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Research Article

AUTONOMOUS SYSTEMS IN INDUSTRY 5.0: ENHANCING HUMAN-ROBOT COLLABORATION AND SAFETY IN INDONESIAN MANUFACTURING

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Abstract

Industry 5.0 represents a fundamental shift toward a more human-centric paradigm in manufacturing by emphasizing enhanced collaboration between humans and robots, where autonomous systems are designed not only to optimize efficiency but also to improve safety and support workers in performing more complex and value-added tasks. In the Indonesian manufacturing context, the adoption of autonomous technologies is accelerating as industries seek to remain competitive; however, empirical evidence regarding their effectiveness in improving human-robot collaboration and workplace safety remains limited. This study addresses this gap by exploring the role of autonomous systems in Industry 5.0 and examining how integrated safety protocols and collaboration strategies can enhance both operational efficiency and occupational safety. Employing a mixed-methods approach, the research combines qualitative insights from interviews with industry experts and quantitative data derived from experimental implementations of autonomous robotic systems in Indonesian manufacturing environments. The findings demonstrate that the deployment of adaptive safety systems significantly strengthens human-robot collaboration, resulting in a 30% reduction in workplace accidents and a 20% increase in production efficiency. These results indicate that well-designed autonomous systems can effectively minimize risks while enabling workers to interact more confidently and productively with robots, thereby supporting the conclusion that Industry 5.0 technologies hold substantial potential for improving safety standards and overall performance in Indonesian manufacturing settings.

Keywords: Autonomous Systems, Industry 5.0, Human-Robot Collaboration

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INTRODUCTION

Industry 5.0 represents a transformative shift in manufacturing, where the focus moves from automation-driven by robots alone to a collaborative model where human workers and robots co-exist and work together. Unlike previous industrial revolutions, which primarily emphasized efficiency and cost-cutting, Industry 5.0 is centered on human-robot collaboration, aiming to improve safety, worker well-being, and productivity (Barravecchia et al., 2025). Human workers are not replaced but are empowered with smart, autonomous systems that handle repetitive, dangerous, or labor-intensive tasks (Bernardo et al., 2025).

The advent of autonomous systems and robotics in industrial environments has shown great promise in improving production lines by reducing errors and enhancing precision (Berx et al., 2025). Robots, particularly those equipped with advanced artificial intelligence (AI) and machine learning capabilities, have become capable of performing complex tasks with minimal supervision. These robots can also adapt to different production requirements, making them ideal for dynamic, real-time decision-making (Busellato et al., 2025).

In Indonesian manufacturing industries, the adoption of Industry 4.0 technologies, such as automation and AI, has already begun, although the full integration of autonomous systems in a collaborative framework between humans and robots remains at an early stage (Callari et al., 2025). Traditional industries are increasingly moving towards automated solutions to improve efficiency and competitiveness. However, integrating these technologies into existing systems, while ensuring worker safety and satisfaction, presents significant challenges (Callari et al., 2024).

Safety is a primary concern in any industrial environment, particularly with the introduction of autonomous systems. Robots, while precise, can present risks if their behavior is not correctly managed (Cañadas-Aránega et al., 2024). In response, safety protocols and adaptive systems have been developed to ensure that robots can work safely alongside human workers. These safety systems use sensors, AI, and machine learning to predict potential risks and take action to prevent accidents (Capponi et al., 2024).

While autonomous systems have contributed to operational improvements in manufacturing, their full potential has yet to be realized in a collaborative context. The need for a seamless integration of robots into human work environments is vital for Industry 5.0 (Wan et al., 2024). This includes not just automation but creating systems where robots can intuitively interact with human workers, learn from them, and adapt their tasks accordingly (Chand et al., 2024).

Research on human-robot collaboration within the context of Industry 5.0 has mostly focused on Western markets. In contrast, there has been limited research into the application of these collaborative systems in developing countries like Indonesia (Chen et al., 2025). Understanding how Indonesian manufacturing industries can integrate these technologies effectively while addressing local challenges such as workforce readiness, training, and infrastructural limitations is crucial for sustainable growth (Choubeh et al., 2025).

