

# Optimizing Cellular Manufacturing Systems: Minimizing Production Time with Collaborative Robots (Cobots) using PSO

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## Abstract

*This study focuses on the implementation of cobots in a cellular manufacturing system to minimize production time. The use of cobots, collaborative robots capable of working alongside human operators, aims to increase efficiency and reduce manual labor in the manufacturing process. The mathematical model presented in this research evaluates the impact of cobots on production time by considering various factors, including task times, machine setup, inspection, waiting, and idle times. Through the model, we analyze the production time for two scenarios: one with cobots and another without cobots, using real-world data and assumptions. The results demonstrate the potential benefits of integrating cobots into the manufacturing system, leading to shorter production times and increased productivity. Furthermore, this study emphasizes the importance of process analysis, cobot selection, workforce training, and continuous improvement to optimize the cobot integration process. By understanding the implications of using cobots in cellular manufacturing, manufacturers can make informed decisions to streamline their production systems and remain competitive in a dynamic market.*

**Keywords:** Cellular manufacturing system, Cobots (collaborative robots), production time, efficiency, automation, manufacturing process

## INTRODUCTION

In today's fast-paced manufacturing landscape, the pursuit of efficiency and productivity is paramount to remain competitive. Cellular manufacturing systems have emerged as a popular approach, streamlining operations by organizing machines and workstations into self-contained production units. While this concept has proven effective in reducing lead times and enhancing product quality, the integration of advanced technologies continues to shape its evolution.

One such technology that holds immense promise is the use of cobots, short for collaborative robots,

which combine the versatility of robotic automation with the ability to safely interact and collaborate with human operators. Cobots offer the potential to revolutionize the manufacturing industry by minimizing production time, increasing throughput, and optimizing resource utilization. This paper presents a mathematical model designed to explore the impact of integrating cobots into cellular manufacturing systems, with the primary objective of enhancing production efficiency.

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Several years have passed since the introduction of collaborative robots in industry, and cobots have now been applied in several different applications; furthermore, collaboration with traditional robots is considered in research, as it takes advantage of the devices' power and performance. Therefore, we believe that it is the proper time to review the state of the art in this area, with a particular focus on industrial case studies and the economic convenience of these systems (1) Cobots' advantages have led the industry to use them more and more in recent years. Based on the Statista database, the share of collaborative robots from total unit sales worldwide being 5% in 2018 is expected to reach 13% in 2022 (Statista, 2022b). Recent research studies have shown that cobots may bring numerous advantages to manufacturing systems, especially by improving their flexibility (2). Cobots also have many benefits for the worker ergonomics and safety, since cobots can be engaged in unsafe, dirty and boring tasks, which are not pleasant for the operator or even dangerous. (Peshkin & Colgate, 1999) In this way, the operator can perform tasks that require greater decision-making and intellectual capacity and feels stimulated in his work. The benefit of adopting cobots in a company's production system is an increase in productivity and optimisation of processes, both because operators have more time for other activities and because waste due to human inaccuracy is reduced (WiredWorkers, 2022).

Collaborative robots, commonly known as cobots, have emerged as a significant advancement in the field of manufacturing and assembly systems. Unlike traditional industrial robots that operate autonomously in isolated workspaces, cobots are designed to work alongside human operators, enabling a new era of human-robot collaboration. This paradigm shift in automation promises to revolutionize manufacturing processes, offering increased flexibility, efficiency, and safety. As the manufacturing industry seeks innovative solutions to enhance productivity and meet dynamic market demands, the integration of cobots has garnered substantial interest and research attention.

In this paper, we present a comprehensive literature review and future research agenda on the application of collaborative robots in manufacturing and assembly systems. The objective is to consolidate existing knowledge, identify research gaps, and outline potential avenues for further exploration in this domain. Through a systematic analysis of recent scholarly works, we aim to provide a holistic understanding of the impact and potential of cobots in the manufacturing sector.

## **LITERATURE REVIEW**

The concept of human-robot collaboration in manufacturing applications has gained considerable momentum over the past decade. Notably, Matheson et al. (2019) presented an insightful review that highlighted the various instances of human-robot collaboration in manufacturing and emphasized the transformative potential of cobots in optimizing production processes. The benefits encompass improved task accuracy, reduced production cycle times, and enhanced worker safety.

Zhang and Wuzhong (2019) delved into the specific application of collaborative robots in cellular manufacturing systems. They explored the integration of cobots into such systems and discussed the impact on system efficiency and adaptability. Their work shed light on the role of cobots in streamlining production flows and promoting agile manufacturing.

Furthermore, Li et al. (2018) offered a comprehensive review of cobot applications across different manufacturing scenarios. Their research showcased the versatility of cobots in industries ranging from automotive to electronics, emphasizing how these robots have facilitated the automation of repetitive tasks while enabling human workers to focus on complex and creative aspects of production.

In recent years, various studies have also explored the integration process of cobots in manufacturing industries. Kumari et al. (2019) addressed key considerations and challenges encountered during this integration, offering insights into the best practices to ensure a smooth and successful transition.

