

Industrial Revolution 4.0 In Mechanical Engineering: A Literature Review On The Application Of Iot And Automation In Production Systems

Arie Wahyu Prananta¹, Dwiyanto²

Universitas Trunojoyo Madura, Indonesia¹, Politeknik Penerbangan Surabaya, Indonesia²

Email : arie.prananta@trunojoyo.ac.id

Received: June 22, 2025
Accepted: August 02, 2025

Revised : July 25, 2025
Published: August 22, 2025

ABSTRACT

The Industrial Revolution 4.0 has revolutionized the mechanical engineering production paradigm through the integration of digital technologies such as the Internet of Things (IoT), cyber-physical systems (CPS), and intelligent automation. This study aims to evaluate the strategic role of IoT and automation in realizing an adaptive, efficient, and sustainable mechanical engineering production system. Using a qualitative approach with a literature review method, this study analyzes the latest findings from relevant scientific sources over the past five years. The results of the review indicate that the implementation of IoT contributes to increased efficiency through predictive maintenance, reduced downtime, and real-time data-driven decision-making. On the other hand, the evolution of automation includes precision robotics, cloud-based CNC, and intelligent PLCs that enhance production flexibility and quality. However, several challenges have been identified, such as limited digital human resources, inadequate infrastructure, and system interoperability issues. Therefore, adaptive strategies such as continuous technical training, cross-sector collaboration, and strengthening industrial digitalization policies are needed. This study concludes that the integration of IoT and automation is a key foundation for the transformation of mechanical engineering towards inclusive and sustainable smart manufacturing, and emphasizes the importance of synergy between technology, people, and policies in supporting a systemic and contextual industrial revolution.

Keywords: Automation; Internet of Things; Mechanical Engineering

INTRODUCTION

The Industrial Revolution 4.0 has revolutionized the global manufacturing landscape, including in mechanical engineering, through the integration of digital technologies and physical systems. Key concepts such as cyber-physical systems (CPS), the Internet of Things (IoT), and big data analytics form the foundation of smart manufacturing systems, emphasizing connectivity, data integration, and autonomous decision-making (Anaam et al., 2022). In this context, production systems are no longer merely mechanistic but rather adaptive entities capable of responding to environmental changes in real time. This transformation is not only changing the way production is carried out but also redefining the role of technology in the manufacturing value chain.

The role of the Internet of Things (IoT) in supporting this revolution is becoming increasingly significant, particularly in mechanical engineering, which has traditionally focused on mechanical aspects and conventional manufacturing. Through IoT devices, every machine component can be integrated into an interconnected digital network. Installed sensors enable continuous data collection on temperature, vibration, pressure, and other parameters, which are then sent to a cloud-based control center for analysis.



This implementation contributes to improved predictive maintenance capabilities, downtime avoidance, and energy efficiency, ultimately enhancing the sustainability of the overall production system (Dewadi et al., 2025).

One of the tangible implications of implementing IoT in mechanical engineering is the creation of a proactive and responsive production system (Murni & Adibah, 2024). Unlike traditional systems that rely on fixed maintenance schedules, IoT-based systems enable early, automatic detection of damage or wear on machine components. This significantly reduces maintenance costs and losses due to sudden breakdowns. Furthermore, the collected data also provides critical insights for more strategic and evidence-based production planning.

Along with the integration of IoT, automation plays a central role in driving operational efficiency and productivity in the mechanical engineering industry. Modern automation encompasses logic-based control systems (PLCs), industrial robotics, and CNC (Computer Numerical Control) technology, which have evolved into intelligent systems that can learn and adapt (Pramudita et al., 2024). Automation not only replaces humans in repetitive and dangerous tasks but also creates new opportunities in manufacturing precision, reducing product variability, and end-to-end process integration.

In the context of mechanical engineering-based production, automation systems integrated with IoT create a more holistic work ecosystem. For example, industrial robots connected to sensor systems and data analytics can automatically adjust speed, force, and work patterns based on workpiece characteristics or changes in the work environment (Trista, 2022). This allows manufacturing processes to become more flexible and responsive to variations in market demand, eliminating the need for time-consuming and costly manual system resets (Oztemel & Gursev, 2020).

However, the implementation of IoT and automation in the industrial world still faces several structural challenges. One major obstacle is the lack of adequate digital infrastructure, particularly in developing countries, which leads to limitations in connectivity, network reliability, and the availability of supporting technology (Herdiana et al., 2023). Furthermore, the workforce skills gap is a critical barrier, as the adoption of new technologies requires a multidisciplinary understanding involving mechanical, electronic, programming, and data analytics aspects.

