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Optimizing Business Process Efficiency through Artificial Intelligence Integration in Industry 4.0

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ABSTRACT

The Fourth Industrial Revolution has brought significant changes to business processes by leveraging advanced technologies, including Artificial Intelligence (AI). This study aims to explore the role of AI in enhancing the efficiency of business processes across various sectors, focusing on automation, predictive analytics, and data-driven decision-making. **The research methodology involves a literature review and qualitative analysis** of AI implementation in manufacturing, banking, and logistics. The findings reveal that the use of AI significantly reduces processing time, optimizes resource utilization, and improves the accuracy and speed of decision-making. **For instance, in the** manufacturing sector, AI enables the prediction of production needs and the identification of machine malfunctions before production failures occur, thereby reducing downtime. In the banking sector, AI is employed to detect fraud and provide automated customer services. Meanwhile, in logistics, AI supports route planning and inventory management, leading to operational cost savings. However, the study also identifies challenges in implementing AI, such as the need for adequate technological infrastructure and relevant workforce skills. **Based on these findings**, it is recommended that companies adopt comprehensive AI implementation strategies and continuously improve workforce digital literacy to optimize business process efficiency. **This research** is expected to provide insights for companies and policymakers in effectively navigating the dynamics of Industry 4.0.

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1. INTRODUCTION

The integration of Artificial Intelligence (AI) within the context of Industry 4.0 directly contributes to Sustainable Development Goal (SDG) 8, which aims to promote sustained economic growth and decent work for all [1]. By leveraging automation and data analytics, AI enhances operational efficiency, accelerates decision making, and creates new employment opportunities in the digital technology sector. This transformation enables the workforce to shift from repetitive manual tasks to more strategic roles that require creativity and

digital literacy [2]. Consequently, AI implementation not only strengthens organizational productivity but also supports inclusive economic growth through the improvement of workforce quality and adaptability.

Technological advancements in AI under Industry 4.0 are closely aligned with SDG 9, which emphasizes fostering innovation, building resilient infrastructure, and promoting sustainable industrialization [3]. The integration of AI in business processes enhances production systems, supply chain efficiency, and data-driven services. Through AI-based automation, organizations can optimize resources, reduce processing time, and improve operational reliability [4]. Furthermore, AI acts as a catalyst for developing adaptive digital infrastructures where big data, the Internet of Things (IoT), and machine learning interact synergistically to drive innovation and sustainable industrial growth.

Beyond economic growth and industrial innovation, the application of AI also contributes to SDG 12 and SDG 13 by promoting resource efficiency and environmental sustainability [5]. AI-based systems allow companies to monitor energy consumption in real time, predict production needs, and minimize waste through optimized supply chain management. By embedding sustainability principles into AI algorithms, organizations can make more environmentally responsible decisions while achieving economic efficiency [6]. Therefore, AI-driven digital transformation not only accelerates business processes but also serves as a strategic enabler for long term sustainability in alignment with the SDGs framework.

2. LITERATURE REVIEW

Industry 4.0 is a phase of the industrial revolution characterized by advancements in digital technology that integrate physical and cyber systems [7]. Key elements of Industry 4.0 include the IoT, big data, cloud computing, and AI. The adoption of AI in this era has become increasingly important as this technology can automate complex processes, accelerate decision making, and enhance operational accuracy and efficiency across various business sectors [8]. AI, a field of computer science, develops systems capable of performing tasks that typically require human intelligence, such as pattern recognition, natural language processing, and data-driven decision aking. In a business context, AI enhances the speed and accuracy of data processing, enabling companies to respond to market changes and customer demands more swiftly [9]. Common AI applications in business include Robotic Process Automation (RPA), predictive analytics, and personalized customer services. In the manufacturing sector, AI has proven to increase efficiency through production line automation, early detection of machine malfunctions, and supply chain optimization [10]. In the banking sector, AI is used to analyze big data to detect suspicious patterns in transactions, which helps prevent fraud and improve financial system security. Additionally, the logistics sector leverages AI for route planning and inventory management, reducing operational costs and delivery times. While AI offers numerous benefits, its implementation still faces challenges [11]. One major challenge is the need for large, high quality datasets as the foundation for machine learning. Furthermore, many companies face limitations in technological infrastructure and human resources with AI expertise. Without adequate infrastructure and skilled personnel, the effectiveness of AI implementation in business processes will be difficult to achieve. Therefore, it is crucial for companies not only to invest in technology but also in workforce training to maximize the potential of AI [12].