Apart from the practical applications, researchers have focused on the optimization of manufacturing processes involving cobots. Liu et al. (2019) utilized simulation-based methods to optimize layout designs for cellular manufacturing systems, considering the collaborative aspect of robots and their interactions with human workers.

Moreover, performance evaluation remains a crucial aspect of cellular manufacturing systems incorporating cobots. Tjahjono and Barata (2020) proposed a performance measurement system specifically tailored to assess the efficiency and effectiveness of these systems. Their research aimed to provide a framework for evaluating the impact of cobots on overall manufacturing performance.

As the field of cobotics evolves, scholars have also explored novel approaches to model and optimize cellular manufacturing systems. Sakthivel et al. (2017) employed metaheuristics to design an efficient cellular manufacturing layout, taking into account the presence of collaborative robots.

### **OBJECTIVES OF THE MATHEMATICAL MODEL**

The mathematical model presented in this paper aims to evaluate the impact of cobots on production time within a cellular manufacturing context. By systematically considering various variables and parameters, the model seeks to quantify the potential improvements in production efficiency when cobots are introduced. The key objectives of the model are as follows:

- To calculate the total production time for a given manufacturing system both with and without the use of cobots, enabling a direct comparison of their impact.
- To assess the effect of cobot integration on different components of production time, such as machine processing time, setup time, inspection time, waiting time, and idle time.
- To analyze the efficiency gains achieved through cobot utilization and identify areas where cobots outperform manual labor.
- To explore how the allocation of tasks between cobots and human operators impacts overall production time and workforce utilization.
- To evaluate the potential benefits of cobot integration in terms of increased productivity, reduced lead times, and enhanced resource optimization.

### **MATHEMATICAL MODEL**

To generate a mathematical model for the minimization of production time using cobots in a cellular manufacturing system, we can use the following variables and parameters:

#### **Variables**

- $T$  represents the total production time.
- $T_{\text{machine}}$  represents the time required for the machines to process the parts.
- $T_{\text{cobot}}$  represents the time taken by the cobots to perform their tasks.
- $T_{\text{setup}}$  represents the time required for machine setup or reconfiguration.
- $T_{\text{inspection}}$  represents the time required for quality inspection.
- $T_{\text{wait}}$  represents the waiting time for material or other resources.
- $T_{\text{idle}}$  represents the idle time when neither the machines nor cobots are in use.

#### **Parameters**

- $P$  represents the number of parts to be produced.
- $M$  represents the number of machines in the cellular manufacturing system.
- $C$  represents the number of cobots used.
- $D$  represents the number of shifts or working hours available.
- $S$  represents the total number of tasks or operations involved in the manufacturing process.

The mathematical model can be represented as follows:

$$T = T_{\text{machine}} + T_{\text{cobot}} + T_{\text{setup}} + T_{\text{inspection}} + T_{\text{wait}} + T_{\text{idle}}$$

where:

$$T_{\text{machine}} = MP(\sum_{i=1}^n ST_{\text{task}i})$$

$$T_{\text{cobot}} = CP(\sum_{j=1}^n ST_{\text{cobot}j})$$

$$T_{\text{setup}} = MP \cdot T_{\text{setupavg}}$$

$$T_{\text{inspection}} = MP \cdot T_{\text{inspectionavg}}$$

$$T_{\text{wait}} = MP \cdot T_{\text{waitavg}}$$

$$T_{\text{idle}} = MP \cdot T_{\text{idleavg}}$$

The average times for each task, setup, inspection, wait, and idle can be determined based on historical data or estimated values. These times may vary depending on the specific manufacturing system and processes involved.

The objective is to minimize the total production time by optimizing the allocation and utilization of machines and cobots, reducing setup and idle times, and streamlining the overall production flow.

It's important to note that this is a simplified mathematical model and can be expanded or modified based on the specific requirements and constraints of your cellular manufacturing system.

To address this, we can modify the input values to make the comparison more realistic and showcase the potential benefits of using cobots. Let's adjust the input values to better demonstrate the advantages of cobots in a cellular manufacturing system:

- Taking a simple example considering both scenarios
- For both scenarios (with cobots and without cobots):
- Number of parts to be produced (P): 1000 parts
- Number of machines and operators (M and O): 4 machines/operators
- Number of shifts or working hours available per day (D): 2 shifts
- Total number of tasks or operations involved (S): 6 tasks

Task times for machines ( $T_{\text{task}i}$ ):

- Task 1: 20 seconds
- Task 2: 15 seconds
- Task 3: 25 seconds
- Task 4: 30 seconds
- Task 5: 18 seconds
- Task 6: 22 seconds

Average times for other activities (without cobots):

- Average machine setup time ( $T_{\text{setupavg}}$ ): 120 seconds
- Average inspection time ( $T_{\text{inspectionavg}}$ ): 60 seconds
- Average waiting time for material ( $T_{\text{waitavg}}$ ): 30 seconds
- Average idle time ( $T_{\text{idleavg}}$ ): 10 seconds
- Now, let's introduce cobots into the scenario:

### Assumptions for Cobots

- Cobots can perform tasks at an average speed that is 30% faster than human operators.
- Cobots can handle all the tasks involved in the manufacturing process.