Furthermore, interoperability between systems and devices from various manufacturers is also a strategic issue for the successful implementation of Industrial Revolution 4.0 technologies. Without established technical standards and an open architecture, cross-platform integration will be difficult. This hinders the development of a modular and scalable production ecosystem. Therefore, a collaborative approach between industry, research institutions, and government is needed to create a regulatory framework and technology policies that encourage widespread adoption of IoT and automation systems (Dafflon et al., 2021).

Considering these dynamics, literature review is crucial as a basis for understanding developments and best practices in IoT and automation applications across various mechanical engineering sectors. A review of the latest scientific literature allows for the identification of technology trends, implementation challenges, and adoption models that have proven effective in industrial settings. This approach not only provides conceptual understanding but also establishes an empirical foundation that can be used in designing contextual and sustainable implementation strategies in the future.

METHOD

This study uses a descriptive qualitative approach with a literature review as the primary strategy for data collection and analysis. This approach was chosen because it is suitable for exploring in-depth the theoretical and empirical dynamics related to the application of IoT (Internet of Things) technology and automation in mechanical engineering-based production systems in the Industrial Revolution 4.0 era. The literature review allows researchers to formulate a conceptual synthesis through a systematic review of various relevant academic literature sources, such as scientific journal articles, conference proceedings, scientific books, and technical research reports published in the last five years.

The stages in conducting this literature study include the processes of identification, selection, critical evaluation, and synthesis of information. First, the researcher identified relevant literature using leading scientific databases such as Scopus, IEEE Xplore, ScienceDirect, and Google Scholar, with keywords focused on "Industrial Revolution 4.0", "IoT in Mechanical Engineering", "Automation in Manufacturing", and "Smart Production Systems". Second, source selection was carried out based on inclusion criteria such as the year of publication (maximum of the last five years), publisher credibility, and direct relevance to the research focus.

Following the selection process, each selected literature was analyzed in depth using a thematic analysis approach to identify patterns, trends, and research gaps within the topic under study. This process involved categorizing key issues, such as the role of IoT in production systems, dominant forms of automation in mechanical engineering, and factors influencing the success or failure of 4.0 technology adoption in the industrial sector. These findings were then compiled into a structured thematic narrative to build a comprehensive and critical understanding of the study's subject matter.

This research does not attempt to provide numerical generalizations as with quantitative approaches, but rather focuses on in-depth understanding and interpretation of the meaning of the phenomena studied within the context of existing literature. Therefore, validity in this study is maintained through a process of triangulation of literature sources and cross-checking of findings. Furthermore, the researcher also applies the principle of scientific reflexivity in every stage of the analysis, consciously considering interpretive biases and epistemological positions regarding the secondary data used.

With this methodology, it is hoped that the literature study will be able to produce a theoretical understanding that can be used as a conceptual basis for further research, as well as as policy recommendations and implementation strategies in the development of mechanical engineering production systems integrated with IoT and automation technologies in a sustainable manner. This research also plays a role in filling the literature gap that is still minimal in comprehensive mapping between technological readiness, infrastructure capacity, and human resource challenges in the context of the Industrial Revolution 4.0.

RESULT AND DISCUSSION

1. IoT Integration in Mechanical Engineering Production Systems: A Transformation Direction Towards Smart Manufacturing

The integration of IoT in mechanical engineering is strongly supported by various research findings that demonstrate a positive correlation between production digitalization and increased operational efficiency. According to Zhong et al. (2017), the IoT-based Smart Manufacturing concept enables the realization of cyber-physical

production systems (CPPS), a system in which physical elements such as machines and production components can interact directly with digital systems through sensors and actuators, forming an intelligent and adaptive communication and control network. This transforms the traditional manufacturing paradigm into a system based on rapid, flexible, and adaptive responses to changes in demand and technical conditions on the production floor.

In the context of predictive maintenance, research by Latipah et al., (2025) suggests that the use of IoT sensors connected to machine learning systems can significantly reduce maintenance costs by up to 30% and reduce machine downtime by more than 50%. This approach, called data-driven predictive analytics, is a crucial foundation for condition-based maintenance, replacing the less efficient time-based preventive maintenance approach in the long run.

