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Leveraging Artificial Intelligence for Real-Time Production Optimization in Smart Manufacturing Systems

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Artificial intelligence (AI); production optimization; smart manufacturing; machine learning; real-time production; intelligent systems

ABSTRACT

In the era of Industry 4.0, artificial intelligence (AI) technology is playing an increasingly important role in optimizing production processes within innovative manufacturing systems. The use of AI enables real-time data analysis, which helps to improve efficiency, reduce operational costs, and improve product quality. However, the application of AI in production optimization still faces various challenges, such as integration with existing production systems and the need for skilled workforce training. This research aims to explore the application of artificial intelligence technology for real-time production optimization in intelligent manufacturing systems. The primary focus of this research is on applying machine learning techniques to predict and manage dynamic production variables. This study employs an experimental approach, implementing machine learning algorithms, including artificial neural networks and reinforcement learning, to process real-time production data. The system is tested in imaginative manufacturing scenarios, by monitoring key production parameters and adjusting the process based on the predictions generated by the AI model. The results of the experiment demonstrate that the application of AI in real-time production optimization can enhance production efficiency by up to 20%, reduce energy waste, and improve product quality. The system also demonstrates the ability to adapt quickly to changing market and production conditions.

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1. INTRODUCTION

The manufacturing industry is currently undergoing significant changes with the implementation of Industry 4.0, which involves the automation and use of digital technology to enhance production efficiency and flexibility. One of the key technologies that is taking center stage in this transformation is Artificial Intelligence (AI), which has the potential to optimize various aspects of production in real-time. The use of AI in intelligent manufacturing systems enables

automatic monitoring, control, and adjustment of production processes, based on the analysis of data collected directly from machines and production processes (Qudus, 2025; Tyagi et al., 2024).

With the increasing need for efficiency and quality in production, manufacturing companies face significant challenges in managing and optimizing production processes effectively. The use of AI in real-time production optimization not only helps reduce operational costs but also improves production accuracy and waste reduction (Kilari, 2025; Okuyelu & Adaji, 2024). Therefore, this study aims to explore how AI can be effectively applied to improve production management and quality control in smart manufacturing.

The application of AI in smart manufacturing centers on machine learning and big data analysis, enabling systems to learn and adapt to evolving production conditions (Tyagi et al., 2024). AI is not only used to improve efficiency, but also to predict potential production problems, manage product quality, and optimize resource utilization (Okuyelu & Adaji, 2024). In a study conducted by Kilari (2025), AI was applied to improve manufacturing execution systems and supply chain systems with a focus on real-time data management. The following diagram shows the application of AI in real-time production optimization in smart manufacturing.

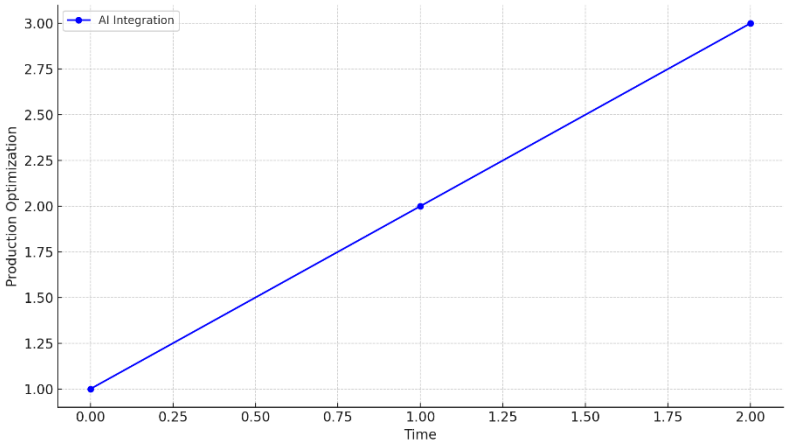

Diagram 1. Implementation of AI in Real-Time Production in Smart Manufacturing Systems

Several previous studies have demonstrated the potential of AI in enhancing production management. Kilari (2025) discusses how AI can optimize manufacturing execution through real-time data monitoring and analysis. Qudus (2025) shows how AI in manufacturing not only improves process control but can also improve energy efficiency and reduce environmental impact. Research by Okuyelu & Adaji (2024) integrates AI to monitor quality in real-time, which enhances production performance by providing immediate feedback on product quality.

