machine idle time across workstations to evaluate improvements in production efficiency.

3. **Comparative Evaluation Between Manual Scheduling and Algorithmic Optimization.** The research quantitatively compares the existing manual schedule with the optimized CDS schedule, demonstrating measurable efficiency improvements in both makespan and idle time.
4. **Visualization-Based Scheduling Evaluation.** The study incorporates Gantt chart analysis and visual scheduling comparisons to illustrate the operational impact of optimization, providing practical decision-support insights for production managers.
5. **Practical Decision-Support Contribution for Manufacturing Planning.** The results demonstrate that a simple heuristic method, such as CDS, can significantly improve production planning without requiring complex computational infrastructure.

Through these contributions, the research provides practical evidence that heuristic scheduling algorithms can effectively improve production efficiency in flow shop manufacturing systems, particularly in small and medium-sized enterprises that still rely on manual scheduling practices.

## CONCLUSION

This study examined the optimization of production scheduling in a flow shop manufacturing system using the Campbell, Dudek, and Smith (CDS) heuristic method to minimize makespan and improve production efficiency. The existing scheduling system, which relied on manual job sequencing, generated a makespan of 163 minutes with relatively high machine idle time. After applying the CDS method, the optimal job sequence J4 - J5 - J3 - J1 - J2 was obtained, reducing the makespan to 147 minutes, a 16-minute reduction (9.8%).

Visual analysis through infographic charts, before-and-after comparison graphs, and Gantt chart representations shows that the optimized schedule creates a more synchronized production flow, reduces waiting time between machines, and improves workload balance across the cutting, lathe, and finishing processes. Overall, the findings demonstrate that the CDS method provides an effective and computationally efficient approach for improving scheduling performance and reducing production completion time in flow shop manufacturing systems.

## IMPLICATION

The results of this study suggest that the implementation of the Campbell, Dudek, and Smith (CDS) scheduling method can serve as a practical decision-support tool for improving production scheduling in flow shop manufacturing systems. By generating an optimal job sequence, the method helps reduce makespan, minimize machine idle time, and improve overall machine utilization. These improvements enable manufacturing companies to enhance production efficiency, shorten production lead times, and improve delivery reliability. Therefore, the CDS method can be effectively adopted by manufacturing firms, particularly small and medium-sized enterprises, as a simple, computationally efficient approach to improve production planning and operational performance.

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