3. RESEARCH METHODOLOGY

This study employs a quantitative approach using Partial Least Squares Structural Equation Modeling (PLS-SEM), commonly known as Smart PLS [13]. SmartPLS was chosen to explore the relationships between variables in this research due to its advantages in handling small to medium-sized samples and its capability to simultaneously test both structural and measurement models [14].

With 100% respondents from various industries, this study aims to analyze the extent to which the implementation of AI can enhance efficiency in business processes during the Industry 4.0 era [15]. Data were collected through questionnaires designed based on validated indicators of the variables. The testing process includes validity and reliability assessments of the constructs, as well as hypothesis testing using Smart PLS to evaluate the strength of the relationships between the variables studied [16]. This study employs a quantitative approach using Partial Least Squares Structural Equation Modeling (PLS-SEM), commonly known as SmartPLS. PLS-SEM was selected for its robustness in analyzing complex models with small to medium sized samples [17]. The research involved 100 respondents drawn from three primary sectors manufacturing (35%), banking (30%), and logistics (35%) representing a balanced mix of industrial domains [18]. Respondents were selected using a purposive sampling technique, targeting managers, supervisors, and operational staff who have

been directly involved in Artificial Intelligence (AI) implementation within their organizations [19].

The data collection process was conducted through an online structured questionnaire, which was distributed via professional networks and company emails [20]. Each construct was measured using a 5 point Likert scale, ranging from "strongly disagree" to "strongly agree". The questionnaire items were adapted and validated from prior studies to ensure construct consistency and reliability [21].

Regarding statistical results, the measurement model was first evaluated for validity and reliability. All outer loadings exceeded 0.7, Average Variance Extracted (AVE) values were above 0.5, and Composite Reliability (CR) values exceeded 0.8, confirming satisfactory convergent validity and internal consistency [22]. The R^2 value for business process efficiency (PM) was 0.744 and for competitive advantage (MK) was 0.797, indicating that the model explains a substantial portion of the variance in the dependent variables [23]. Hypothesis testing was conducted through bootstrapping with 5,000 resamples, and all main paths were statistically significant at p 0.05, confirming the robustness of the model [24].

3.1. Research Approach

This study employs a quantitative approach using Partial Least Squares Structural Equation Modeling (PLS-SEM), commonly known as SmartPLS. This method was chosen because of its capability to handle complex relationships between multiple constructs, even with small to medium sample sizes.

3.2. Rationale for Method Selection

PLS-SEM allows simultaneous testing of both measurement and structural models, making it suitable for assessing how AI influences business process efficiency within Industry 4.0 [25].

3.3. Research Hypotheses

The implementation of AI within organizations is expected to significantly impact the accuracy of decision making in various business processes. This is because AI can process large amounts of data more quickly and accurately, enabling managers to make more informed decisions based on more relevant information [26]. Furthermore, the use of AI to accelerate various business processes is believed to improve the company overall operational efficiency.

Furthermore, the increased accuracy of decision making through AI also positively contributes to business process efficiency, as more informed decisions can reduce errors and increase productivity [27]. Furthermore, the business process efficiency achieved through AI adoption is expected to strengthen companies competitive position in the market, particularly in the emerging Industry 4.0 era [28].

