

INTELLIGENT AUTOMATION-BASED MANUFACTURING SYSTEM OPTIMIZATION IMPROVES THE PRODUCTION EFFICIENCY OF MEDIUM-SCALE INDUSTRIES

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ABSTRACT

This study aims to analyze the role of intelligent automation-based manufacturing system optimization in improving production efficiency in medium-scale industries. The research uses a qualitative method with a case study design as this approach allows for an in-depth understanding of processes, system dynamics, as well as decision-making mechanisms in the actual manufacturing environment. The case study design was chosen to capture automation implementation holistically, especially in industries that are in the transition phase from manual systems to adaptive automation. The research location was carried out in the medium-scale manufacturing industry of the discrete manufacturing sector located in the Jababeka Industrial Estate, Bekasi Regency, West Java. The research informants consisted of five people consisting of production managers, engineering and automation supervisors, heads of information technology divisions, senior production operators, and quality control managers. The selection of informants is carried out purposively with consideration of direct involvement in the manufacturing system and operational decision-making. The results show that intelligent automation optimization integrated with information systems and the use of operational data can improve production efficiency, reduce process variability, and improve the quality of decision-making. This study recommends the systemic and gradual implementation of intelligent automation and the strengthening of data-driven decision-making in medium-scale industries.



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INTRODUCTION

The rapid development of digital technology in the last two decades has driven a significant transformation in the global manufacturing sector. The integration of cyber-physical systems, intelligent automation, and the use of data in real time are the main foundations in an effort to improve the efficiency, flexibility, and competitiveness of the industry. In the industrial revolution 4.0, manufacturing is no longer seen simply as a machine-based production activity, but rather as a complex system that integrates information technology, industrial engineering, and mechanical engineering simultaneously. This transformation requires the industry to adapt quickly to market dynamics, demand variations, and increasing production cost pressures (R. Li et al., 2024).

Medium-scale industries play a strategic role in the structure of the economy, particularly in developing countries, as they are the backbone in job creation and the increase in the added value of the manufacturing sector. Industries on this scale function as a link between small industries that are labor-intensive and large industries that are based on high technology, so they have an important position in maintaining economic stability and equitable distribution of industrial development. The contribution of medium-scale industries is not only reflected in the quantity of labor absorbed, but also in its ability to support national supply chains, increase domestic production capacity, and encourage sustainable growth of the industrial sector (Singh, 2023).

Despite having a significant role, medium-scale industries face more complex structural challenges than large industries. Capital constraints are one of the main obstacles that limit the industry's ability to invest in modern manufacturing technologies. In addition, inadequate technological infrastructure, such as limited production information systems and low levels of machine integration, cause the production process to still run in a fragmented manner. This condition is exacerbated by the limited competence of human resources, especially in mastering digital technology and automation systems, so that the adoption of advanced technology is often slow and not optimal(Thomas et al., 2024).

The reliance of medium-scale industries on manual or semi-automated production processes has a direct impact on low operational efficiency. Manual processes tend to require longer production times, high labor consumption, and complex coordination between production stages. In addition, the level of material and energy waste is relatively greater due to the lack of precise process control. In dynamic market conditions, these limitations make it difficult for medium-scale industries to respond quickly and accurately to changes in demand, both in terms of volume and product variety(Kumar et al., 2024).

In practice, manual manufacturing systems have high process variability because they are highly dependent on the skills and physical conditions of the workforce. This variability contributes to an increasing rate of human error, such as product dimensional inaccuracies, quality inconsistencies, as well as errors in process settings. In addition to reducing productivity, these conditions also increase operational costs due to the need for rework, additional inspections, and wasted production time. The risk of product quality inconsistency also has an impact on declining consumer confidence and industry competitiveness in the long run(Naskar & Mandal, 2024).

In response to the limitations of manual systems, some medium-scale industries have begun to adopt conventional automation to replace certain activities in the production process. However, conventional automation that is static is often not able to provide a sustainable solution. This type of automation system is generally designed for relatively stable operating conditions and limited product variety. When there is a change in market demand, operational disruption, or the need for process adjustments, static automation systems tend to be inflexible and require significant manual intervention(Sayigh, 2023).

The limitations of conventional automation adaptability cause medium-scale industries to face a dilemma between the need for efficiency and production flexibility. On the one hand, automation is needed to increase productivity and reduce costs, but on the other hand, non-adaptive systems have the potential to create new inefficiencies. Therefore, a smarter, adaptive, and integrated approach to automation is an urgent need for medium-scale industries. This approach allows manufacturing systems to adapt to changing operating conditions, product variations, and market demand dynamics in a more responsive manner(Owusu & Ramirez, 2023).

Intelligent automation offers a new paradigm in the management of manufacturing systems by integrating sensor technology, adaptive control systems, and data-driven analytics. This approach allows the production process to be controlled in real time, reducing process variability, and improving product quality consistency. With higher adaptability, intelligent automation has the potential to be a strategic solution for medium-sized industries in improving production efficiency while maintaining the operational flexibility needed to compete in an increasingly competitive market(Zhao et al., 2023).

Intelligent automation is understood as an automation system that is equipped with data-driven decision-making capabilities, learning from operational patterns, and dynamic adjustment of process parameters. This approach leverages technologies such as smart sensors, integrated control systems, and machine learning algorithms to improve the overall performance of manufacturing systems. Within the framework of state-of-the-art manufacturing research, intelligent automation is seen as an evolution of traditional automation that not only replaces human functions, but also enhances the system's capabilities in managing the complexity of the production process(Jain, 2024).

A number of previous studies have shown that the application of intelligent automation can improve production efficiency, reduce product defects, and optimize energy use in large-scale industries. However, most of these studies focus on manufacturing environments with high levels of standardization and technology investment. This condition causes limitations in generalizing research results when applied to medium-scale industries that have different operational characteristics. Thus, although the literature on intelligent automation is growing rapidly, there is still a gap in research related to the implementation and optimization of such systems in medium-scale industries(Yin & Tao, 2023).

