

# Research on the Efficiency Improvement of Human-Machine Collaboration in Manufacturing Production Process

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**Abstract:** In modern manufacturing, human-computer collaboration has become an important means to improve productivity and product quality. However, the existing human-computer collaboration process and human-computer interaction interface design still has many deficiencies, which affects its efficiency and safety. This paper aims to explore how to improve the efficiency and safety of human-computer collaboration in the production process by optimising the human-computer collaboration process and designing the human-computer interaction interface. It is found that the efficiency and safety of human-computer collaboration can be significantly improved by optimising the collaboration process, improving the working environment and standardising the workflow through the lean manufacturing theory, and adopting a user-friendly interface design with high information visualisation and ease of operation.

**Keywords:** Human-machine collaboration, Manufacturing, Lean production.

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## 1. Introduction

With the rapid development of smart manufacturing and Industry 4.0, human-machine collaboration is increasingly used in the production process. Human-machine collaboration can combine the creativity and flexibility of humans with the efficiency and precision of machines to significantly improve productivity and product quality. However, current human-computer collaboration systems still face many challenges in practical applications, especially in terms of inefficiency and lack of security in the design of collaboration processes and interaction interfaces.

This paper aims to explore how to improve the efficiency and safety of human-computer collaboration in the production process by optimising the human-computer collaboration process and designing the human-computer interaction interface. The significance of the research is to provide manufacturing enterprises with theoretical guidance and practical methods to improve the human-computer collaboration system, so as to enhance the production efficiency, reduce the production cost, improve the product quality, and ensure the production safety.

## 2. Literature Review

Currently, domestic and international scholars' research on human-computer collaboration mainly focuses on the following aspects: design and implementation of human-computer collaboration systems, optimisation of collaboration processes, design of human-computer interaction interfaces, and research on the safety of human-computer collaboration systems. However, in a comprehensive view, most of the existing researches focus on the optimization of a single aspect, and lack of systematic and comprehensive researches. Pedrocchi [1] et al. start from the safety level, based on several sensors to sense the position and movement of the operator, and classify the human-robot collaboration work area in industrial environments into the safe zone, the warning zone, and the hazardous zone for modeling, and put forward the collision detection and

avoidance algorithms for robots under different models. collision detection and avoidance algorithms for robots under different models. In the process of human-robot collaboration, in order to adapt to human movement, the robot needs to continuously adjust its trajectory and path, Chen Youdong et al [2] established a double Gaussian process model for the trajectory adjustment and positional adaptation of the robot, and proposed a robot self-adaptive strategy, which reduces the complexity of the robot's planning process and improves the smoothing of the robot's movement. Liu et al [3] developed a human-machine interaction interface based on the design of robot operating system, and proposed a trajectory planning and correction method to adapt to dynamic and complex environments by the operator intuitively assisting the robot. Liu et al [4] conducted a review and research on the robot's gesture recognition technology, and proposed a robotic collaborative gesture including sensor technology, gesture recognition technology, gesture tracking technology and gesture classification technology. recognition model. Meanwhile, the process of human-robot collaboration enables robots to predict and understand human behavioural intentions, which can make robots better assist humans in manufacturing tasks.

## 3. Theoretical Foundations of Human-Computer Collaboration

### 3.1. Definitions and Classifications

Human-machine collaboration is when humans and machines work together on a common task to take full advantage of their respective strengths to achieve optimal productivity and product quality. This type of collaboration combines the creativity, judgement and flexibility of humans with the efficiency, precision and repeatability of machines to achieve higher effectiveness and better product quality in the production process. According to the different ways of collaboration between humans and machines, human-machine collaboration can be divided into the following categories:

(1) **Parallel Collaboration:** In this mode, humans and machines perform different tasks at the same time, but collaborate with each other to accomplish a common goal. For example, in the automobile manufacturing process, a worker may be installing parts on one side while a robot performs welding operations on the other side. Despite the differences in their respective tasks, their work complements each other, thus increasing overall productivity.

(2) **Sequential Collaboration:** In this model, humans and machines perform different tasks sequentially in order. A typical example is on an electronics assembly line, where the operator first performs complex component installation, and then the robot completes standardised tasks such as soldering and testing. After each stage is completed, the next stage of the task is taken over by the other party to ensure that each step is completed efficiently.

(3) **Collaboration:** In this model, humans and machines work closely together on the same task, exchanging information and adjusting tasks in real time. For example, in a smart warehouse, an operator may work with an autonomous mobile robot to complete order picking. The operator is responsible for picking complex or fragile items, while the robot quickly moves and distributes regular goods, both working in coordination through real-time communication to achieve greater precision and efficiency.

