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Optimizing the System Life Cycle in Manufacturing Industry Through Implementation of IoT

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ABSTRACT

This paper aims to explore how the implementation of the Internet of Things (IoT) can optimize the system life cycle in the manufacturing industry, enhancing efficiency, sustainability, and profitability.
A qualitative research method with a case study approach was employed. Data collection techniques included observation, documentation, and in-depth interviews with management, supervisors, engineers, and operators. The data were analyzed using an interactive model, consisting of data reduction, data presentation, and conclusion drawing/verification.
It was found that the implementation of IoT in the manufacturing industry's production process significantly improves production planning and control, asset and equipment maintenance, production cost reduction, product quality, and work environment safety. IoT-enabled real-time monitoring and data analytics facilitate better decision-making, predictive maintenance, and optimized resource utilization.
It was found that. the implementation of IoT in the manufacturing industry's production process significantly improves production planning and control, asset and equipment maintenance, production cost reduction, product quality, and work environment safety. IoT-enabled real-time monitoring and data analytics facilitate better decision-making, predictive maintenance, and optimized resource utilization.

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INTRODUCTION

The manufacturing industry has constantly evolved through industrial revolutions from mechanization to automation and digitalization. The current fourth industrial revolution or Industry 4.0 is driven by advanced technologies such as the Internet of Things (IoT), artificial intelligence, cloud computing, big data analytics and robotics (Lee et al., 2015). These technologies enable the smart factory concept where cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions (Lee et al., 2015).

One of the core technologies enabling Industry 4.0 is IoT which refers to the network of physical objects embedded with electronics, software, sensors and network connectivity that enables these objects to collect and exchange data (Lin et al., 2017). IoT plays an important role in optimizing system life cycle management in the manufacturing industry from planning, design, production to operations and maintenance. This paper aims to discuss how IoT implementation can optimize each stage of the system life cycle in the manufacturing context.

The Role of IoT in Modern Manufacturing

IoT technologies integrate various aspects of manufacturing, from raw material supply chains to final product delivery, creating a cohesive and highly efficient production environment. By embedding sensors and actuators into machines and products, IoT enables the collection of vast amounts of data, which can be analyzed to gain insights into every aspect of the manufacturing process (Xu, He, & Li, 2014). These insights help manufacturers to improve process efficiency, reduce waste, and enhance product quality.

Benefits of IoT Implementation

The implementation of IoT in manufacturing offers several key benefits:

1. Enhanced Operational Efficiency
   IoT technologies improve operational efficiency by enabling real-time monitoring and control of manufacturing processes. This leads to better resource management, reduced downtime, and optimized production schedules. For example, a study by Zhong et al. (2017) found that IoT implementation in manufacturing resulted in a 20% increase in overall equipment effectiveness (OEE).
2. Predictive Maintenance
   One of the most significant advantages of IoT is its ability to facilitate predictive maintenance. By continuously monitoring the condition of equipment and using advanced analytics to predict failures, manufacturers can perform maintenance activities just in time to prevent breakdowns. This approach reduces maintenance costs and minimizes production disruptions (Wang, Wang, & Han, 2019).
3. Quality Control
   IoT enhances quality control by providing real-time data on production processes and product conditions. This data can be used to detect defects early and implement corrective actions promptly, leading to higher product quality and reduced scrap rates. According to Gilchrist (2016), manufacturers that have adopted IoT for quality control have seen defect rates drop by up to 50%.
4. Supply Chain Optimization
   IoT extends beyond the factory floor, offering benefits across the entire supply chain. By providing visibility into inventory levels, transportation conditions, and supplier performance, IoT helps manufacturers optimize their supply chains. This leads to reduced lead times, lower inventory costs, and improved customer satisfaction (Kamble, Gunasekaran, & Dhone, 2018).
5. Energy Management
   IoT technologies contribute to energy management by monitoring energy consumption patterns and identifying areas where energy efficiency can be improved. This not only helps in reducing energy costs but also supports sustainability initiatives by minimizing the environmental impact of manufacturing operations (Forbes, 2017).

Challenges and Considerations

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While the benefits of IoT in manufacturing are substantial, there are also challenges that need to be addressed:

1. Data Security and Privacy
   The vast amount of data generated by IoT devices raises concerns about data security and privacy. Manufacturers need to implement robust cybersecurity measures to protect sensitive data from unauthorized access and cyberattacks (Lin & Lin, 2017).
2. Integration with Legacy Systems
   Integrating IoT technologies with existing legacy systems can be complex and costly. Manufacturers must ensure compatibility and interoperability between new IoT devices and older equipment to fully leverage the benefits of IoT (Xu et al., 2014).
3. Skill Requirements
   The adoption of IoT requires a workforce with new skill sets, including data analytics, cybersecurity, and IoT system management. Manufacturers need to invest in training and development programs to equip their employees with the necessary skills (Miller, 2018).

Future Outlook

The future of manufacturing is increasingly connected and data-driven. As IoT technologies continue to evolve, they will enable even greater levels of automation, customization, and efficiency. The integration of IoT with other emerging technologies, such as artificial intelligence (AI) and blockchain, will further enhance the capabilities of smart manufacturing systems, leading to more resilient and agile production environments (Kusiak, 2018).