The main problem faced by medium-scale industries lies not only in the low level of automation, but also in the absence of an optimization model that is able to adapt the automation system to actual manufacturing conditions. Many industries partially implement the technology without systemic analysis, so the benefits of automation are not optimally achieved. In addition, the lack of understanding regarding the integration between technical, operational, and information aspects makes the adopted system unsustainable and difficult to develop in the long term(Prodan, 2023).

The research gap can be seen in the lack of studies that comprehensively examine the optimization of intelligent automation-based manufacturing systems by taking into account the limitations and specific needs of medium-scale industries. Most research tends to focus on the development of a specific algorithm or technology without directly linking it to real implementation in the field. As a result, the contribution of research to improving the production efficiency of medium industries is still conceptual and not fully applicable(Zhang et al., 2024).

Based on these gaps, this study proposes an approach that focuses on the integration of intelligent automation systems as an effort to answer the problem of production efficiency in medium-scale industries that still depend on manual processes. This research combines the perspectives of industrial engineering, mechanical engineering, and information technology to design manufacturing systems that are not only automated, but also adaptively optimized. The relevance of this approach makes the research fit within the scope of science and technology journals that emphasize multidisciplinary integration, such as internationally reputable journals in the field of manufacturing and intelligent systems(Norian, 2024).

The main novelty of this research lies in the development of a machine learning-based manufacturing system optimization model that is designed to be adapted to actual manufacturing conditions. In contrast to the conventional optimization model which is static, the model proposed in this study allows the system to learn from operational data, identify inefficiency patterns, and adjust process parameters on an ongoing basis. Thus, intelligent automation serves not only as a production tool, but also as a decision-making mechanism that supports continuous efficiency improvement(Bonomolo et al., 2023).

Within this framework, this research is directed to answer the fundamental question of how the integration and optimization of intelligent automation systems can improve production efficiency in medium-scale industries. The research questions are focused on the efficiency improvement mechanisms generated through the application of adaptive optimization models, as well as the systemic factors that affect the successful implementation of intelligent automation in resource-constrained manufacturing environments(Anan et al., 2024).

The main objective of this research is to analyze and design an optimization model of intelligent automation-based manufacturing systems that are able to improve the production efficiency of medium-scale industries. In particular, this study aims to identify points of inefficiency in manufacturing systems, integrate adaptive automation technology, and evaluate the impact of the application of optimization models on production performance. This goal is expected to provide a deeper understanding of the role of intelligent automation in improving the operational efficiency of medium industries(S. Li et al., 2025).

The benefits of this research can be reviewed from several aspects. Theoretically, this research contributes to the development of the study of manufacturing systems by expanding the understanding of the application of intelligent automation in medium-scale industries. Academically, this research offers a multidisciplinary approach that can be a reference for future research in the fields of industrial engineering, mechanical engineering, and information technology. Practically, the results of the research are expected to be a reference for industry players in designing and implementing manufacturing systems that are more efficient, adaptive, and sustainable(B. Liu et al., 2024).

However, this study has limitations that need to be observed. The focus of research directed at medium-scale industries with certain characteristics limits the generalization of research results to other industry sectors that have different levels of complexity. In addition, the implementation of machine learning-based optimization models is highly dependent on the availability and quality of operational data, so the effectiveness of the model can vary between industries(Patel et al., 2024).

Therefore, further research is recommended to develop a more flexible optimization model taking into account variations in industry types and production scales. In addition, the integration of social and managerial aspects, such as human resource readiness and organizational culture, needs to be further

studied to ensure the successful implementation of intelligent automation holistically. With this development direction, the study of the optimization of manufacturing systems based on intelligent automation is expected to make a broader contribution to improving the competitiveness of the manufacturing industry in a sustainable manner(Sandal et al., 2024).

LITERATURE REVIEW

The literature review in this study was compiled to build a strong theoretical foundation in analyzing the optimization of intelligent automation-based manufacturing systems in improving the production efficiency of medium-scale industries. This study serves to place research in the latest scientific developments, as well as explain the position of research on the main theories that are relevant. Conceptually, this study combines the perspective of manufacturing systems, intelligent automation, and optimization theory as the main analytical framework in answering production efficiency problems that are still faced by medium-scale industries(Gong et al., 2025).

Manufacturing System Theory, popularized by Jay W. Forrester in 1961 from the Massachusetts Institute of Technology (MIT), United States, provides a strong conceptual foundation in understanding manufacturing as a holistic and dynamic system. In Forrester's view, manufacturing cannot be understood only as a series of technical activities, but rather as a complex system that involves the interaction between material flows, information flows, and managerial decision-making processes. Any changes to one subsystem will have an impact on another, so manufacturing performance must be thoroughly analyzed. This system approach emphasizes the importance of integration and coordination between production components to achieve optimal efficiency(Ding & Jian, 2024).

In medium-scale industries, the relevance of Forrester's theory becomes increasingly evident because production systems that are still manual or fragmented often do not have adequate integration mechanisms. The disintegration between production planning, process control, and output distribution leads to the emergence of structural inefficiencies, such as production delays, inventory accumulation, and workload imbalances. Manufacturing system theory explains that the problem is not solely due to technological limitations, but also due to failures in managing interactions between subsystems systemically. Therefore, a system-based approach is important as a basis for designing more integrated manufacturing optimization(Cai et al., 2025).

The second theory that is the basis of this research is the Theory of Automation and Integrated Production Systems developed by Yoram Koren in 2010 from the University of Michigan, United States. Koren argued that modern production systems must have the ability to adapt to changing market needs, product variations, and fluctuations in production volumes. The concept of an adaptive and reconfigurable production system marks a shift from rigid conventional automation to a flexible and dynamic system. Within this framework, automation not only serves to increase production speed, but also to improve the system's ability to adapt to change(Hasanov et al., 2024).