From a machine-to-machine (M2M) perspective, Wibowo (2025) explains that IoT architecture enables integration between previously unconnected machines, forming an intelligent production network capable of self-optimization. In practice, this system can shift workloads, optimize production routes, or perform real-time decision-making based on artificial intelligence algorithms that manage big production data in a decentralized manner on edge computing.

The readiness of industrial digital infrastructure is a critical concern discussed in the Industry 4.0 Maturity Index model developed by Kurniawan et al. (2024). This model states that digital transformation requires infrastructure maturity encompassing hardware (sensors, gateways, edge devices), software (IoT platforms, cloud computing), and connectivity (industrial communication protocols such as MQTT, OPC-UA, and 5G). Industries that have not yet reached the connected operations stage will face a significant technology gap if they do not immediately adopt retrofit systems or open IoT standards.

Regarding cybersecurity issues, the industrial IoT ecosystem is highly vulnerable to denial of service (DoS) attacks, spoofing, and sensor and actuator control takeovers (Nugrowibowo & Muslim, 2023; Irawan et al., 2024). Therefore, they suggest implementing blockchain for IoT as an approach capable of ensuring the integrity and authentication of data transactions between IoT devices in the manufacturing industry.

In terms of human resource readiness, Zheng et al. (2018) highlighted the importance of a digital competency framework encompassing both technical skills (e.g., mastery of IoT protocols, sensor data processing, Python/Node-RED programming) and strategic competencies (e.g., data analytics, cybersecurity awareness, and digital production system management). Training based on digital twin simulation and virtual commissioning is an effective method for bridging the knowledge gap among the conventional mechanical engineering workforce.

Ultimately, the transformation towards smart manufacturing through IoT cannot be separated from the sustainability dimension. A study by Ryalat et al. (2024) confirmed that IoT-based production systems can minimize waste, increase energy efficiency, and extend equipment lifespan through data-driven lifecycle management. This makes IoT not only an efficiency tool but also an enabler for sustainable manufacturing, aligning with the green industrial development agenda.

2. Evolution of Automation in Mechanical Engineering: The Role of Robotics, CNC, and Intelligent Control Systems in the Industry 4.0 Era

The development of automation technology in mechanical engineering has become a major focus in various scientific publications and industry reports, particularly in the context of the application of Cyber-Physical Systems (CPS) and Internet of Things (IoT) principles in modern manufacturing (Herdiana et al., 2023). Automation systems

now not only replace manual tasks but also create a production environment capable of learning and adapting, as defined in the smart factory framework of the German Industry 4.0 Platform (Hamrol et al., 2019).

Modern industrial robotics has demonstrated significant performance improvements in terms of repeatability and dynamic workloads. According to the World Robotics 2023 report by the International Federation of Robotics (IFR), the penetration rate of robots in the manufacturing sector is increasing by 12% annually globally, with Asia being the most progressive region. Machine vision technology, AI-based path planning, and sensor feedback enable robots to perform tasks such as precision welding with deviations of less than ± 0.02 mm (Soori et al., 2024), supporting the mechanical engineering industry's need for high product reliability.

Cloud-based CNC machines have also become an important topic of study in digital manufacturing. Barari et al., (2021) explain that the use of digital twins and edge computing in CNC systems enables predictive analysis and distributed control, which accelerates anomaly detection by up to 40% compared to conventional CNC systems. Another study by Mulge (2024) proves that this system can increase Overall Equipment Effectiveness (OEE) by up to 25% through automatic G-code programming optimization and the integration of AI-based feedback loops.

Meanwhile, PLC technology has evolved into a decentralized control system with support for industrial protocols such as OPC UA and MQTT, which are compatible with industrial IoT (IIoT) architectures. Intelligent PLCs connected to MES and SCADA systems enable control responses in < 50 ms, making them ideal for environments requiring high operational stability such as precision manufacturing (Jannah & Saifullah, 2024). This is in line with research by Gunawan (2024), which emphasizes the importance of PLCs in supporting reconfigurable manufacturing systems (RMS).

The smart production ecosystem formed from the interconnection of automation and IoT significantly supports the principles of just-in-time (JIT) and mass customization. IoT-based manufacturing systems can adjust production lines in less than 10 minutes to changes in market demand, thanks to sensor-based architecture and demand prediction algorithms (Wawan, 2025). This supports the flexibility of mechanical engineering production at various scales, especially in the manufacturing of heavy equipment and automotive parts.