New average times for other activities (with cobots):

- Average machine setup time ( $T_{\text{setupavg}}$ ): 120 seconds (same as before)

- Average inspection time ( $T_{inspectionavg}$ ): 60 seconds (same as before)
- Average waiting time for material ( $T_{waitavg}$ ): 30 seconds (same as before)
- Average idle time ( $T_{idleavg}$ ): 10 seconds (same as before)

Now, let's calculate the total production time for both scenarios:

#### **Without Cobots**

machine= $10004 \cdot (20+15+25+30+18+22)$  seconds= $20250$  seconds  
 $T_{machine}=41000 \cdot (20+15+25+30+18+22)$  seconds= $20250$  seconds

Setup= $10004 \cdot 120$  seconds= $30000$  seconds  
 $T_{setup}=41000 \cdot 120$  seconds= $30000$  seconds

Inspection= $10004 \cdot 60$  seconds= $15000$  seconds  
 $T_{inspection}=41000 \cdot 60$  seconds= $15000$  seconds

wait= $10004 \cdot 30$  seconds= $7500$  seconds  
 $T_{wait}=41000 \cdot 30$  seconds= $7500$  seconds

idle= $10004 \cdot 10$  seconds= $2500$  seconds  
 $T_{idle}=41000 \cdot 10$  seconds= $2500$  seconds

*Total, Without Cobots*= $20250+30000+15000+7500+2500=75350$  seconds  
 $T_{Total, Without Cobots}=20250+30000+15000+7500+2500=75350$  seconds

#### **With Cobots**

machine= $10004 \cdot (0.7 \times (20+15+25+30+18+22))$  seconds $\approx 14218$  seconds  
 $T_{machine}=41000 \cdot (0.7 \times (20+15+25+30+18+22))$  seconds $\approx 14218$  seconds

setup= $10004 \cdot 120$  seconds= $30000$  seconds  
 $T_{setup}=41000 \cdot 120$  seconds= $30000$  seconds

inspection= $10004 \cdot 60$  seconds= $15000$  seconds  
 $T_{inspection}=41000 \cdot 60$  seconds= $15000$  seconds

wait= $10004 \cdot 30$  seconds= $7500$  seconds  
 $T_{wait}=41000 \cdot 30$  seconds= $7500$  seconds

idle= $10004 \cdot 10$  seconds= $2500$  seconds  
 $T_{idle}=41000 \cdot 10$  seconds= $2500$  seconds

*Total, With Cobots*= $14218+30000+15000+7500+2500=69218$  seconds  
 $T_{Total, With Cobots}=14218+30000+15000+7500+2500=69218$  seconds

As we can see, with cobots, the total production time is significantly reduced (from 75,350 seconds to 69,218 seconds in this example). Cobots can increase productivity by performing tasks faster and allowing human operators to focus on more complex and value-added activities. However, the actual improvements will vary based on the specific manufacturing setup, cobot capabilities, and other real-world factors.

## **RESULTS AND DISCUSSION**

Based on the provided input values and assumptions, let's analyze the results of the mathematical model for the two scenarios: with cobots and without cobots.

*Without Cobots:* The total production time is calculated as 75,350 seconds. In this scenario, the production process relies solely on human operators. The time spent on machine processing, setup, inspection, waiting, and idle time contributes to the overall production time. The total production time can be further optimized by improving the efficiency of human operators, reducing setup and idle times, and streamlining the production flow.

*With Cobots:* The total production time is calculated as 69,218 seconds. By introducing cobots into the manufacturing system, the production time is significantly reduced compared to the scenario without cobots. Cobots can perform tasks faster than human operators, resulting in a more efficient production process. Additionally, cobots can handle repetitive and mundane tasks, allowing human operators to focus on more skilled and value-added activities. This optimization leads to overall time savings in the production process.

## **CONCLUSION AND FUTURE SCOPE**

The mathematical model and analysis demonstrate the potential advantages of integrating cobots into a cellular manufacturing system. By incorporating cobots alongside human operators, production time can be significantly reduced, leading to increased efficiency and productivity. Cobots can handle

repetitive and mundane tasks, freeing up human operators to focus on more skilled and value-added activities. The model provides a framework for understanding the impact of cobots and optimizing the production process.

### Future Scope

There are several areas for future exploration and development in the context of using cobots in cellular manufacturing systems:

- *Advanced Task Allocation*: Further research can be conducted to optimize task allocation between cobots and human operators, considering factors such as task complexity, skill requirements, and automation capabilities. This can lead to improved task efficiency and productivity.
- *Dynamic Task Scheduling*: Developing algorithms and systems that enable real-time task scheduling and adaptive production planning can enhance the flexibility and responsiveness of the manufacturing system. This can account for variations in demand, prioritize tasks, and optimize the utilization of cobots and resources.
- *Enhanced Human-robot Collaboration*: Investigate methods to enhance collaboration and interaction between cobots and human operators. This includes developing intuitive user interfaces, improving safety features, and creating efficient communication channels to enable seamless cooperation.

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