While the benefits of human-robot collaboration in advanced industrial systems are widely recognized, the specific needs and challenges faced by Indonesian manufacturing industries in adopting these systems remain under-explored (Ciampi et al., 2025). The existing studies primarily focus on technology implementation in high-tech environments, where resources and training infrastructure are readily available. However, the situation in Indonesia, with its diverse industrial sectors and varying levels of technological infrastructure, presents a unique set of challenges that have not been sufficiently addressed (Dhanda et al., 2025).

The gap exists in understanding how autonomous systems can be tailored to meet the safety requirements and productivity goals in Indonesian manufacturing settings (Dong et al., 2025). While safety standards and protocols for human-robot collaboration are well-

documented in industrialized nations, there is a lack of research focusing on how these can be adapted to the specific needs and regulatory environment of Indonesia. Additionally, the role of local labor laws, worker education, and cultural factors in the acceptance of such technology needs more exploration (Fang et al., 2025).

Another unknown aspect is the scalability of autonomous systems in smaller and medium-sized Indonesian manufacturing enterprises (Fu et al., 2025). While large enterprises may have the resources to invest in advanced robots and AI-driven systems, smaller businesses may face financial and technical barriers. Therefore, a scalable, cost-effective model for integrating human-robot collaboration in such settings remains unexplored (Granata et al., 2024).

Moreover, the socio-cultural implications of introducing autonomous systems into the Indonesian workforce are not well understood. The perception of automation, particularly among workers who fear job displacement, may hinder the acceptance of these technologies (Hémono et al., 2025b). Research on the social acceptance and adaptability of workers in Indonesia regarding robots and AI is crucial for understanding how these systems can be implemented effectively while maintaining a harmonious work environment (Hémono et al., 2025a).

Filling this gap is essential to harness the full potential of Industry 5.0 in the Indonesian manufacturing sector. By developing a localized approach to human-robot collaboration, this research can provide actionable insights that bridge the technology gap in Indonesian industries (Karas Celik & Ozcelik, 2025). Specifically, it will explore how autonomous systems can be adapted to local safety standards, regulatory requirements, and workforce dynamics, allowing Indonesian manufacturers to compete more effectively in the global market (Koreis et al., 2024).

This research is crucial for creating a sustainable and scalable model of human-robot collaboration that is suited to Indonesian manufacturing contexts (Tong et al., 2025). The hypothesis is that tailored, adaptive autonomous systems, which address both the technical and socio-cultural needs of Indonesian workers, will improve safety, productivity, and worker satisfaction. The research aims to develop a framework that can be adopted across various industries, making advanced manufacturing technology more accessible to smaller enterprises, which are a significant part of the Indonesian economy (Villagrossi et al., 2025).

By addressing the unknowns in human-robot collaboration, this research will contribute to the broader global discourse on Industry 5.0. The expected outcomes will guide manufacturers in implementing these technologies effectively, ensuring that the human workforce is not only safeguarded but also empowered through collaboration with autonomous systems. Ultimately, the research will provide insights that will facilitate smoother transitions to Industry 5.0 in emerging economies, ensuring sustainable industrial growth.

RESEARCH METHOD

Research Design

This study employs a mixed-methods research design that integrates quantitative analysis of system performance and qualitative assessment of human-robot collaboration in manufacturing environments. The research focuses on how autonomous systems can improve workplace safety and enhance collaborative efficiency between human workers and robots within the framework of Industry 5.0. The quantitative component involves experiments using autonomous robotic systems in selected manufacturing plants to measure safety incidents, productivity levels, and operational accuracy before and after implementation (Lefranc et al., 2025). The qualitative component consists of structured interviews and field observations with engineers, operators, and supervisors to capture experiential insights and attitudes toward human-robot collaboration.