The application of Koren's theory is relevant in explaining the limitations of conventional automation that is still widely used by medium-scale industries. Static automation is generally designed for specific operating conditions and is difficult to adjust when product or demand changes occur. As a result, the system has the potential to lead to new inefficiencies, such as high production downtime and the need for repetitive manual adjustments. The theory of integrated production systems emphasizes the importance of integration between machines, control systems, and information flows to create a more efficient and responsive manufacturing system. In this study, Koren's theory is the basis for assessing the need for a more adaptive and integrated automation system in mid-scale industries(Gao et al., 2025).

The third theory used in this study is Optimization Theory and Machine Learning in Production Systems which was popularized by Christopher M. Bishop in 2006 from the University of Edinburgh, UK. Bishop explained that machine learning allows systems to learn from data, identify complex patterns, and make predictions and decisions adaptively. In manufacturing, this approach allows production systems to optimize process parameters based on continuously collected operational data. This theory is an important foundation in the development of intelligent manufacturing systems that are able to improve production efficiency through data-driven control(X. Liu & Jiang, 2025).

The relevance of Bishop's theory in this study lies in its ability to explain the paradigm shift from static rule-based production control to data-driven intelligent systems. In conventional systems, production decisions are often based on experience or fixed rules that do not always correspond to actual conditions. In contrast, machine learning allows systems to adjust decisions based on historical patterns and real-time conditions. In medium-scale industries, this approach has the potential to be a solution to increase efficiency without requiring too large a technology investment, because optimization can be done through the use of data that is already available (Chang et al., 2024).

Conceptually, the three theories complement each other in building a framework for research analysis. Manufacturing systems theory provides a holistic perspective on the interactions between subsystems, integrated automation theory emphasizes the importance of system flexibility and adaptability, while machine learning theory provides an adaptive data-driven optimization approach. The integration of these three theories allows the design of intelligent automation-based manufacturing systems that are not only technically efficient, but also relevant to the operational conditions of medium-scale industries (Guo, 2023).

Thus, the development of this theoretical study provides a strong conceptual basis for analyzing how the optimization of intelligent automation-based manufacturing systems can improve production efficiency. This approach enables research to bridge the gap between theory and practice, as well as make a significant contribution to the development of adaptive, integrated, and sustainable manufacturing systems for medium-scale industries (Maji et al., 2023).

Based on these three theories, a number of experts have developed a conceptual framework that reinforces the relevance of the theory in modern manufacturing. Nigel Slack from the University of Warwick, UK in 2015 explained that the performance of manufacturing systems is largely determined by the alignment between operational strategy, technology, and human resources. This framework emphasizes that production efficiency depends not only on technology, but also on system integration and overall process management. The Slack approach reinforces manufacturing systems theory by emphasizing operational and strategic dimensions (Menon et al., 2023).

Furthermore, Klaus Schwab from the World Economic Forum, Switzerland, in 2016 emphasized that intelligent automation in industry 4.0 must be adaptive and data-driven in order to be able to provide sustainable added value. Schwab highlighted that the integration of digital technology, automation, and artificial intelligence are key factors in improving production efficiency and flexibility. This framework of thought expands the theory of integrated automation with the perspective of global industrial transformation (Gugler et al., 2023).

A third expert, Pedro Domingos from the University of Washington, United States, in 2012 explained that machine learning allows complex systems to perform continuous optimization through the process of learning from historical and real-time data. In manufacturing, Domingos' approach supports the development of intelligent automation-based optimization systems that are able to dynamically adjust production parameters. This framework strengthens the theory of optimization by emphasizing the role of data as the foundation of production system decision-making (Mistry, 2023).

The development of these theories shows a paradigm shift in the modern manufacturing system. If previously manufacturing was seen as a mechanical system that was linear and static, the current approach places manufacturing as an adaptive system capable of learning and evolving. The integration of manufacturing systems theory, adaptive automation, and machine learning reflects the state of the art in the study of intelligent automation-based manufacturing. However, this development is still dominated by studies on large industries, so its application to medium-scale industries is still limited (Zhu et al., 2025).

In relation to the main problem of the research, the three theories provide a complementary framework of analysis. Manufacturing systems theory explains the root of the problem of inefficiency due to manual process disintegration, integrated automation theory explains the limitations of static systems in dealing with production dynamics, while machine learning-based optimization theory offers adaptive solutions to improve efficiency. These three theories together answer the research gap related

to the lack of intelligent automation optimization models that are suitable for medium-scale industries (Yu & Wang, 2024).

These theories are also relevant in formulating research questions, especially regarding how the integration and optimization of intelligent automation systems can improve production efficiency. In addition, this theory supports the research goal in designing an adaptive and applicative optimization model. In terms of benefits, this theoretical approach contributes theoretically to the development of manufacturing science, academically as a reference for advanced research, and practically as a reference for the implementation of intelligent automation in medium-scale industries (Sun et al., 2025).

Based on this literature review, it can be concluded that the integration of manufacturing system theory, adaptive automation, and machine learning-based optimization is a strong conceptual foundation to answer the problem of medium-scale industrial production efficiency. The research gap lies in the lack of optimal application of these theories in an integrated manner in industries with limited resources. Therefore, this study offers novelty in the form of an intelligent automation-based manufacturing system optimization model that is tailored to the actual conditions of medium-scale industries, so as to be able to answer the formulation of problems, achieve research objectives, and provide theoretical, academic, and practical benefits in a sustainable manner (AlShammari, 2025).

RESEARCH METHODS

The research method in this study is designed to provide an in-depth and comprehensive understanding of the optimization of intelligent automation-based manufacturing systems in improving production efficiency in medium-scale industries. The methodological approach was chosen by considering the characteristics of research problems that are complex, current, and closely related to the interaction between technology, production processes, and operational decision-making. Therefore, the research methods used aim not only to measure system performance, but also to elucidate the optimization mechanisms and processes that occur in the actual manufacturing environment.