The reduction of variability and increased precision through automation has been extensively researched. In a study by Gupta et al. (2022), a CNC and robotics-based automation system demonstrated a 60% reduction in defect rates in precision machining processes compared to manual methods, with a 35% increase in cycle time efficiency. This reinforces the argument that automation is not just about speed, but also about product quality and consistency.

However, the literature also highlights the challenges of automation adoption, particularly at the MSME scale. A study by Visconti et al. (2024) cited initial investment costs and limited digital talent as key barriers, followed by limited integration of legacy systems. Therefore, a hybrid retrofitting approach and training strategies based on upskilling and reskilling are key to an inclusive automation transformation.

These findings demonstrate that the evolution of automation in mechanical engineering is not simply a matter of technology adoption, but rather an industrial paradigm shift involving data integration, artificial intelligence, and high connectivity. Robotics, cloud CNC, and intelligent PLCs are catalysts in shaping manufacturing that is precise, flexible, and responsive to global market dynamics in the Industry 4.0 era.

3. Challenges of Implementation and Industrial Adaptation Strategies to Technology 4.0 in Mechanical Engineering

The implementation of Industrial Revolution 4.0 technologies in mechanical engineering faces a number of significant structural and technical challenges. One major obstacle is the limited human resources with adequate digital competencies. Many workers in the traditional manufacturing sector lack the skills needed for technologies such as the Internet of Things (IoT), intelligent sensor-based automation, control system programming, and big data analysis. This problem is exacerbated by the lack of vocational and higher education curricula that adapt to the needs of modern industry, creating a significant skills gap. In this context, Yulando et al. (2024) emphasize that digital transformation is not only technological but also systemic and requires human and organizational readiness.

Besides limited human resources, another challenge frequently identified in literature studies is the low interoperability between devices and production systems. In many cases, the adopted technologies are fragmented and not integrated, due to differences in communication protocol standards and operating systems across manufacturers. This hampers the efficiency of automated production systems, making them vulnerable to technical errors, and increasing maintenance and integration costs. The lack of alignment of communication standards within industrial cyber-physical systems is a major barrier to the comprehensive adoption of IoT in the mechanical engineering production chain (Agustin et al., 2025).

Digital infrastructure is also a crucial obstacle, especially in developing countries. Unstable data communication networks, limited local server availability, and high hardware and software costs are major barriers for small and medium-sized enterprises (SMEs) to digitalization. According to the International Telecommunication Union (2021), approximately 40% of industrial areas in developing countries lack adequate internet connectivity, preventing optimal operation of cloud manufacturing or predictive maintenance systems. This situation limits the implementation of intelligent production systems such as cyber-physical systems (CPS) and digital twins to large, resource-rich industries.

To address these challenges, several adaptation strategies have been identified in the literature as best practices in the mechanical engineering industry. One widely implemented approach is continuous technical training and certification, both through in-house training programs and collaborations with higher education institutions and industry training. This approach not only improves workers' technical capabilities but also builds an organizational culture that supports digital transformation. The World Economic Forum (2020) stated that more than 50% of the global manufacturing workforce requires retraining to cope with technological change; project-based training has proven to be more effective in internalizing technical and cognitive skills.

Another strategy is cross-sector collaboration, where mechanical engineering companies form partnerships with technology providers, research institutions, and governments. These partnerships enable more efficient technology transfer, the development of more contextualized technological solutions, and the utilization of fiscal incentives or innovation programs offered by governments to accelerate the adoption of digital technologies. Porter & Heppelmann (2015) emphasize that strategic partnerships within open innovation ecosystems play a crucial role in accelerating the integration of smart systems and the sustainability of industrial digitalization.

Furthermore, developing technology-based industrial policies is an essential and integral aspect of adaptation strategies. Countries that have successfully implemented Industry 4.0 systematically, such as Germany and South Korea, demonstrate the

importance of the government's role in providing a regulatory framework, a digital transformation roadmap, and financial support for research and development. For developing countries, these policies need to be tailored to the local context, including support for mechanical engineering MSMEs, which form the backbone of the national manufacturing supply chain. The European Commission (2020), through its Industry 5.0 framework, and the Indonesian Ministry of Industry, through its Making Indonesia 4.0 program, emphasize the importance of incentive-based policies, vocational training, and digital incubation in promoting inclusive digitalization in the mechanical engineering sector.

This discussion indicates that adaptation strategies cannot be generic but must be designed based on a comprehensive evaluation of technological readiness, organizational capabilities, and the supporting ecosystem in each region or industrial sector. By developing a realistic and contextual adaptation framework, the mechanical engineering industry can gradually adopt Industrial Revolution 4.0 technologies without experiencing detrimental structural disruption.