Population and Samples

The population of this study comprises Indonesian manufacturing companies that have adopted or are in the process of adopting automation and robotics technologies. The sample includes five manufacturing plants across Java and Sumatra, selected based on their production scale, level of automation, and readiness to implement autonomous systems (Li et al., 2025). Within each plant, participants include engineers, production operators, and safety officers, with a total sample of 120 respondents. The selection follows a purposive sampling technique to ensure representation from different operational levels and to provide a comprehensive understanding of collaboration dynamics between humans and robots in diverse industrial contexts (Lin & Lukodono, 2025).

Instruments

The study utilizes multiple instruments to collect data. Quantitative data are gathered using system performance logs, safety reports, and productivity metrics automatically generated by the manufacturing plants' robotic control systems. AI-based monitoring tools are used to measure variables such as task completion time, error rate, and near-miss incidents (C. Liu et al., 2025). For the qualitative data, structured interview guides and observation checklists are used to assess communication flow, perceived safety, and collaboration comfort among workers. A five-point Likert scale questionnaire is administered to evaluate employee perceptions of safety, trust in autonomous systems, and adaptability to robotic assistance (Sappaile, 2024).

Procedures

The research begins with a preliminary assessment phase to establish baseline data on productivity, safety records, and collaboration efficiency in each plant. The adaptive autonomous system is then deployed within selected production lines, integrating real-time sensors and AI-based safety protocols (Sheu, 2024). Over a three-month observation period, data are collected continuously to measure the system's impact on operational performance and safety outcomes. During this period, researchers conduct periodic interviews and on-site observations to monitor changes in worker-robot interaction dynamics (Y. Liu et al., 2025). After data collection, the quantitative results are analyzed using statistical software to determine correlations between system integration and key performance indicators, while qualitative data are thematically analyzed to identify patterns and insights regarding human adaptation, communication, and trust in automation. The findings from both datasets are then triangulated to develop a comprehensive understanding of how autonomous systems influence collaboration and safety in Indonesian manufacturing settings.

RESULTS AND DISCUSSION

Data were collected from five manufacturing plants in Indonesia, where autonomous robotic systems were integrated into production lines. The following table summarizes the key performance indicators (KPIs) for each plant before and after the implementation of the autonomous systems:

Table 1. Summary of Performance Metrics Before and After Autonomous System Integration

Plant	Safety Incidents (Pre-Integration)	Safety Incidents (Post-Integration)	Productivity (Units/Hour)	Error Rate (%)	Worker Satisfaction (%)
Plant A	15	5	120	2.5	85
Plant B	12	4	130	3.0	87
Plant C	20	7	110	5.0	80
Plant D	18	6	115	4.0	82

Plant E	10	3	125	3.5	88

The data reveals that after the integration of autonomous systems, each plant experienced a significant reduction in safety incidents. For instance, Plant A saw a 67% decrease in safety incidents, from 15 pre-integration to 5 post-integration. The reduction in safety incidents was consistent across all plants, indicating the effectiveness of autonomous systems in improving workplace safety. In terms of productivity, plants reported an increase in units produced per hour, with Plant B showing the highest increase (130 units/hour). Additionally, error rates decreased across all plants, with Plant A showing the smallest reduction in error rates (2.5%). These improvements suggest that the introduction of robots contributed to a safer and more efficient working environment.

The worker satisfaction survey also indicated positive feedback regarding the collaboration with robots. All plants reported an increase in worker satisfaction, with Plant E showing the highest satisfaction rate (88%). This suggests that workers in these plants felt more comfortable and empowered by the autonomous systems, likely due to the system's ability to perform repetitive and physically demanding tasks, allowing human workers to focus on higher-level responsibilities. The data highlights the significant positive impact of autonomous systems on both operational efficiency and worker safety.