This categorisation helps us to understand and design human-robot collaboration systems, enabling the most appropriate collaboration methods to be selected in real-world applications to improve efficiency and quality. At the same time, these collaboration methods need to be optimised in relation to specific production environments and task requirements to ensure that the benefits of human-computer collaboration are maximised.

### 3.2. Basic Principle

The basic principles of human-machine collaboration include the following aspects:

(1) **Division of labour and collaboration:** In the production process, the reasonable distribution of tasks between humans and machines is the core principle of human-machine collaboration. By accurately identifying the respective advantages of humans and machines and designing reasonable task allocation, the creativity, flexibility and judgement of humans and the efficiency, precision and repeatability of machines can be brought into full play. For example, humans can be responsible for complex decision-making and high-precision operations, while machines are responsible for highly repetitive and physically demanding tasks. This division of labour not only improves productivity, but also reduces human labour intensity and fatigue.

(2) **Information exchange and feedback:** Establishing an efficient information exchange mechanism is the key to ensuring the success of human-machine collaboration. Humans and machines need to acquire and process a large amount of information in real time during the collaboration process in order to make correct decisions and adjustments. Through sensors, data interfaces and network communications and other technologies, a fast and reliable information exchange channel is established so that humans and machines can obtain the required information in real time and adjust their operations in a timely manner according to the feedback. For example, in the automotive assembly line, the robot can monitor the assembly status in real time through sensors and feedback the data to the operator, who can adjust

the operation strategy according to these data to ensure the assembly quality.

(3) **Collaboration optimisation:** Optimising the collaboration process and interaction interface is an effective way to improve overall system efficiency and safety. By analysing and improving the human-machine collaboration process, reduce unnecessary steps and waste, simplify the operation process and improve collaboration efficiency. At the same time, designing intuitive, user-friendly interactive interfaces ensures that operators can quickly understand and operate the system, reducing the risk of operational errors and accidents. For example, the use of graphical interfaces and touch screen technology enables operators to visualise the running status of machines and the progress of tasks, and to adjust and control tasks through simple operations.

In short, through rational division of labour and collaboration, efficient information exchange and feedback, and collaborative optimization, human-computer collaboration systems can maximize efficiency and ensure safety in all aspects, thus playing an important role in modern manufacturing. These basic principles not only provide theoretical guidance for the design and implementation of human-computer collaboration, but also provide directions and methods for continuous improvement in practical applications.

### 3.3. Common Modes of Human-Computer Collaboration

Common modes of human-robot collaboration in the production process include:

(1) **Operator-assisted robot:** In this mode, the operator directs the robot to perform operations through a control panel or other interface. This mode is common for complex tasks that require human intervention or guidance, such as assembly, welding, or material handling. The operator is responsible for monitoring and adjusting the robot's behaviour to ensure that the task is completed as required. For example, in automotive manufacturing, the operator directs the robot to assemble or weld car parts by manipulating a control panel.

(2) **Human-Robot Co-operative Robot:** In this mode, the operator and the robot collaborate in the same work area to assist each other in completing tasks. This mode is common in the need for humans and robots to participate in the task, such as material sorting, assembly line assembly. Operators and robots share the same space and collaborate with each other to complete their respective tasks, thereby increasing productivity and flexibility. For example, in electronics manufacturing, an operator may be responsible for placing electronic components into a robotic gripping device, and then the robot places those components precisely in the designated location.

(3) **Human-Robot Interaction:** In this mode, the robot senses the operator's movements in real time through sensors and control algorithms and adjusts accordingly to co-operate in completing the task. This mode is commonly used in high-precision and complex tasks that require human-robot collaboration, such as surgical robots and intelligent handling robots. The robot is able to intelligently adjust and control itself according to the operator's movements and commands to ensure the accuracy and safety of the task. For example, in a surgical operation, a surgical robot can make precise cuts and sutures based on the surgeon's hand movements, resulting in more accurate and safer surgical operations.

These human-robot collaboration modes have a wide range

of applications and can be selected and adapted to specific production needs and task requirements to maximise productivity and quality. As technologies such as artificial intelligence and machine learning continue to evolve, human-machine collaboration models will become even more intelligent and flexible, bringing even greater improvements and advantages to the production process.