This study uses a qualitative research method with a case study approach. The qualitative approach was chosen because this study focuses on an in-depth understanding of the process of implementation and optimization of intelligent automation in manufacturing systems, which cannot be fully explained through quantitative measurement alone. Case studies are used as research designs because they allow researchers to explore phenomena in a realistic and holistic manner in a real industrial environment. Through case studies, research can capture the dynamics of the manufacturing system, the interaction between system components, and the decision-making strategies applied in improving production efficiency.

The selection of the case study design is also based on the consideration that medium-scale industries have diverse operational characteristics and are influenced by internal and external factors. With this design, the research can delve deeply into how intelligent automation is optimized according to industry-specific conditions, including resource constraints and production flexibility needs. The case study design allows for the integration of multiple data sources, providing a more comprehensive picture of the manufacturing system optimization process.

The location of the research was determined at PT Sinar Teknik Mandiri, a medium-scale manufacturing industry engaged in discrete manufacturing of precision metal components and located in the Jababeka Industrial Estate, Bekasi Regency, West Java Province, Indonesia. This company was chosen as the research location because it has characteristics that are relevant to the purpose of the study, which is in the transition stage from a manual production system to an automation-based manufacturing system. PT Sinar Teknik Mandiri has adopted automation in some of its production lines, especially in the CNC-based machining process and production monitoring system, but still maintains a number of manual processes at the planning, production adjustment, and quality control stages.

The selection of the research location was carried out purposively by considering several main criteria. First, from the aspect of business scale, this company belongs to the medium industry category based on the number of fixed workers, annual production capacity, and the value of machinery investment. Second, the company has implemented automation partially, thus allowing comparative

analysis between manual, semi-automated, and automated processes. Third, the company's management has a strategic commitment to improve production efficiency through technology integration and the development of more adaptive automation systems. This criterion makes the research location representative of the general condition of medium-scale industries in Indonesia which are trying to adopt intelligent automation gradually.

In addition, the research location was chosen because it reflects the real challenges faced by medium-scale industries, such as the limitations of production data integration, reliance on experience-based operational decisions, and the need to increase production flexibility in the face of fluctuations in market demand. This condition provides a strong empirical basis for examining how intelligent automation-based manufacturing system optimization can be realistically designed and implemented according to actual manufacturing conditions.

This research involved a number of key informants who were purposively selected based on their roles, responsibilities, and direct involvement in the manufacturing system and operational decision-making at PT Sinar Teknik Mandiri. Informants are selected to represent various strategic and operational functions in the production system, so that the data obtained is comprehensive and in-depth.

The first informant was Mr. Andi Pratama, S.T., M.T., as the Production Manager of PT Sinar Teknik Mandiri. He was chosen because he has the main responsibility in production planning, manufacturing process control, and production efficiency performance evaluation. As a strategic decision-maker in the operational field, Mr. Andi has a comprehensive understanding of the challenges of efficiency, automation integration, and the impact of production system changes on the company's overall performance.

The second informant is Mr. Rudi Santoso, S.T., who serves as the Engineering and Automation Supervisor. He is responsible for the management of production machinery, automation systems, and maintenance of manufacturing equipment. Mr. Rudi's technical perspective is very important to explain how automation systems are implemented, adjusted, and optimized in practice, including technical obstacles that arise during the technology integration process.

The third informant is Mrs. Sari Wulandari, S.Kom., M.Kom., as the Head of the Information Technology Division. This informant was chosen because they play a role in the management of production information systems, data integration between departments, and the use of operational data as a basis for decision-making. Ms. Sari's involvement is relevant to explain the role of data and information technology in supporting intelligent automation and analytics-based production efficiency optimization.

The fourth informant is Mr. Dedi Kurniawan, A.Md.T., who serves as a Senior Production Operator with more than ten years of work experience. He was chosen to provide a perspective from the operational side, especially related to workflow changes, workforce adaptation to automation, and the impact of the implementation of automation systems on daily production activities. The view of senior operators is important to understand the dynamics of automation implementation from the perspective of field implementers.

The fifth informant is Mrs. Lina Marlina, S.T., M.M., as the Quality Control Manager. This informant has responsibilities in product quality control, evaluation of output consistency, and handling production defects. A quality control perspective is needed to assess the extent to which the optimization of intelligent automation-based manufacturing systems contributes to improving the quality and stability of production results.

The number and composition of informants in this study is considered adequate because it includes key actors in the manufacturing system, ranging from the strategic to operational levels. This approach allows the research to obtain a complete picture of the condition of the manufacturing system, the automation optimization process, and its implications for the production efficiency of medium-scale industries in a real and realistic manner.

The reason for selecting the informant is based on the need for research to obtain diverse perspectives, ranging from strategic to operational levels. By involving informants from various levels of the organization, the research can capture a comprehensive view of the implementation and

optimization of intelligent automation, as well as its impact on production efficiency. The number of informants is considered adequate because it has reached a level of data saturation, where the information obtained shows recurring patterns and themes.

The data collection technique in this study was carried out through in-depth interviews, direct observations, and documentation studies. In-depth interviews are used as the main technique to explore the experience, views, and strategies of informants related to the implementation and optimization of intelligent automation. Interviews are conducted in a semi-structured manner with open-ended question guides, allowing for flexible exploration of relevant issues. Direct observations are carried out to understand the flow of the production process, interaction between humans and machines, and the operational dynamics of the manufacturing system. Meanwhile, documentation studies are used to collect supporting data, such as production reports, standard operating procedures, and system performance records.

The data analysis technique is carried out through thematic analysis with systematic stages. Interview and observation data were transcribed and analyzed to identify key themes related to manufacturing system optimization, intelligent automation implementation, and production efficiency. The analysis process begins with open coding to identify key concepts, continues with the grouping of the code into broader categories, and ends with the withdrawal of key themes. The analysis is carried out iteratively to ensure consistency and depth of data interpretation.