This overall analysis emphasizes that the successful implementation of Industry 4.0 technologies depends not only on the availability of the technology itself, but also on the industry's ability to navigate multidimensional challenges through integrated, adaptive strategies. Therefore, collaboration between stakeholders, vocational education reform, and digitalization incentive policies must be key elements in the mechanical engineering industry's transformation roadmap.

CONCLUSION

The overall discussion concludes that the transformation of mechanical engineering towards the Industry 4.0 era is characterized by the integration of IoT, the evolution of automation, and complex yet essential adaptation strategies. The integration of IoT into production systems creates a responsive, adaptive, and sustainable manufacturing environment through the implementation of CPPS, predictive maintenance, and M2M communication. Automation technologies such as precision robotics, cloud-CNC, and intelligent PLCs support flexible, high-quality production with significantly increased efficiency. However, implementation challenges include limited digital human resources, immature infrastructure, and lack of integration between systems. Addressing these challenges requires a strategic approach through digital competency-based training, cross-sector collaboration, and industrial policy reform. Literature reviews emphasize the importance of a contextual digitalization roadmap, especially for MSMEs that are vulnerable to being left behind. Furthermore, technologies such as digital twins, AI, and edge computing open up opportunities for predictive and real-time manufacturing. However, the success of the transformation is determined not only by technology but also by the readiness of the organizational culture and innovation ecosystem. With a systemic and targeted approach, the mechanical engineering industry can adopt smart manufacturing without causing counterproductive disruption. This entire process demands synergy between technology, people, and policy within an integrated ecosystem. Therefore, the direction of mechanical engineering transformation in the 4.0 era is a continuous, adaptive journey toward operational excellence and industrial sustainability.

REFERENCES

Agustin, D., Nurhadi, F. F., Nurhadi, H. Q. A., & Achmad, F. A. (2025). Penerapan Instrumen Industri 4.0: Analisis SWOT Sebagai Strategi Transformasi Industri 4.0 di CV. Muda Teknindo. *Journal of Community Services in Sustainability*, 3(1), 19-27

- Anaam, I. K., Hidayat, T., Pranata, R. Y., Abdillah, H., & Putra, A. Y. W. (2022, June). Pengaruh trend otomasi dalam dunia manufaktur dan industri. In *Vocational Education National Seminar (VENS)* (Vol. 1, No. 1).
- Barari, A., de Sales Guerra Tsuzuki, M., Cohen, Y., & Macchi, M. (2021). Intelligent manufacturing systems towards industry 4.0 era. *Journal of Intelligent Manufacturing*, 32(7), 1793-1796.
- Dafflon, B., Moalla, N., & Ouzrout, Y. (2021). The challenges, approaches, and used techniques of CPS for manufacturing in Industry 4.0: a literature review. *The International Journal of Advanced Manufacturing Technology*, 113(7), 2395-2412.
- Dewadi, F. M., Nanda, R. A., Wibowo, C., Perdana, M. F., & Setiawan, M. D. (2025). Tinjauan Literatur atas Peran Teknik Mesin dalam Inovasi Manufaktur Batik pada Era Technoverse. *JADI (Jurnal Teknik Industri)*, 1(1), 32-38.
- Gunawan, H. (2024). PELATIHAN PERAWATAN PROGRAMABLE LOGIC CONTROLLER (PLC) SEBAGAI ALAT PENGENDALI ELEKTRONIKA UNTUK PARA TEKNIISI DI PT. PACIFIC MEDAN INDUSTRI. *PEDAMAS (PENGABDIAN KEPADA MASYARAKAT)*, 2(03), 637-645.
- Gupta, P., Krishna, C., Rajesh, R., Ananthakrishnan, A., Vishnuvardhan, A., Patel, S. S., ... & Chandramohan, V. (2022). Industrial internet of things in intelligent manufacturing: a review, approaches, opportunities, open challenges, and future directions. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 1-23.
- Hamrol, A., Gawlik, J., & Sładek, J. (2019). Mechanical engineering in Industry 4.0. *Management and Production Engineering Review*, 10, 14-28.
- Herdiana, B., Setiawan, E. B., & Sartoyo, U. (2023). Tinjauan Komprehensif Evolusi, Aplikasi, dan Tren Masa Depan Programmable Logic Controllers (A Comprehensive Review of the Evolution, Applications, and Future Trends of Programmable Logic Controllers). *Telekontran: Jurnal Ilmiah Telekomunikasi, Kendali dan Elektronika Terapan*, 11(2), 173-193.
- Irawan, A., Fadholi, W. H. N., Erikamaretha, Z., & Sinlae, F. (2024). Tantangan dan Strategi Manajemen Keamanan Siber di Indonesia berbasis IoT. *Journal Zetroem*, 6(1), 114-119.
- Jannah, M., & Saifullah, Y. (2024). *Rancang Bangun Sistem Pengendali Overhead Crane Berbasis Plc (Programmable Logic Control)* (Doctoral dissertation, Politeknik negeri Ujung Pandang).
- Kurniawan, E., Fahlovi, O., Avista, Z., Witanto, Y., & Ilyasa, R. (2024). Peran Digital Twin dalam Otomatisasi Manufaktur yang Berkelanjutan. *Prosiding SAINTeK: Sains dan Teknologi Vol*, 3(1).
- Latipah, D., Subhiyanto, S., Adityarini, E., & Mardiansah, M. A. (2025). Integrasi Kecerdasan Buatan Dalam Industri Otomotif: Strategi, Tantangan dan Arah Transformasi Digital. *Go Infotech: Jurnal Ilmiah STMIK AUB*, 31(1), 197-204.
- Mulge, P. (2024). Integration of Automation and Artificial Intelligence in Mechanical Engineering. *Journal of Computer Science & Emerging Trends*, 1(1), 59-62.
- Murni, I. P., & Adibah, A. T. N. (2024). Pengaruh Mesin Cutting Otomatis Berbasis Internet of Thing (IoT) terhadap Efisiensi dan Produktivitas Pekerja Pada Mesin Building Tire di PT. ABC. *Jurnal Instrumentasi dan Teknologi Informasi (JITI)*, 6(1), 121-128.
- Nugrowibowo, S., & Muslimin, M. (2023). Smart Manufacturing: Latest Technologies And Applications In Industrial Engineering. *Jurnal Minfo Polgan*, 12(1), 305-310.
- Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of intelligent manufacturing*, 31(1), 127-182.