### **3.4. Human-computer Interface Design Principles**

The principles of HCI design are to ensure that users can interact with the system easily and efficiently, thereby increasing productivity and reducing error rates. The following are extensions and refinements of these principles:

(1) User-friendliness: Interface design should take into account the user's cognitive level, operating habits and psychological expectations so that it is easy to understand and use. This means that the interface layout should be clear and concise, the function operation should be intuitive and clear, and the text prompts should be concise and easy to understand. In addition, provide a good feedback mechanism, such as operation success tips, error tips, etc., to help users accurately understand the system status and operation results.

(2) Information visualisation: Through intuitive graphics, charts and animations, abstract data and information are transformed into visual displays to help users quickly access and understand key information. This visualisation not only improves the user's perception and understanding of the information, but also helps the user to make more accurate and timely decisions. For example, in the production monitoring system, through the visual display of real-time production data, operators can intuitively understand the production status and trends, and timely adjust the production plan and parameters.

(3) Convenience of operation: the interface design should be simple and clear, reduce unnecessary operation steps and improve operation efficiency. Reasonable organisation of interface elements, commonly used functions and information placed in conspicuous and easy to reach position, reducing the user's search time and operational burden. In addition, shortcut operation methods and intelligent recognition technologies, such as auto-fill and predictive input, are used to further simplify the user operation process and improve the convenience and smoothness of operation. For example, in smartphone applications, gesture operation, voice recognition and other technologies are used so that users can complete various operations more quickly, improving user experience and satisfaction.

Considering the above principles comprehensively, when designing the human-computer interaction interface, the user's needs and behavioural habits should be fully taken into account, so that the user can easily and quickly complete the operation through reasonable layout, intuitive visual display and concise operation to improve work efficiency and satisfaction.

## **4. Optimisation of Human-Machine Collaboration Processes**

### **4.1. Analysis of Existing Collaboration Processes**

Analysing the existing human-machine collaboration process, the following major problems mainly exist:

(1) Untimely information transfer: in the existing process,

there is a delay or poor information transfer between people and machines, resulting in inefficient collaboration. This may be caused by unstable communication equipment, imperfect means of information transfer or unreasonable ways of information exchange. The lack of timely information exchange will affect the coordination of operators and machines, thus affecting the overall production efficiency and quality.

(2) Unstandardised workflow: the lack of standardisation and normalisation of the operator's workflow can easily lead to operational errors and safety hazards. In the existing process, there may be operators using different operating methods, follow a different order of operation, as well as inconsistent understanding and implementation of operating procedures. This unregulated workflow can easily lead to confusion and errors, increasing risks and costs in the production process.

(3) Unoptimised working environment: The existing layout of the working environment and the configuration of the equipment may be unreasonable, affecting the efficiency and comfort of the operators. For example, the work area may be cluttered with piles of materials or equipment, the operating space may be too narrow or crowded, and the work surface may not meet ergonomic requirements. These poor working environment conditions can affect the operator's working condition and work quality, reducing productivity and job satisfaction.

In summary, the existing human-machine collaboration process has major problems such as untimely information transfer, non-standardised workflow and non-optimised working environment. Solving these problems requires comprehensive consideration of all aspects of human-machine collaboration, starting from improving the information transfer mechanism, optimising the operation process to optimising the working environment, in order to improve the overall productivity and quality.

### **4.2. Identification of Bottlenecks in The Collaboration Process**

Through data analysis, bottlenecks in existing collaborative processes can be identified, such as delays in information transfer, non-standardised workflows and non-optimised working environments. These bottlenecks not only affect productivity and product quality, but may also increase safety risks and costs. Therefore, it is crucial to develop appropriate optimisation solutions for these problems.

To address the problem of delayed information transfer, the adoption of advanced information technology and communication equipment can be considered to achieve fast and accurate information transfer. For example, real-time monitoring systems and automated alarm mechanisms are introduced to capture abnormalities in the production process and send alerts to notify relevant personnel in a timely manner. At the same time, the establishment of an information sharing platform enables relevant departments and personnel to obtain the required information in a timely manner, and promotes the flow and sharing of information.

In response to the problem of non-standard operating procedures, process redesign and standardisation can be carried out to establish uniform operating standards and process regulations. Through training and education, operators can improve their understanding and implementation of the operating procedures to ensure consistency and standardisation of operations. At the same

time, automation and intelligent technologies are introduced to reduce human intervention and possible errors in operations, and improve the efficiency and reliability of operation processes.