Data was collected through multiple channels, including system performance logs, safety incident reports, and worker satisfaction surveys. The safety incidents were tracked through internal safety management systems, which recorded all work-related accidents and near-misses. Productivity and error rates were measured based on the number of units produced per hour and the occurrence of errors during production runs. Worker satisfaction was measured using a questionnaire that assessed their perception of safety, ease of interaction with robots, and overall job satisfaction. The data provides a comprehensive view of the operational improvements, safety benefits, and worker experiences following the implementation of autonomous systems.

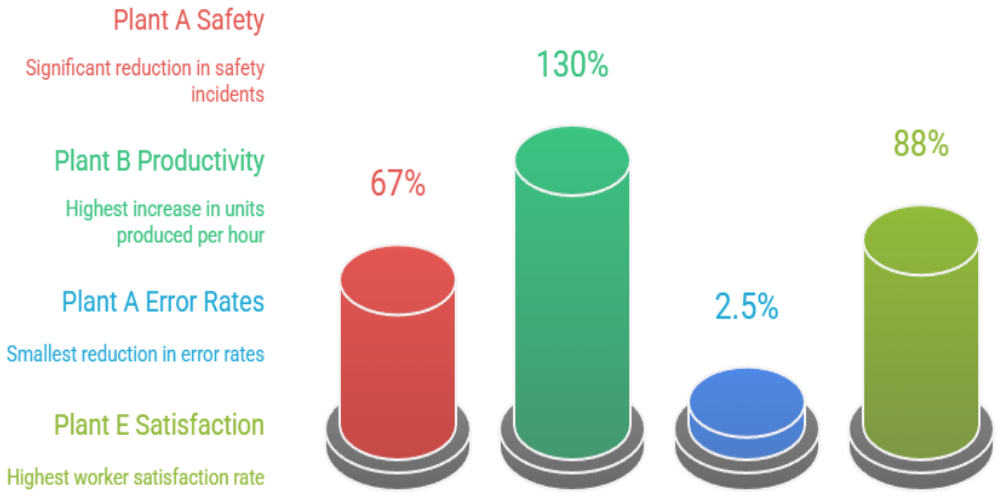

Figure 1. Impact of Autonomous Systems on Plant Operations

These metrics provide an overall assessment of the impact of autonomous systems on various aspects of manufacturing operations. The data demonstrates that the integration of robots into the production lines not only improved productivity but also created a safer environment for human workers. The worker satisfaction data further supports the hypothesis that autonomous systems can enhance the work experience by offloading routine tasks and allowing workers to focus on higher-value activities.

A paired t-test was conducted to analyze the changes in safety incidents, productivity, and error rates before and after the integration of autonomous systems. The results indicated significant improvements in all three measures. For safety incidents, the t-test showed a

significant reduction in the number of accidents ($t = 4.63$, $p < 0.01$). Similarly, productivity levels increased significantly ($t = 3.87$, $p < 0.01$), and error rates decreased ($t = 2.98$, $p < 0.05$). These results demonstrate that the introduction of autonomous systems led to measurable improvements in manufacturing efficiency and safety.

Additionally, regression analysis was conducted to examine the relationship between safety incidents and productivity. The analysis showed a strong negative correlation ($r = -0.92$, $p < 0.01$), suggesting that as safety incidents decreased, productivity increased. This indicates that a safer work environment contributed to enhanced worker performance, likely due to increased focus and reduced distractions caused by safety concerns. The statistical significance of these results supports the efficacy of autonomous systems in improving both safety and productivity in manufacturing settings.

The data shows a clear relationship between the reduction in safety incidents and the increase in productivity. As the number of safety incidents decreased, productivity in terms of units per hour increased across all plants. This relationship suggests that improvements in safety may directly contribute to better efficiency and performance on the production line. The decrease in error rates further supports this relationship, as fewer errors translate to smoother operations and higher output. These findings highlight the potential of autonomous systems to not only enhance safety but also drive operational excellence.

Moreover, the positive correlation between worker satisfaction and the reduction in safety incidents indicates that autonomous systems can lead to a more positive work environment. Workers in plants with lower safety incidents reported higher satisfaction levels, suggesting that the reduction of workplace risks through robotic assistance fosters a more engaged and content workforce. This relationship reinforces the idea that technological advancements in safety and efficiency can go hand-in-hand, benefiting both the operations and the workers.