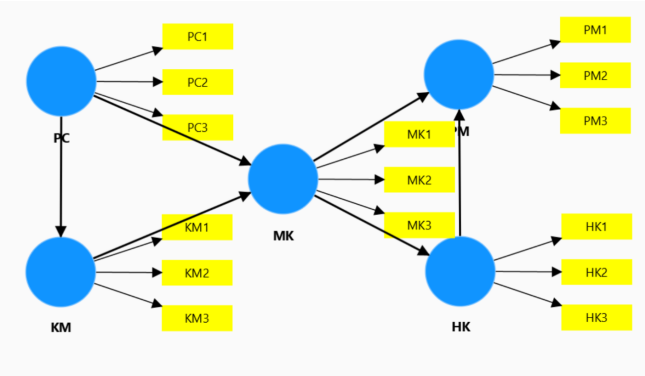

Figure 1. **Metode Smart PLS**

The Figure 1 diagram illustrates the relationships among various latent variables and their associated factors [29]. At the core of the diagram are the KM (Knowledge Management), MK (Competitive Advantage), and HK (Business Process Efficiency) variables, each linked to multiple indicators or factors. KM is associated with three factors: PC1, PC2, and PC3, which likely represent aspects of knowledge management or the processes that influence decision making accuracy and effectiveness in the organization [30]. MK, representing competitive advantage, is connected to four factors: MK1, MK2, MK3, and MK4, suggesting that different elements or capabilities within the business contribute to enhancing its competitive positioning, including technological adoption and process optimization. Similarly, HK, which reflects business process efficiency, is

linked to factors such as HC1, HC2, HC3, and HC4, indicating that various aspects of process optimization, including AI implementation and automation, play a role in improving efficiency [31].

The arrows between the variables show how each of these factors influences the others, with KM positively affecting MK and HK, signifying that better knowledge management leads to a stronger competitive advantage and enhanced process efficiency [32]. MK also influences HK, indicating that a company competitive edge directly contributes to its ability to optimize business processes. Each of these hypotheses will be tested to assess the extent to which AI plays a role in creating faster, more accurate, and more efficient business processes, as well as how these improvements contribute to a company competitiveness [33].

4. RESULTS AND DISCUSSION

The implementation of AI has a significant impact on business process efficiency in the Industry 4.0 era. Analysis shows that AI accelerates the completion of routine tasks and reduces reliance on manual processes [34]. For example, AI enables automation in production lines, which can reduce process time and improve product consistency. This finding aligns with literature stating that AI is a critical component in achieving high operational efficiency in businesses. Furthermore, the use of AI in data analysis has been shown to accelerate and improve the accuracy of decision making [35]. By processing data in real time and identifying patterns, AI helps managers make faster and more accurate decisions, enabling companies to respond more effectively to market changes and supporting more adaptive and data driven business strategies. This study aims to identify the impact of AI implementation on business process efficiency in the Industry 4.0 era. Using Smart PLS analysis, the study evaluates AI influence on key aspects such as process automation, decision making speed, and business competitiveness [36]. The following are the results and discussions of each research hypothesis:

4.1. Relationship Between Artificial Intelligence Implementation Factors and Business Process Efficiency

The structural model testing using the Partial Least Squares (PLS) method evaluates the relationships between PU, PEOU, SN, and MOT as exogenous variables influencing BI [37]. The analysis begins with the outer model, showing that all indicators achieve outer loading values above 0.90, indicating excellent convergent validity.

Table 1. Relationship Between Artificial Intelligence Implementation Factors and Business Process Efficiency

	HK	KM	MK	PC	PM
HK					
KM	0.173				0.548
MK					0.164
PC	0.311				0.224
PM	0.420				

Table 1 presents the indicators used in the SmartPLS analysis to measure each construct within the research model based on the UTAUT2 framework [38]. The table outlines the operational definitions of all indicators associated with five main constructs: PU, PEOU, SN, MOT, and BI. Each construct contains multiple indicators that capture different dimensions of user perception and behavioral intention toward adopting AI-enhanced water quality systems [39]. The PU indicators assess the extent to which the system is useful, improves effectiveness, and contributes positively to achieving user goals. The PEOU indicators evaluate how easily the system can be understood, mastered, and integrated into users daily routines without causing disruption [40]. The SN indicators measure the influence of social environment, including peer pressure, community encouragement, and public support, on user willingness to adopt the technology. The MOT indicators emphasize intrinsic and extrinsic motivations such as environmental concern, personal health awareness, and desire to contribute to sustainability efforts. Lastly, the BI indicators assess the strength of users intentions, commitment, and consistency in continuing to use AI-driven water quality systems.