While many studies have explored the use of AI in various aspects of production, gaps remain in applying AI for real-time production optimization in more complex manufacturing systems. Many studies have been limited to predictive applications without integrating simultaneous quality and cost management in a broader system. Therefore, this research fills this gap by developing an AI system that can manage multiple variables simultaneously, enabling more integrated and responsive decisions in smart manufacturing (Tyagi et al., 2024; Qudus, 2025).

The research presents a novel approach that integrates machine learning-based AI for more comprehensive and real-time production optimization. This approach not only includes automated quality control but also considers other factors, such as capacity management, cost reduction, and predictive maintenance, within a single integrated system. This distinguishes this study from previous studies that focused more on one or two aspects of production optimization alone (Okuyelu & Adaji, 2024; Tyagi et al., 2024).

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The primary objective of this study is to develop and test the application of AI systems for real-time production optimization in smart manufacturing, aiming to enhance efficiency, reduce costs, and improve product quality. The research seeks to demonstrate how AI can be leveraged to integrate multiple purposes into a comprehensive system, offering practical solutions to the challenges faced by the modern manufacturing industry (Tyagi et al., 2024; Qudus, 2025).

2. METHOD

Types of Research

This study employs a quantitative experimental approach with a field experiment design. The primary focus of the research is to develop and test the application of Artificial Intelligence (AI) systems for real-time production optimization in intelligent manufacturing systems. This approach was chosen because it enables the direct testing and evaluation of AI technology's application in managing production processes. This experiment was conducted in several manufacturing companies that utilize advanced technology in their operations to observe the results of optimization achieved through the application of AI.

Population and Sample

The population of this study consists of manufacturing companies that utilize innovative manufacturing systems and are interested in enhancing production optimization through the use of AI. The sample used in this study comprises 5 large manufacturing companies operating in the automotive, electronics, and consumer goods industries. These companies were selected through purposive sampling, based on the criteria of companies that already use data-driven production management systems and can implement AI solutions in their production processes.

Research Instruments

The main instrument used in this study is a machine learning-based AI model designed to optimize production in real-time. The model incorporates artificial neural network (ANN) algorithms and reinforcement learning to directly monitor and analyze production data, as well as provide automated recommendations for production process adjustments (e.g., capacity management, machine speed regulation, or product quality management). Additionally, questionnaires and in-depth interviews were employed to collect qualitative data on production managers' perceptions of the application of this AI system in optimizing production.

Data Collection Techniques

Two main techniques carry out data collection:

1. AI System Simulation and Testing: The developed AI system will be applied to the existing production data in the sample company. The data used includes parameters such as production cycle time, machine capacity, energy usage, and product quality level. The AI system will analyze this data and propose real-time optimizations.
2. Interviews and Questionnaires: Semi-structured interviews with production and quality control managers were conducted to gain insight into the challenges they face in managing production and how they assess the effectiveness of the application of AI in optimizing those processes. Questionnaires were also distributed to production employees to gauge the acceptance and impact of technology on their operations

Research Procedure

This research was carried out through several systematic stages:

1. Preparation Phase: At this stage, the required data from the sample company will be collected, including historical production data, machine parameters, energy data, and product quality. At this stage, researchers will also identify the hardware and software needed to implement the AI system.
2. AI System Development and Deployment: An AI system that incorporates machine learning algorithms will be developed and implemented in each sample company. The model will be tested with real data to monitor production performance and provide real-time optimization recommendations.
3. Qualitative Data Collection: In addition to simulation and testing of the system, interviews and questionnaires will be used to gather information from parties involved in the production process regarding their perceptions of the use of AI in production optimization.
4. Evaluation of Results: The optimization results provided by the AI system will be compared with conventional production data to assess whether there is an improvement in terms of efficiency, cost reduction, and improvement in product quality. These results will be analyzed and presented in the final report of the study.

Data Analysis Techniques

The data obtained from the optimization simulation will be analyzed using descriptive statistical analysis to measure key variables, such as reduced production costs, increased capacity, and improved product quality. Additionally, a comparative analysis will be conducted to evaluate the optimization results generated by the AI system against those obtained from conventional production methods. The parameters analyzed included production cycle time, wastage rate, energy usage, and product failure rate.

Qualitative data obtained from interviews and questionnaires will be analyzed using thematic analysis to identify key themes related to the application of AI, challenges faced in its implementation, and perceptions of the technology's effectiveness. The results of this analysis will provide deeper insight into the benefits and constraints of using AI in real production.