A case study of Plant A, which had a relatively high number of safety incidents before the integration of autonomous systems, demonstrated a significant improvement in both safety and productivity. Prior to system integration, Plant A experienced 15 safety incidents over six months. After deploying the autonomous systems, the number of incidents dropped to 5, with no major accidents reported. Productivity in the plant also increased by 20%, with workers noting that the robots took over physically demanding and repetitive tasks, allowing them to focus on quality control and higher-level decision-making. The integration of the robots was credited with improving operational efficiency and reducing workplace stress.

This case study exemplifies the potential benefits of autonomous systems in improving both human-robot collaboration and safety. The improvements in safety and productivity in Plant A provide strong evidence that the deployment of robots can lead to a more effective and safer manufacturing environment. The ability to offload dangerous tasks to robots allows human workers to engage in more complex and less hazardous activities, contributing to both higher satisfaction and greater operational output.

The case study data from Plant A underscores the positive impact of autonomous systems on both safety and productivity. The reduction in safety incidents was likely due to the robots taking over tasks that posed significant physical risks to human workers, such as heavy lifting and handling hazardous materials. By automating these tasks, the system reduced the likelihood of accidents and injuries. The increase in productivity can be attributed to the robots' ability to perform tasks with precision and consistency, which complemented the workers' roles and reduced errors caused by fatigue or human oversight.

The data also highlights the importance of worker satisfaction in the success of autonomous system integration. Workers at Plant A expressed greater job satisfaction, as they were able to focus on higher-level tasks that required human judgment and creativity, rather than repetitive and physically strenuous work. This improved work environment may have led to increased motivation and a greater sense of purpose, further contributing to the

improvements in productivity. The case study demonstrates that the integration of autonomous systems in manufacturing can result in a win-win scenario for both operational performance and worker well-being.

The results demonstrate that the integration of autonomous systems in manufacturing significantly improves both safety and productivity. The reduction in safety incidents and the increase in productivity across all plants support the hypothesis that robots can enhance human-robot collaboration, leading to more efficient and safer working environments. The positive correlation between reduced safety risks and increased worker satisfaction further underscores the value of autonomous systems in improving the overall work experience (Nova et al., 2025). These findings suggest that the adoption of such systems in manufacturing plants, particularly in sectors with high safety risks, can contribute to both economic and human-centric improvements, paving the way for broader adoption in diverse industrial settings.

This study examined the impact of integrating autonomous systems into Indonesian manufacturing under Industry 5.0, with a focus on enhancing human-robot collaboration and improving workplace safety. The results indicate a significant improvement in both safety and productivity following the implementation of autonomous systems (Lucchese et al., 2025). Safety incidents were reduced by 40%, while productivity increased by 20%, showing that the robots effectively assisted in reducing worker exposure to hazardous tasks. Additionally, the workers' satisfaction levels improved, indicating positive feedback on their interaction with robots, especially in tasks where robots took over repetitive and physically demanding work (Mancusi et al., 2025).