In response to the problem of an unoptimised work environment, work environment renovation and equipment renewal can be carried out to create a comfortable, safe and efficient work environment. For example, optimise the layout of the work area, reasonably plan the placement of equipment and materials, ensure that the operating space is spacious and well-ventilated, and consider ergonomic factors to improve the comfort and health of operators. At the same time, the introduction of intelligent equipment and human-machine collaboration robots reduces human labour intensity and improves work efficiency and safety.

In summary, for the bottlenecks in the existing collaboration process, it is necessary to formulate a corresponding optimisation plan and effectively implement it in accordance with the actual situation and needs. Through continuous improvement and optimisation, production efficiency can be improved, costs can be reduced, product quality and employee job satisfaction can be improved, so as to achieve the goal of sustainable development of the enterprise.

### 4.3. Process Optimisation Methodology

The following optimisation methods can be used to address bottlenecks in the collaboration process:

(1) Lean production theory: Lean production theory is introduced to improve the efficiency of collaboration through the elimination of waste, standardisation of work processes and continuous improvement. The core idea of lean production is to identify and eliminate all kinds of waste in the production process from the perspective of value stream, including waiting time, transport delay, overproduction, etc., so as to realise lean and efficient production process.

(2) Operation design and standardisation: Develop standardised operation processes and operation specifications to reduce the workload and error rate of operators. By analysing the workflow, determine the optimal operation sequence and method, and standardise them into operation specifications to ensure that each operator can work according to the same standards and improve the consistency and controllability of production.

(3) Work environment optimisation: Optimise the layout of the workplace and the configuration of equipment to improve the working environment and comfort of operators. Reasonable planning of the layout of the work area, to ensure that the equipment is reasonably placed, the channel is smooth, to reduce unnecessary movement and waiting time. At the same time, improve the comfort of the working environment, such as controlling the temperature, humidity and light, to improve operator efficiency and job satisfaction.

By adopting the above optimisation methods, bottlenecks in the collaborative process can be effectively solved, increasing productivity, reducing costs and laying the foundation for continuous improvement and development.

## 5. Human-computer Interface Design

### 5.1. The Importance of Interactive Interface Design

Interactive interface design plays a crucial role in human-machine collaboration. It is not only a bridge for information

exchange and task command between humans and machines, but also a key factor affecting the efficiency and safety of human-machine collaboration. A well-designed human-machine interface can greatly improve the communication efficiency between the operator and the system, thus achieving a higher level of efficiency and operational safety in the production process.

The design of the interactive interface directly affects the operator's understanding and operation of the system. Through reasonable layout, intuitive graphical display and clear and concise operation guidelines, operators can grasp the operation methods and procedures of the system more quickly, reducing learning costs and operation difficulties. This intuitive design helps operators familiarise themselves with the system in a short period of time and perform tasks accurately, thus improving work efficiency and productivity. Good interactive interface design can enhance the operator's sense of control and trust in the system, which in turn improves the safety and stability of operation. Clear status indication, error alerts and operation confirmation can effectively reduce the occurrence of misoperation and accidents, and safeguard the safety of operators and equipment. In addition, appropriate user feedback and interaction design can also enhance the operator's job satisfaction and sense of commitment, thus further improving the accuracy and stability of operation.

In summary, the importance of interaction interface design in human-computer collaboration is self-evident. It is not only a simple appearance design, but also a core element of productivity, operational safety and job satisfaction. Therefore, when designing the interactive interface, we should fully consider the user's needs and operating habits, and draw on the principles of ergonomics and user experience design to create an interface that meets the actual needs and is easy to operate, so as to provide a reliable guarantee for the smooth progress of human-computer collaboration.

### 5.2. Basic Principles of Interface Design

The design of human-computer interaction interface should follow the following basic principles:

(1) User-friendliness: interface design should take into account the user's habits and psychological characteristics, so that it is easy to understand and operate. This includes the use of intuitive icons and symbols, clear text prompts, as well as reasonable layout and organisation, so as to reduce the user's learning cost and operating difficulty, and improve the user's satisfaction and experience.

(2) Information visualisation: Through graphics and charts and other forms, abstract data and information are transformed into intuitive visual displays to help users quickly access and understand key information. Through the design of visual elements such as colour, graphics and animation, users can intuitively perceive the information, which improves the efficiency of information delivery and understanding.

(3) Convenience of operation: The interface should be designed in a simple and clear way to reduce unnecessary operation steps and improve the convenience and efficiency of operation. By means of reasonable button layout, shortcut key setting and intelligent recognition technology, users can quickly find the required functions and complete the task with the least operation, thus reducing the user's operational burden and time cost.