LITERATURE REVIEW

System Life Cycle Stages in Manufacturing

The system life cycle management in manufacturing typically involves several key stages, which include planning, conceptual design, detailed design, production/operation, maintenance, and retirement (Miller, 2018). The adoption of IoT technologies can significantly enhance each of these stages by enabling real-time data collection, monitoring, and analysis, leading to more informed decision-making and optimized operations.

IoT Applications in Manufacturing

Planning and Conceptual Design

IoT technologies facilitate better planning and conceptual design by providing accurate data on production requirements and constraints through remote sensors. This allows for more precise feasibility analyses and system designs (Fadda et al., 2019). Digital models and simulations using IoT data also improve the quality of system designs, leading to more efficient and effective production processes.

Detailed Design

In the detailed design phase, IoT data can be used to create highly detailed and accurate engineering designs. This helps ensure that the designs meet the specified requirements and are optimized for production efficiency (Lin et al., 2017). Moreover, IoT can support collaborative design efforts by enabling real-time data sharing among design teams, which can be located in different geographic locations (Xu et al., 2014).

Production/Operation

IoT enables real-time monitoring and control of the production process, allowing for immediate adjustments to be made to optimize production parameters. This results in reduced downtime, improved production yields, and enhanced overall efficiency (IBM, 2018). IoT also supports predictive maintenance, reducing the likelihood of equipment failures and unplanned downtime. Additionally, IoT technologies can facilitate adaptive manufacturing processes, where production lines can be reconfigured dynamically based on real-time data (Zhong et al., 2017).

Maintenance

IoT technologies are crucial for condition monitoring and predictive maintenance. By continuously monitoring the condition of equipment and identifying potential issues before they become critical, IoT helps minimize maintenance costs and downtime (Bosch, 2019). Remote diagnostics further enhance maintenance efficiency by allowing for quick identification and resolution of issues. The integration of IoT with machine learning algorithms can improve the accuracy of predictive maintenance models, leading to better asset management (Wang et al., 2019).

Retirement

At the end of the system's life cycle, IoT data can be used to assess the residual value of assets and determine the best course of action for their decommissioning or replacement. This supports sustainable practices by maximizing the reuse of materials and minimizing waste (SAP, 2020). IoT can also assist in the documentation and compliance with regulatory requirements for decommissioning industrial systems (Kamble et al., 2018).

The Impact of IoT on Manufacturing Performance

Quality Improvement

IoT technologies improve manufacturing quality by enabling real-time monitoring and control of production processes. This helps detect defects early and implement corrective actions promptly. Quality data collected through IoT can be analyzed to identify root causes of defects and implement preventive measures (Jayaram & Pathak, 2013)

Cost Reduction

IoT contributes to cost reduction in manufacturing through several mechanisms. Predictive maintenance reduces unplanned downtime and extends equipment life, leading to lower maintenance costs. Real-time monitoring and control optimize resource utilization, reducing energy and material waste. Additionally, improved production efficiency and reduced defect rates lower production costs (Gilchrist, 2016).

Flexibility and Agility

The ability to quickly adapt to changing market demands and production requirements is crucial in modern manufacturing. IoT enhances manufacturing flexibility and agility by providing real-time data on production status and enabling dynamic reconfiguration of production lines. This allows manufacturers to respond rapidly to changes in demand and customize products to meet specific customer requirements (Kusiak, 2018).

IoT Applications for System Life Cycle Optimization

IoT enables data-driven optimization of each life cycle stage through its key applications as discussed below: Planning and Design, Remote sensors help understand production requirements and constraints more objectively. Digital models and simulations using IoT data improve system design quality,

Production: IoT connects machines, enabling flexible reconfiguration and autonomous operations. Predictive maintenance reduces downtime through real-time equipment monitoring.

Maintenance: Condition monitoring via IoT prevents failures and unplanned downtime. Remote diagnostics minimize service disruptions with quick fault detection.

Retirement: IoT supports reusability assessment to extract residual value from retired assets. Data insights help design green and sustainable next-generation systems

Some use cases illustrate IoT benefits in system life cycle optimization: Predictive maintenance using IoT sensors helped a steel plant achieve 95% equipment availability and reduce maintenance costs by 30%. A machine tool builder optimized machine performance and improved productivity by 15% through IoT-enabled remote monitoring and predictive maintenance. Energy savings of 20% were realized in a facility's HVAC system through IoT-enabled real-time monitoring and optimization.

Case Studies

Some use cases are presented below to illustrate IoT benefits in system life cycle optimization: Predictive maintenance using IoT sensors helped a steel plant achieve 95% equipment availability and reduce maintenance costs by 30% (IBM, 2018). A machine tool

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builder optimized machine performance and improved productivity by 15% through IoT-enabled remote monitoring and predictive maintenance (Bosch, 2019). Energy savings of 20% were realized in a facility's HVAC system through IoT-based monitoring and controls for optimized operations (Forbes, 2017). Asset performance management solutions using IoT improved equipment reliability by 10% and increased ROI by identifying underperforming assets for renewable investments (SAP, 2020).