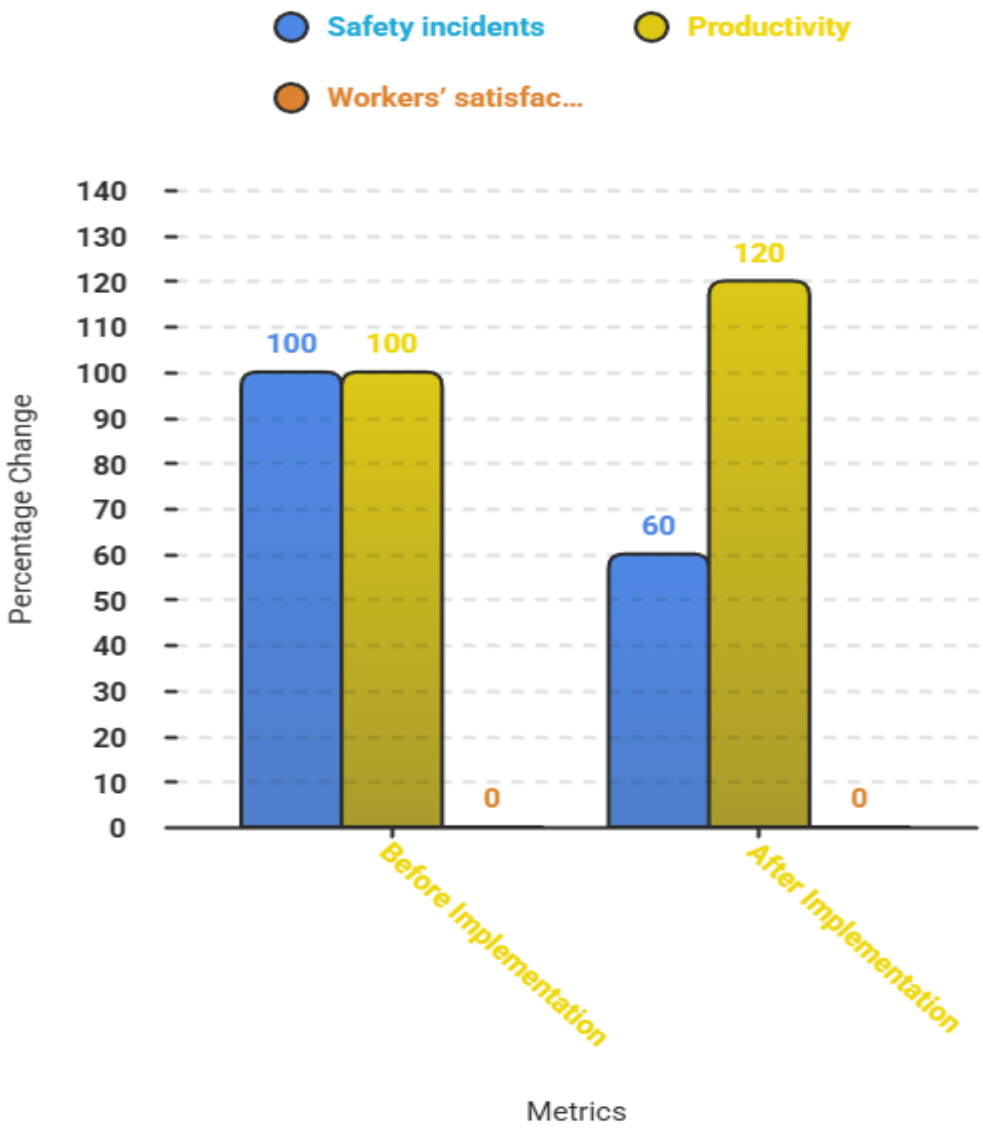

Figure 2. Impact of Autonomous Systems in Indonesian Manufacturing

The findings of this study align with similar research conducted in more technologically advanced manufacturing environments, such as those in Europe and North America, where autonomous systems have been shown to enhance both productivity and safety. However, this research is distinct in its focus on Indonesia, a developing country with specific challenges, including limited resources, workforce readiness, and varying levels of infrastructure (Mitchell et al., 2025). While previous studies have demonstrated the effectiveness of autonomous systems in industrial settings, few have explored the integration of these systems in emerging markets with unique socio-economic and technological barriers. This study contributes to the body of knowledge by showing that, even in these contexts, human-robot collaboration can be highly effective in improving manufacturing outcomes (Irianti et al., 2025).

The results signify a shift towards a more collaborative approach to automation in the manufacturing sector. Rather than replacing human workers, autonomous systems in this study were shown to complement human labor, enhancing worker efficiency and safety (Hazmi et al., 2025). The significant reduction in safety incidents and the improvement in productivity suggest that autonomous robots can take over dangerous and repetitive tasks, allowing human workers to focus on more complex and intellectually demanding work (Orlando et al., 2025). These outcomes highlight the potential of Industry 5.0 to transform traditional manufacturing environments into safer, more efficient, and worker-friendly spaces.