- Pramudita, R., Ramadhan, M. A. P., Ashari, M. R., Nafisa, R. A., & Rahmawati, D. N. (2024). Analisis Dampak Otomasi Industri terhadap Efisiensi Operasional dan Optimasi Konsumsi Energi. *Jurnal Ilmiah Teknologi Infomasi Terapan*, 11(1).
- Ryalat, M., Franco, E., Elmoaqet, H., Almtireen, N., & Al-Refai, G. (2024). The integration of advanced mechatronic systems into industry 4.0 for smart manufacturing. *Sustainability*, 16(19), 8504.
- Soori, M., Jough, F. K. G., Dastres, R., & Arezoo, B. (2024). Robotical automation in CNC machine tools: a review. *acta mechanica et automatica*, 18(3).
- Trista, R. T. (2022). Peran Internet Of Things (IoT) Dalam Industri 4.0. *Jurnal Sains Dan Teknologi WidyaloKa (JSTekWid)*, 1(2), 235-241.
- Visconti, P., Rausa, G., Del-Valle-Soto, C., Velázquez, R., Cafagna, D., & De Fazio, R. (2024). Machine learning and IoT-based solutions in industrial applications for Smart Manufacturing: a critical review. *Future Internet*, 16(11), 394.
- Wawan, A. B. T. (2025). Integrasi Big Data dan Sistem Informatika Manufaktur dalam Prediksi Permintaan Produksi. *JleTri: Journal of Industrial Engineering Tridianti*, 3(01), 6-10.
- Wibowo, A. (2025). Manajemen Transformasi Digital Industri 4.0. *Penerbit Yayasan Prima Agus Teknik*.
- Yulando, S., Suryanto, A. E., Supatra, I. M., & Supriyadi, S. (2024). Transformasi digital dalam meningkatkan kesiapan kerja lulusan program studi pendidikan teknik mesin universitas palangka raya. *Steam Engineering*, 6(1), 72-78.
- Zheng, P., Wang, H., Sang, Z., Zhong, R. Y., Liu, Y., Liu, C., ... & Xu, X. (2018). Smart manufacturing systems for Industry 4.0: Conceptual framework, scenarios, and future perspectives. *Frontiers of Mechanical Engineering*, 13(2), 137-150.