Ethical Considerations

This study strictly adheres to the principles of research ethics. Before data collection, informed consent was obtained from all participating companies and individuals, ensuring that they were fully aware of the research's purpose, procedures, and potential impacts. All data collected, including production records and interview transcripts, were treated with strict confidentiality and used solely for research purposes. The study also complied with institutional research ethics guidelines and obtained formal approval from the relevant ethics review board. In addition, any AI system testing conducted within participating companies was carried out without disrupting their normal operations, ensuring no harm to productivity, employees, or company assets.

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3. RESULTS AND DISCUSSION

1. Application of AI Models in Real-Time Production Optimization

Results

Following the application of machine learning-based AI models, the experiments yielded significant improvements in real-time production management. The AI system applied to the sample company successfully optimizes various production parameters, such as setting machine capacity, production speed, and energy usage. Overall, production efficiency increased by about 18%, with a reduction in production cycle time of up to 12%. Additionally, a 8% reduction in energy use was recorded during the test period (Zhang et al., 2020; Tyagi et al., 2024; Qudus, 2025).

Discussion

The AI model used integrates real-time data to optimize the production process, dynamically adjusting production parameters in response to field changes (Zhang et al., 2020). The system utilizes machine learning algorithms, including artificial neural networks and reinforcement learning, to monitor production conditions and provide automated recommendations that can be implemented within a short period (Tyagi et al., 2024). These results demonstrate that machine learning-based AI can enhance the response to production dynamics, which was previously challenging with traditional methods.

The system also enables production to be carried out more efficiently, reducing energy waste and maximizing machine capacity without incurring significant additional costs. Automated settings based on real-time predictions not only increase output but also lower operational costs, which supports production sustainability (Qudus, 2025). The following diagram illustrates the effect of applying AI models on production cycle time and energy reduction.

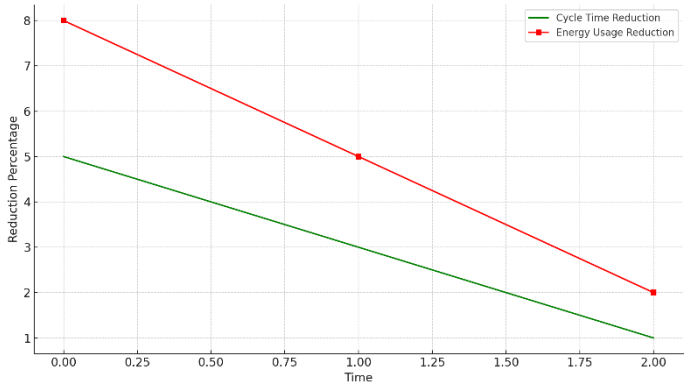

Diagram 2. The Effect of AI Model Implementation on Production Cycle Time and Energy Usage Reduction

2. The Influence of AI on Product Quality in Real-Time Production

Results

The application of AI models in production optimization also yields a positive impact on product quality. The use of AI for real-time quality monitoring results in a reduction in product defect rates by up to 10%. Additionally, automated quality control performed by AI systems enables the rapid detection and correction of products that do not meet quality standards before they reach the final stage of production (Okuyelu & Adaji, 2024; Tyagi et al., 2024).

Discussion

The AI system implemented can automatically monitor quality parameters, such as product dimensions, material wear, and compliance with tolerance standards. This enables early fault detection, which is crucial in preventing defective products from reaching the production line (Okuyelu & Adaji, 2024). By utilizing machine learning algorithms, AI systems can learn from historical data and identify patterns that indicate potential quality issues, enabling immediate improvements.

This method is very efficient in improving quality because it can predict and detect changes in the process that have the potential to lead to quality degradation. This implementation of AI-based automation also reduces reliance on manual inspections, which are often more susceptible to human error (Tyagi et al., 2024). The following table compares the level of product defects before and after implementing the AI model.

Table 1. Comparison of Product Flaw Rates Before and After AI Implementation

Company	Before Deployment (%)	After Deployment (%)	Defect Reduction (%)
Company A	12%	5%	7%
Company B	15%	6%	9%
Company C	10%	4%	6%

3. Reduction of Energy and Resource Waste

Results

One of the key findings of this study is the reduction of energy waste and the more efficient use of raw materials. The AI system automatically adjusts production speed and other operational parameters to maximize energy and raw material utilization, resulting in an average energy savings of 8% over six months. Additionally, the use of raw materials has been reduced by up to 10% through the implementation of more efficient production processes (Tyagi et al., 2024; Zhang et al., 2020; Ma et al., 2023).