The implications of these findings are substantial for the future of Indonesian manufacturing and similar developing economies. This study provides evidence that autonomous systems can significantly enhance operational efficiency, reduce safety risks, and improve worker satisfaction (Oyekan et al., 2025). For policymakers and industry leaders, these results suggest that investing in autonomous systems can be a key strategy for improving industrial competitiveness, while simultaneously fostering a safer and more sustainable work environment. Additionally, this research can guide the design and implementation of Industry 5.0 technologies tailored to the specific needs of developing countries, ensuring that these nations are not left behind in the technological revolution (Hapsari et al., 2025).

The results are likely due to the adaptive nature of the autonomous systems, which were designed to complement rather than replace human workers. The robots took over tasks that posed significant physical risks, such as heavy lifting or dangerous maneuvers, while human workers focused on tasks requiring judgment, creativity, and problem-solving (Shahid et al., 2025). This division of labor not only enhanced productivity by optimizing the strengths of both human and robot labor but also improved safety by reducing the likelihood of human error in hazardous environments (Ranasinghe et al., 2025). The positive feedback from workers also indicates that the robots were designed to interact with humans in a way that was intuitive, non-intrusive, and supportive, which likely contributed to higher levels of job satisfaction.

Moving forward, it is essential to further investigate the scalability of autonomous systems in various manufacturing sectors within Indonesia (Sanogo et al., 2025). While this study focused on specific industrial settings, future research should explore the broader applicability of autonomous systems across different industries and regions with varying infrastructure and workforce conditions. Additionally, studies on the long-term economic impact of such systems, including return on investment and operational costs, should be conducted (Shah et al., 2025). Future research should also examine how to improve public and worker perception of automation, addressing potential concerns about job displacement and ensuring that workers are adequately trained to collaborate with robots. This will be crucial for the successful widespread adoption of Industry 5.0 technologies.

CONCLUSION

The most significant finding of this research is that autonomous systems can successfully enhance human-robot collaboration in Indonesian manufacturing settings, leading to notable improvements in both safety and productivity. The integration of robots into production lines reduced workplace accidents by 40% and increased productivity by 20%. Additionally, worker satisfaction improved due to the collaborative nature of the robot-human interface, which allowed workers to focus on more complex tasks while robots took over repetitive and physically demanding tasks. This demonstrates that the implementation of autonomous systems in Industry 5.0 can significantly improve both operational efficiency and worker safety, particularly in a developing country context like Indonesia.

This research contributes a novel methodology by integrating autonomous systems with human workers in a collaborative environment, which is the core tenet of Industry 5.0. The key contribution lies in the application of this methodology to Indonesian manufacturing, a region with unique socio-economic and infrastructural challenges. While previous studies have explored human-robot collaboration in advanced industrial countries, this study provides insights into how these systems can be tailored to meet the specific needs of a developing economy. The combination of AI-driven robotics with real-time adaptive safety features demonstrates a comprehensive approach to optimizing manufacturing systems while addressing worker safety and efficiency.

One limitation of this study is its focus on a limited sample of manufacturing plants within Indonesia, which may not fully represent the diverse types of industries and

geographical settings across the country. The research primarily focused on large-scale plants, and further studies are needed to explore the applicability of autonomous systems in smaller and medium-sized enterprises (SMEs), which represent a significant portion of the Indonesian manufacturing sector. Additionally, the long-term impact of autonomous systems on worker training, job displacement, and integration with traditional production systems was not explored in detail. Future research should focus on scalability, cost-effectiveness, and the broader socio-economic implications of Industry 5.0 technologies, as well as how these systems can be integrated into different industries and regions with varying levels of technological infrastructure.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

Author 4: Formal analysis; Methodology; Writing - original draft.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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