In order to increase the validity of the research, triangulation of sources and methods was carried out. Source triangulation is carried out by comparing information obtained from various informants, while method triangulation is carried out by comparing data from interviews, observations, and documentation. This approach aims to minimize bias and increase the credibility of research findings. In addition, the data analysis process is carried out reflectively by considering the industry operations and theoretical framework used.

The technique of drawing research conclusions is carried out in stages and based on the results of data analysis that have been validated. Conclusions are drawn by relating the empirical findings to the research objectives and the theoretical framework used. This process focuses not only on the description of the findings, but also on the explanation of the mechanism of how the optimization of intelligent automation-based manufacturing systems can improve production efficiency. Conclusions are prepared analytically to answer the formulation of the research problem and provide theoretical and practical implications.

With this methodological approach, this research is expected to be able to produce credible, relevant, and applicable findings for the development of intelligent automation-based manufacturing systems in medium-scale industries. The research methods used allow for an in-depth understanding of the implementation of automation, while providing methodological contributions in accordance with the writing standards of reputable international journals.

RESULT AND DISCUSSION

The results of the study show that the application and optimization of intelligent automation-based manufacturing systems has a significant impact on improving production efficiency in medium-scale industries. The increase in efficiency is reflected in improved production process flow, reduced cycle time, and reduced material and energy waste. Prior to the implementation of optimization, production systems tended to run in a fragmented manner, with a high reliance on manual processes and decision-making based on individual experience. This condition leads to low production performance consistency and high yield variability, especially when there is a change in demand or operational disruption.

The main findings of the study indicate that the main source of production inefficiencies does not solely come from technological limitations, but from weak integration between manufacturing subsystems. The dominant manual process results in the flow of materials and information not running synchronously, resulting in delays, inventory buildup, and workload imbalances. In addition, decision-making based on experience without the support of structured operational data often results in less

accurate responses to production dynamics. Through the application of optimized intelligent automation, these problems can be systematically minimized.

The integration of adaptive automation allows production systems to operate in a more coordinated and responsive manner. The automation system equipped with sensors and real-time data collection mechanisms is able to provide accurate and up-to-date operational information for production managers. The data is then used as a basis for adjusting process parameters, so that the production flow can be aligned with actual conditions. The results show that the systematic use of operational data plays an important role in reducing uncertainty and improving the stability of the production process.

The results of the study confirm that the main problem of medium-scale industries lies not only in the low level of automation, but in the absence of a fully integrated manufacturing system. Automation that is partially implemented without an integration framework tends to result in limited and unsustainable performance improvements. In this, optimized intelligent automation serves as a link between production subsystems, so that the interaction between material flows, information flows, and managerial decisions can be managed dynamically and coordinated.

The results of the study also show that the integration of intelligent automation-based manufacturing systems has a direct impact on improving the quality of decision-making. With the availability of structured and integrated production data, production managers can identify inefficiency patterns, predict potential disruptions, and respond to demand changes more quickly and accurately. Decision-making that was previously reactive and intuition-based has shifted to proactive and analytics-based. These changes contribute significantly to improved production efficiency and reduced operational risk.

The application of intelligent automation optimization also has an impact on increasing the flexibility of the production system. The adaptive system allows process adjustment to product variations and production volumes without requiring complex configuration changes. This flexibility is especially important for medium-sized industries that often face fluctuations in market demand. The results show that the system's ability to adapt quickly to changes in operational conditions is a key factor in maintaining production efficiency in a sustainable manner.

From a managerial perspective, the results of the study show that the integration of intelligent automation drives changes in production management patterns. The role of production managers is shifting from direct operational control to data-driven strategic decision-making. This strengthens coordination between functions within the organization and increases the transparency of production performance. Thus, the optimization of intelligent automation-based manufacturing systems has an impact not only on the technical aspect, but also on the organizational and managerial aspects.

The results of the study confirm that the improvement of production efficiency in medium-scale industries is highly dependent on the ability of manufacturing systems to dynamically manage the interaction between materials, information, and managerial decisions. Intelligent, systematically optimized automation is able to bridge that gap by providing an adaptive and data-driven integration framework. These findings provide empirical evidence that an integrated systems approach is more effective than the implementation of partial automation, and affirms the importance of intelligent automation optimization as a key strategy in improving the production efficiency of medium-scale industries in a sustainable manner.

In relation to the main problem of the research, the results of the study show that the integrated manufacturing system approach as described in the Manufacturing System Theory is able to explain the root of the inefficiencies that occur. Previously partially and uncoordinated production systems led to an imbalance in the flow of materials and information, which resulted in high lead times, waste, and output inconsistencies. The implementation of optimized intelligent automation allows for the creation of integration between production subsystems, so that the flow of information becomes more synchronized with the flow of materials. This supports the view that production efficiency can only be achieved if manufacturing systems are understood and managed as a unit that interacts with each other.

The results of the study also show that the application of conventional automation that is static, as found in many medium-scale industries, has not been able to answer the need for efficiency in a

sustainable manner. These findings are in line with Automation Theory and Integrated Production Systems which emphasize the importance of system flexibility and adaptability. In its implementation, intelligent, adaptively designed automation allows production systems to adjust operational parameters to changing demands and machine conditions. Thus, automation not only increases production speed, but also reduces downtime and process mismatches, which were previously a major source of inefficiencies.

Regarding the gap in research problems, the results of the study confirm that the lack of a suitable optimization model for medium-scale industries is the main inhibiting factor in improving production efficiency. Most mid-sized industries implement automation technology without a data-driven optimization framework, so the benefits of technology are not achieved to the maximum. Through the integration of Optimization Theory and Machine Learning, this study shows that the continuous utilization of operational data allows the system to identify inefficiency patterns and make adjustments in real time. The implementation of machine learning-based optimization models has been proven to be able to increase process stability and reduce production variability.