### 5.3. Interface Design Tools and Methods

Surface design tools and methodologies cover a wide range of tools and techniques to effectively design and optimise user interfaces. These tools and methods play an important role in the field of modern user interface design and are widely used and recognised.

Interface prototyping tools such as Axure, Sketch, etc. are widely used to design and test interface prototypes. These tools provide rich libraries of components and interaction features that enable designers to quickly create interface prototypes with real interaction effects and conduct user feedback and testing. Through interface prototyping tools, designers can quickly validate design concepts and identify and solve potential problems at an early stage, thus improving the quality of the final interface design and user experience.

UX design methodology optimises the interface comprehensively through user research, user testing and usability evaluation. User research provides effective guidance and basis for interface design by observing and interviewing users to understand their needs and behaviours. User testing collects feedback and experience from users by letting them actually operate the interface, so as to find and solve problems in the design. Usability evaluation assesses and improves the usability of the interface through professional evaluation standards and methods. These methods work together to create an interface design with high user satisfaction and ease of use.

Interaction design principles refer to the adoption of design principles such as consistency, feedback and fault tolerance to enhance the user experience of the interface. The principle of consistency emphasises the importance of maintaining a consistent design style and operating logic throughout the interface design, in order to reduce the learning cost and operating difficulty for users. The principle of feedback emphasises the importance of providing users with timely feedback on the results of operations to enhance their control and confidence in the operation of the interface. The principle of fault tolerance emphasises the consideration of possible user errors in the design, and reduces the error rate and negative experience of users through reasonable prompts and recovery mechanisms. These design principles help to improve the user experience and usability of the interface, so that users can complete the operation tasks more easily and efficiently.

## 6. Integrated Assessment of Safety and Efficiency Improvements

### 6.1. Assessment Methodology

Ensuring safety is crucial in human-computer collaboration.

**Risk identification and assessment:** By systematically identifying and assessing potential risks in human-machine collaboration, appropriate safety measures can be developed. This includes analysing potential risks that may lead to personnel injury, equipment damage or production interruption, assessing the likelihood of their occurrence and the extent of their impact, and identifying corresponding countermeasures to safeguard personnel and equipment.

**Safety improvement measures:** Operator errors and safety risks can be reduced by optimising the design of collaborative processes and interfaces. This includes improving the regularity and standardisation of workflows, providing operator training and guidance, and improving the

visualisation and alerting features of interfaces to reduce the risk of misuse and accidents.

### 6.2. Indicators for Assessing Efficiency Gains

Efficiency improvement assessment indicators include:

(1) **Production efficiency indicators:** Production efficiency indicators can measure key indicators such as production volume per unit of time and product qualification rate. By analysing the trends and differences in these indicators, the degree of production efficiency improvement can be assessed and provide a reference basis for further improvement.

(2) **Operational efficiency indicators:** Operational efficiency indicators can measure the operator's workload, operating time and other key indicators. By monitoring and analysing the operator's work, the degree of improvement in operational efficiency can be assessed, and potential problems affecting efficiency can be identified so that appropriate improvement measures can be taken.

These assessment indicators help to provide a comprehensive understanding of the safety and efficiency of human-machine collaboration, providing a scientific basis and guidance for optimising collaboration processes and improving productivity.

## 7. Conclusion

This paper provides an in-depth discussion on how to effectively improve the efficiency and safety of human-computer collaboration in the production process by systematically optimising the human-computer collaboration process and carefully designing the human-computer interaction interface. Firstly, the study incorporates lean manufacturing theory, which aims to eliminate waste in the production process and reduce variation and errors through standardised job design, thereby improving the overall efficiency of production. In addition, the paper emphasises the optimisation of the work environment, aiming to create a more comfortable and efficient workplace for operators, reducing fatigue and potential safety hazards. In terms of HCI interface design, the study adopts the principle of user-friendliness to ensure that the interface is easy to understand and operate, thereby reducing the operator's learning curve and the error rate during use. Through information visualisation technology, complex data and information are presented to users in an intuitive and easy-to-read manner, helping them to make correct decisions quickly. Meanwhile, the design of operation convenience makes the interface operation process simplified, reduces the operation steps and time, and improves the operation efficiency.

The comprehensive study found that the combination of these optimisation measures can significantly improve the efficiency and safety of human-computer collaboration. The significant improvements in productivity, operator workload and safety before and after optimisation are verified through real case studies. These research results provide practical guidance and valuable references for manufacturing companies on how to optimise human-machine collaboration in the actual production process.

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