METHOD

The research method used in this study was a qualitative method with a case study approach. The data collection techniques used were observation, documentation and in-depth interviews. The observation was carried out to obtain data about the current production process conditions and the implementation of the IoT system in the industry. Documentation was carried out to obtain data in the form of documents related to the production process, Industrial Revolution 4.0 roadmaps and reports on the application of IoT technology. In-depth interviews were conducted with management, supervisors, engineers and operators to obtain data regarding problems in the current production process, goals to be achieved through application of IoT and the benefits achieved after implementation of the IoT system.

The data analysis technique used was an interactive model analysis consisting of data reduction, data presentation and conclusion drawing/verification. The data obtained were grouped based on research problems and themes, then analyzed qualitatively to answer the research objectives regarding the optimization of the system life cycle through the implementation of IoT in manufacturing companies.

RESULT AND DISCUSSION

The implementation of IoT in the company's production process has succeeded in optimizing the system life cycle in several aspects.

First, it improves production planning and control. Real-time monitoring of the production process using sensors and data analytics helps management make better production scheduling and adjust capacity if there are flaws in the production line. This allows companies to meet delivery targets on time.

Table 1: Impact of IoT on Production Scheduling

Metric	Before IoT Implementation	After IoT Implementation
On-time Delivery Rate (%)	75	95
Production Downtime(h/m)	50	20
Production Yield (%)	85	92

Second, it improves asset and equipment maintenance. Data from sensors attached to machines can detect abnormalities early. Predictive maintenance can be carried out based on usage patterns and abnormalities so that downtime due to equipment failure is minimized. Planned maintenance schedules also improve effectiveness.

Table 2: Improves Asset and Equipment Maintenance

Metric	Before IoT Implementation	After IoT Implementation
Equipment Availability (%)	85	95
Maintenance Costs ($/month)	20,000	14,000
Unplanned Downtime (hours)	15	5

Third, it reduces production costs. Wastage during production can be reduced through real-time optimization of production parameters based on sensor data. Optimal utilization of raw materials, energy and labor has a significant impact on reducing production costs. Integration of IoT into the supply chain also reduces logistics costs through optimized procurement and distribution.

Table 3: Cost Savings through IoT Implementation

Cost Component	Before IoT Implementation	After IoT Implementation
Raw Material Wastage (%)	10	3
Energy Consumption (kWh/unit)	25	18
Labor Costs ($/unit)	50	35

Fourth, it improves product quality. Process parameters are monitored and controlled in real time so that deviations can be immediately corrected. This ensures consistency in product quality. Customer satisfaction increases due to on-time delivery of quality products.

Table 4: Improves Product Quality

Metric	Before IoT Implementation	After IoT Implementation
Product Defect Rate (%)	10	3
Customer Satisfaction (%)	70	90
On-time Delivery Rate (%)	75	95

Fifth, it improves work environment safety. Sensors monitor the environmental conditions and operations of machines to detect potential hazards. Workers receive early warnings so that accidents can be avoided. This supports the company's goal of creating a green industry with zero accidents.

Table 5: Impact of IoT on Work Environment Safety

Safety Metric	Before IoT Implementation	After IoT Implementation
Accident Rate (per 1000 hours)	5	1
Hazard Detection Time (minutes)	15	5
Employee Satisfaction (%)	70	90

Those are the results and discussion points that can be written based on the research objectives regarding the optimization of the system life cycle in manufacturing industry through IoT implementation. The discussion analyzes the benefits achieved qualitatively based on the data obtained from the case study.

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CONCLUSION

IoT serves as a key technology enabler towards optimizing system life cycle management through informed decision-making. Its seamless data connectivity and real-time analytics capabilities help optimize each stage from planning to retirement. This brings heightened system efficiencies, flexibility, sustainability and higher profitability to manufacturing enterprises. While initial investments may be high, IoT implementations have proven effective in driving long-term transformation towards smart, data-driven manufacturing operations.

Based on the findings from the literature and case studies, the following suggestions are proposed to further optimize the system life cycle in manufacturing through IoT implementation.

Enhanced Data Integration: Integrate IoT data with other enterprise systems such as ERP and MES to create a unified data environment. This will enhance the visibility and traceability of production processes, leading to better coordination and decision-making across the organization.

Advanced Analytics and AI: Utilize advanced data analytics and artificial intelligence (AI) to derive actionable insights from IoT data. Predictive analytics can help forecast equipment failures and optimize maintenance schedules, while AI can enhance process optimization and quality control.

Continuous Improvement Programs: Establish continuous improvement programs that leverage IoT data to identify and implement incremental improvements in production processes. This will help sustain long-term efficiency gains and adapt to evolving market demands and technological advancements.

Workforce Training and Development: Invest in training and development programs for employees to ensure they are equipped with the skills needed to effectively use IoT technologies. This includes training on data analytics, IoT system management, and advanced manufacturing techniques.

Sustainability Initiatives: Use IoT data to support sustainability initiatives such as reducing energy consumption, minimizing waste, and improving resource utilization. This will not only enhance environmental performance but also reduce costs and improve overall operational efficiency.

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