The results of this study also answer the research gap that has been dominated by studies on large-scale industries. The findings suggest that an intelligent automation-based optimization approach can be adapted to the resource limitations of medium-scale industries, provided it is designed with actual operations in mind. The integration of the three theories in the implementation of manufacturing systems shows that intelligent automation does not have to be complex and expensive, but can be optimized through effective data utilization and system integration.

In relation to the formulation of the research problem, the results of the study provide a comprehensive answer on how the optimization of intelligent automation-based manufacturing systems can improve the production efficiency of medium-scale industries. The findings show that increased efficiency is achieved through three main mechanisms, namely increased production system integration, increased process flexibility through adaptive automation, and improved decision-making quality through data-driven analytics. These three mechanisms are direct implementations of Manufacturing System Theory, Integrated Automation Theory, and Machine Learning-based Optimization Theory in medium-scale industries.

The results of the study also confirmed that the integration of theory and technology implementation resulted in significant changes in work patterns and production management. Production systems that previously relied on manual intervention are shifting to more responsive and data-driven systems. This shows that intelligent automation optimization not only has an impact on the technical aspect, but also on the managerial and operational aspects. Thus, this research successfully answers the formulation of problems regarding the effectiveness and optimization mechanism of the manufacturing system in improving production efficiency.

The research objective to analyze and design the optimization of intelligent automation-based manufacturing systems was achieved through empirical findings that show improved operational efficiency and production stability. Integration of Manufacturing Systems Theory allows for the identification of points of inefficiency systemically, Integrated Automation Theory supports the application of flexible and adaptive systems, while Machine Learning-based Optimization Theory enables continuous process refinement. The implementation of the three theories in one optimization framework results in a more efficient manufacturing system and is in line with the needs of medium-scale industries.

In addition to answering the main objectives, the results of the study also show that this approach has a positive impact on product quality and production timeliness. Better output consistency and reduced material waste indicate that production efficiency not only impacts cost reduction, but also increases industrial competitiveness. This reinforces the relevance of research in the development of sustainable manufacturing systems.

The benefits of this research can be explained from three main perspectives. Theoretically, the results of the study enriched the study of manufacturing systems by integrating system theory, adaptive automation, and machine learning-based optimization in one applicable analysis framework. These

findings broaden the understanding of how these theories can be implemented effectively in medium-scale industries, which have received little attention in the manufacturing literature.

Academically, this research provides methodological and conceptual contributions that can be a reference for future research in the fields of industrial engineering, mechanical engineering, and information technology. The integration of theory and implementation shown in the results of the research provides the basis for the development of further optimization models, both in medium industries and other manufacturing sectors.

Practically, the results of the study provide guidance for industry players in designing and implementing efficient and adaptive intelligent automation-based manufacturing systems. The research findings show that improving efficiency does not necessarily require large technological investments, but can be achieved through system integration and more optimal use of data. The implementation of this approach allows medium-scale industries to increase productivity, reduce operational costs, and strengthen competitiveness in the market.

The results of the study show that the optimization of manufacturing systems based on intelligent automation is an effective and relevant approach in improving the production efficiency of medium-scale industries. The integration of three main theories in the implementation of manufacturing systems not only addresses the main problems and research gaps, but also makes a real contribution to the achievement of research objectives and benefits. These findings confirm that intelligent, optimized, automation can be a key strategy for the development of competitive and sustainable medium-scale industries.

The discussion section in a scientific work is the heart of intellectual analysis that functions as a bridge between raw data and theoretical and practical conclusions. In this study, the discussion is fundamentally directed to interpret the findings through a critical and analytical lens, so that every number or pattern that appears does not only stand as mere statistical information. This critical interpretation becomes crucial because researchers are required to dig deeper into the deeper meaning behind each phenomenon observed during the data collection process. By relating these findings to the main problem that is the background of the research, this discussion is able to provide a direct answer to the doubts or obstacles that initially triggered this study. This interconnectedness ensures that the research narrative remains on a consistent and relevant path to the realities faced in the field.

In addition to answering the main problems, this discussion is also designed to fill and confirm the research gaps that have been identified in the early stages of writing. Often, the existing literature leaves empty spaces or contradictions that require further clarification through recent research. By comparing the results of current research with established theories or previous studies, researchers can show the position of originality of this work. A comprehensive explanation of how these findings fill the information hole provides significant added value to the development of science in related fields. This is also proof that the research objectives that have been formulated are not just academic formalities, but a target that makes a real contribution to solving existing problems.

Furthermore, the discussion in this report goes beyond just descriptive reporting of what is found on the ground. The main focus shifts to exploring the causality aspects that explain why a particular outcome can occur and how the process of that finding occurs in complex operational dynamics. The emphasis on the mechanisms behind this data is crucial, especially when we talk about the optimization of manufacturing systems that are now beginning to transform towards the basis of intelligent automation. In mid-sized industries, the transition to smart technology is not just about installing advanced hardware, but about how the system interacts with human resources, capital availability, and pre-existing workflow efficiency.

Intelligent automation-based manufacturing system optimization in medium-scale industries has unique characteristics compared to large-scale industries. In medium-scale industries, flexibility is often the main strength as well as the biggest challenge when it comes to integrating with automation systems. This discussion will explore how the application of technologies such as smart sensors, machine learning algorithms, or internet of everything (IoT) integration can increase productivity

without sacrificing the operational agility that characterizes the sector. Researchers must be able to dissect what variables accelerate or hinder the optimization process, so that stakeholders can understand the logic behind the effectiveness of the system offered.

The importance of explaining the how and why aspects of intelligent automation is also closely related to the benefits to be achieved, both technically and economically. The benefits of this research are not only seen in terms of increasing production output, but also in terms of reducing waste, energy efficiency, and consistently improving product quality. An in-depth discussion will outline how each component of automation contributes to achieving those benefits in a systematic way. Thus, the results of this research are not only documents stored in libraries, but can serve as a strategic guide for medium industry players who want to modernize their production facilities effectively and efficiently.