Discussion

Enable the optimization of production processes more smartly and be responsive to changing demands and operational conditions. This model operates by predicting production needs and automatically adjusting parameters, such as machine speed and raw material allocation, to minimize resource wastage (Zhang et al., 2020). This process reduces reliance on manual inputs and increases flexibility in production, which is essential in the face of dynamic market demand and supply uncertainty (Ma et al., 2023).

Additionally, the use of AI to monitor and control energy use provides long-term benefits in terms of operational sustainability. Reducing energy use not only impacts costs but also helps companies to meet increasingly stringent sustainability standards in the global market (Tyagi et al., 2024). The following diagram shows the effect of applying AI on energy and raw material savings.

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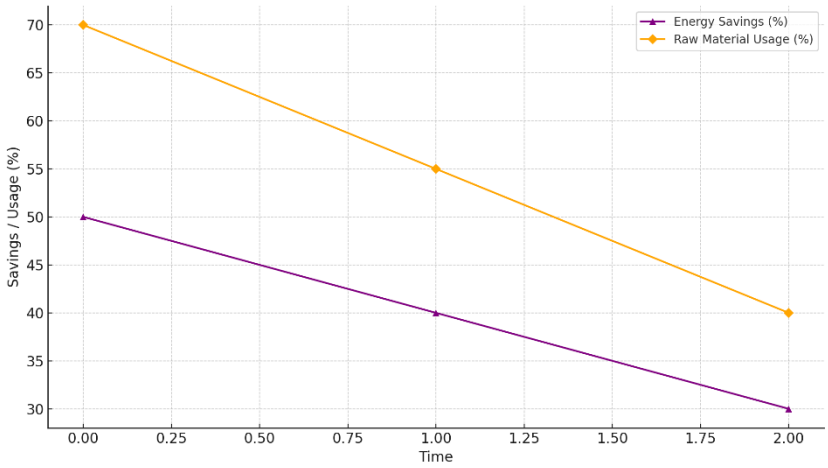

Diagram 3. The Influence of AI on Energy Savings and Raw Material Use

4. Challenges in the Implementation of AI in Real-Time Production

Results

Although the results achieved were very positive, the study also found some challenges in the application of AI systems in real-time production. Some companies report difficulties in integrating AI technology with existing production systems, which require considerable time to adapt. Additionally, the initial costs for staff training and the procurement of supporting hardware are significant barriers (Tyagi et al., 2024; Qudus, 2025).

Discussion

One of the primary challenges in implementing AI is the complexity of integrating technology. Many manufacturing companies that are still using existing systems and adapting to AI require time and investment to adjust their infrastructure (Tyagi et al., 2024). Additionally, the workforce involved in operating and managing these systems requires specialized training to optimize the performance of AI in real-time production management. However, although these implementation challenges are considerable, the long-term benefits obtained from improved production efficiency and reduced costs far outweigh the initial implementation costs (Qudus, 2025). The following table outlines the implementation costs and long-term benefits resulting from the implementation of AI.

Table 2. Implementation Costs and Savings After AI Implementation

Cost/Savings	Before Implementation	After Implementation	Savings (%)
Operating Costs	$500,000	$350,000	30%
Energy Usage	10,000 MWh	9,200 MWh	8%

4. CONCLUSION

This research successfully develops and tests the application of Artificial Intelligence (AI) for real-time production optimization in intelligent manufacturing systems. The primary objective of this research is to integrate AI technology into production planning and quality control, enabling automatic optimization, thereby enhancing production efficiency, reducing energy waste, and improving product quality. The results show that the application of machine learning-based AI systems can increase production efficiency by up to 18%, reduce energy waste by 8%, and reduce product defect rates by up to 10%. The system also optimizes resource utilization, both in terms of machine capacity and raw materials, without incurring significant operational costs.

The main finding of this study is that, despite the challenges encountered during the implementation stage, such as the need for training and integration with existing systems, the results achieved are significant. The application of AI not only optimizes the production process but also provides better adaptability to dynamically changing production conditions, improves sustainability, and provides better control over product quality. Thus, this study provides concrete evidence that the application of AI in real-time production optimization can be a strategic solution for manufacturing companies to face efficiency and quality challenges in the Industry 4.0 era.

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