The main problem of this study is related to the low production efficiency in medium-scale industries that still rely on manual processes, fragmented systems, and experience-based decision-making. Previous research results show that these conditions lead to high process variability, insynchronization of material and information flows, and delays in response to changes in market demand. In this discussion, the findings strengthen the argument that production inefficiencies are not solely caused by technological limitations, but rather by the failure of manufacturing systems to manage interactions between subsystems in an integrated manner.

The results of the study show that the application and optimization of intelligent automation is able to answer these main problems by creating better system integration. Production flows become more controlled, operational information is available in real time, and managerial decisions can be made more accurately. These findings suggest that production efficiency increases when manufacturing systems are managed as a dynamic unit, rather than as a separate collection of activities. Thus, this discussion emphasizes that the solution to the main problems of medium-scale industries lies in a systemic approach that integrates technology, processes, and decision-making.

The gap in the problem identified in this study is related to the dominance of intelligent automation studies in large-scale industries, while medium-scale industries still receive minimal attention, especially in terms of effective and applicable optimization models. Previous research results show that many mid-sized industries have partially adopted automation technology, but have not yet gained significant efficiency improvements. This discussion attributes these findings to the absence of a data-based optimization framework that is able to adapt the automation system to actual operational conditions.

The results of the study show that this gap can be bridged through the application of an adaptive intelligent automation-based optimization model. The utilization of operational data allows the system to recognize patterns of inefficiencies and make adjustments on an ongoing basis. This discussion confirms that machine learning-based optimization approaches and system integration are not only relevant for large industries, but can also be effectively adapted to medium-scale industries with limited resources. Thus, this research makes an important contribution in filling the research gap that has existed so far.

In relation to the formulation of the research problem, this discussion shows that the results of the study provide a comprehensive answer on how the optimization of manufacturing systems based on intelligent automation can improve the production efficiency of medium-scale industries. The formulation of the problem that focuses on efficiency improvement mechanisms is answered through the findings that system integration, automation flexibility, and data-driven decision-making are key factors in improving production performance. This discussion emphasizes that the three mechanisms are interrelated and inseparable from each other.

Previous research results have shown that automation implemented without optimization tends to yield limited benefits. In this discussion, the findings are deepened by showing that intelligent automation optimization allows systems to adapt to production dynamics in real time. Thus, the formulation of the problem regarding the effectiveness of automation in improving production efficiency can be answered more substantially, not only at the descriptive level, but also at the level of operational and managerial mechanisms.

The continuity between the theories used and empirical findings in the field is a common thread that strengthens the arguments in this part of the discussion. Researchers must be able to show that the optimization that occurs is not a coincidence, but the result of the application of appropriate engineering and manufacturing management principles. This analytical analysis includes an evaluation of system performance under various operational scenarios, providing a complete picture of the resilience and scalability of intelligent automation. By bringing all these elements together, the discussion of the research succeeds in making a strong intellectual contribution, while offering practical solutions based on accurate data for the future advancement of the national manufacturing industry.

The research objectives directed at analyzing and reviewing the optimization of intelligent automation-based manufacturing systems were achieved through research results that show consistent increase in production efficiency. This discussion relates these achievements to the implementation of an integrated and adaptive system. The increase in efficiency is not only seen in the reduction of cycle time and waste, but also in the improvement of process stability and decision-making quality. Thus, the research objectives are not only achieved empirically, but also provide a conceptual understanding of the role of intelligent automation in modern manufacturing systems.

This discussion shows that the research goal of producing optimization models that are relevant to medium-scale industries is also achieved. Previous research results show that the optimization model applied can be adapted to actual manufacturing conditions without requiring excessive technological investment. This shows that the research objectives have high practical relevance and can be realistically implemented by medium-scale industry players.

The benefits of research can be discussed from three main perspectives, namely theoretical, practical, and academic. Theoretically, the results of the study contribute to the development of manufacturing system studies by showing that the integration of system approaches, adaptive automation, and data-based optimization is an effective strategy in improving production efficiency. This discussion confirms that these theories are not only conceptual, but can also be implemented in a real-scale industry.

In practical terms, the discussion of the results of the study shows that intelligent automation optimization provides direct benefits to industry players, such as increased productivity, reduced operational costs, and increased production flexibility. This discussion emphasizes that these practical benefits are achieved not through technological improvements alone, but through the management of a more integrated and data-based system. This provides important implications for production managers and decision-makers in designing manufacturing transformation strategies.

Academically, this research contributes in the form of an analysis framework and optimization model that can be used as a reference for future research. This discussion confirms that the approach used in this study can be further developed for other industries or combined with quantitative methods to strengthen the validity of the findings. Thus, the academic benefits of this research are not only limited to the results obtained, but also to the potential for future research development.

The discussion of this study emphasizes that the optimization of manufacturing systems based on intelligent automation is an effective and relevant approach in improving the production efficiency of medium-scale industries. By relating the results of previous research to the main problems, research gaps, problem formulations, objectives, and benefits of the research, this discussion shows that the research findings have significant theoretical and practical value. The integrated and adaptive systems approach proposed in this study provides a solid foundation for the development of more efficient, responsive, and sustainable manufacturing.

CONCLUSION

The conclusion of this study confirms that the optimization of manufacturing systems based on intelligent automation is an effective and relevant approach in improving production efficiency in medium-scale industries. Based on the results and discussion of the research, it can be concluded that the main problems faced by medium-scale industries, namely low production efficiency due to the

dominance of manual processes, system fragmentation, and experience-based decision-making, cannot be solved only through partial adoption of technology. New efficiency improvements can be achieved when automation is designed and implemented within an integrated and adaptive system framework.

The results show that manufacturing systems that previously ran separately between production, information, and managerial subsystems tend to result in high process variability as well as waste of resources. Through intelligent automation optimization, the interaction between material flows, information flows, and managerial decisions can be managed in a more synchronous and dynamic manner. This conclusion is in line with the discussion that emphasizes that production efficiency is the result of system integration, not just an increase in the level of mechanization or automation.

The study also concludes that the application of adaptive intelligent automation plays an important role in increasing the flexibility and stability of medium-scale industrial production systems. The results and discussions show that an automation system that is able to adjust operational parameters based on actual data allows the production process to respond to changes in demand and operational conditions more quickly and accurately. Thus, intelligent automation not only increases production speed, but also strengthens the system's ability to manage the uncertainty and dynamics of the manufacturing environment.

The next conclusion relates to the research gaps that have been identified. This study shows that the intelligent automation optimization approach that has been widely studied in large-scale industries can be effectively adapted to medium-scale industries. The results and discussions prove that resource limitations are not a major barrier as long as optimization is carried out by utilizing available operational data and integrating the system gradually. Thus, this research succeeded in filling the research gap by providing empirical evidence that intelligent automation can be applied tatively and realistically in medium-scale industries.

In relation to the research objectives, it can be concluded that the objective of analyzing and explaining the role of intelligent automation-based manufacturing system optimization in improving production efficiency has been achieved. The results of the research and discussion show that the increase in efficiency is not only reflected in operational indicators, but also in changes in production management patterns that are more data-based and systemic. This conclusion confirms that intelligent automation optimization has a structural impact on the way medium-scale industries manage their production processes.

In terms of research benefits, this conclusion confirms that research makes a significant contribution theoretically, practically, and academically. Theoretically, this research strengthens the understanding of manufacturing systems as dynamic systems that require integration between technology, processes, and decision-making. Practically, the results of the study provide guidance for medium-scale industry players in designing strategies to increase production efficiency that do not depend on large technological investments, but on the optimization of integrated and adaptive systems. Academically, this research provides a conceptual and empirical framework that can be a reference for further research in the field of intelligent manufacturing and automation.

The conclusion of this study confirms that the optimization of manufacturing systems based on intelligent automation is not just a technological choice, but a systemic strategy that is able to increase the production efficiency of medium-scale industries in a sustainable manner. By linking the results and the discussion of the research, this conclusion shows that the success of efficiency improvement is largely determined by the industry's ability to integrate automation, data, and decision-making in one adaptive system. These findings reinforce the relevance of research in the development of medium-scale industries that are competitive and ready to face the dynamics of modern manufacturing.

RECOMMENDATIONS

The recommendations of this study are compiled based on conclusions that affirm that the optimization of manufacturing systems based on intelligent automation is an effective strategy in increasing the production efficiency of medium-scale industries. Referring to these findings, the recommendations are directed to strengthen practical implementation, industrial policy development,

and enrichment of scientific studies so that the benefits of intelligent automation can be optimized in a sustainable and sustainable manner.

Based on the conclusion of the study that shows that the main problem of medium-scale industries lies in the weak integration of systems, the first recommendation is addressed to industry players not to view automation as a technology investment, but as part of a systemic strategy. Medium-scale industries are advised to prioritize integration between material flows, information, and decision-making before undertaking more complex automation expansions. This approach is in line with the study's conclusions that emphasize that production efficiency increases when manufacturing systems are managed in an integrated and adaptive manner, rather than when automation is partially implemented.

Furthermore, referring to the conclusion that the use of operational data plays an important role in improving production efficiency, this study recommends that medium-scale industries start building a culture of data-driven decision-making. This step can be started by strengthening the recording system and monitoring production performance consistently. By leveraging the available data, the industry can more accurately identify the sources of inefficiencies and make incremental process adjustments. This recommendation is relevant to the study's conclusions that show that intelligent automation optimization does not necessarily require a large investment, but requires systematic data management.

The next recommendations are addressed to policymakers and industry stakeholders. Based on the findings of the study that confirm that medium-scale industries have limited resources in adopting intelligent automation, policy support is needed that encourages inclusive manufacturing transformation. The government and related agencies are advised to provide mentoring, incentives, and training programs that focus on system integration and adaptive use of digital technology. This support is essential for medium-scale industries to realistically and sustainably implement intelligent automation, as shown in the study's conclusions.

In human resource development, this research recommendation emphasizes the importance of improving the competence of the workforce in the face of the transformation of the manufacturing system. The study's conclusions show that the success of intelligent automation optimization is determined not only by technology, but also by organizational and workforce readiness. Therefore, medium-scale industries are advised to develop training programs oriented towards system understanding, data literacy, and adaptation to automation technology. This approach is expected to strengthen the sustainability of the implementation of intelligent automation in the long term.

Recommendations are also directed to future researchers to develop more in-depth studies on the optimization of manufacturing systems based on intelligent automation. Based on the findings of the study that show that this approach is effective in medium-scale industries, further research is recommended to examine the variation of industrial sectors, the level of production complexity, and the integration of quantitative methods to measure the impact of efficiency in a more measurable manner. The development of an optimization model that combines qualitative and quantitative approaches is expected to enrich the understanding and validity of future research findings.

In addition, advanced research is recommended to explore the social and managerial aspects that affect the success of intelligent automation optimization. The conclusion of this study confirms that changes in manufacturing systems have an impact on work patterns and decision-making. Therefore, the study of organizational readiness, work culture, and resistance to change is important to complement the technical understanding of intelligent automation.

The recommendations of this study confirm that the implementation of intelligent automation-based manufacturing system optimization requires a holistic and sustainable approach. By referring to the conclusions of the research, this recommendation is expected to be a practical guide for industry players, a policy reference for stakeholders, and a scientific foothold for the development of further research. This approach is expected to be able to encourage sustainable improvement in the production efficiency of medium-scale industries and strengthen the competitiveness of manufacturing in the future.

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