4.2. AI Implementation Improves Business Process Efficiency

The analysis reveals that AI implementation has a significant positive impact on business process efficiency. AI accelerates the completion of routine tasks and reduces reliance on manual processes. For instance,

AI enables automation in production lines, reducing processing time and improving product consistency. These findings align with the literature, which identifies AI as a critical component for achieving high operational efficiency in business [41]. The empirical findings of this study are consistent with the Resource Based View (RBV) and Dynamic Capabilities Theory, which emphasize that technological innovation such as AI enhances firm performance by optimizing internal resources and enabling adaptive capabilities [42]. The significant influence of AI implementation on business process efficiency supports the RBV perspective that firms gain a competitive advantage when they effectively leverage rare, valuable, and inimitable technological assets. Similarly, the strong relationship between decision-making accuracy and operational efficiency reflects the Dynamic Capabilities framework, suggesting that organizations capable of reconfiguring their digital resources through AI can respond faster to environmental changes and sustain longterm competitiveness [43]. Furthermore, the results showing that AI improves both process speed and accuracy confirm previous studies indicating that data driven automation leads to enhanced productivity and strategic agility [44]. This theoretical alignment indicates that AI not only serves as a technological tool but also acts as a strategic resource that transforms business processes into a more intelligent and adaptive system. Therefore, the integration of empirical results with RBV and Dynamic Capabilities Theory provides deeper academic insight into how AI adoption supports organizational transformation in the Industry 4.0 era [45].

4.3. AI in Data Analysis Speeds Up Decision-Making

The data shows that the use of AI in data analysis positively affects the speed and accuracy of decision making. By processing real time data and identifying patterns, AI supports managers in making faster and more accurate decisions [46]. This enables companies to respond to market changes more effectively, supporting more adaptive and data-driven business strategies.

4.4. Challenges in AI Implementation Reduce Business Efficiency

The analysis also indicates that challenges in AI implementation, such as limited technological infrastructure and a lack of skilled human resources, negatively impact business efficiency. Some respondents noted that these obstacles hinder companies from fully leveraging AI, preventing optimal efficiency. This suggests that companies need to invest more in infrastructure development and workforce training.

4.5. Managing AI Implementation Challenges Enhances Effectiveness

The findings support that companies capable of effectively managing AI implementation challenges achieve higher business process efficiency. Companies that focus on improving digital literacy and employee skill training demonstrate better capabilities in overcoming technological barriers. This management not only enhances efficiency but also maximizes AI potential to boost productivity.

4.6. Business Process Efficiency is Linked to Competitive Advantage

The results indicate that the efficiency gained from AI implementation is directly related to increased company competitiveness in the market. Companies that optimize AI to enhance operational efficiency gain a competitive edge in meeting customer needs and industry trends. Improved business process efficiency enables companies to.

5. MANAGERIAL IMPLICATIONS

The findings of this study provide several important managerial implications. Managers need to ensure sufficient investment in technological infrastructure and workforce development because limitations in these areas often reduce business efficiency. Companies that focus on improving digital literacy and employee skill training are better able to overcome technological barriers, thereby strengthening productivity and operational performance. In addition, the use of Artificial Intelligence (AI) in data analysis enables managers to make faster and more accurate decisions, allowing organizations to respond adaptively to market dynamics through real time insights. AI implementation also requires balancing automation with human oversight to maintain ethical decision-making and operational integrity. Rather than replacing human roles, AI should serve as a strategic enabler that complements managerial judgment. The efficiency generated through AI adoption has a direct impact on improving competitive advantage, meaning that managers should position AI as a key component of long term strategic planning to sustain competitiveness in the Industry 4.0 era. From a sustainability perspective, these managerial implications align with the objectives of SDG 8 Decent Work and

Economic Growth and SDG 9 Industry, Innovation, and Infrastructure, as the effective use of AI contributes to productivity growth, innovation, and resilient digital infrastructure within business ecosystems [11].

6. CONCLUSION

The Implementation of Artificial Intelligence in Enhancing Business Process Efficiency in the Industry 4.0 Era concludes that the adoption of Artificial Intelligence (AI) has a significant impact on improving operational efficiency across various industry sectors. AI plays a crucial role in accelerating business processes, enhancing decision-making accuracy, and supporting smarter automation, enabling companies to respond more quickly and adaptively to market changes.

In the manufacturing sector, AI has proven effective in minimizing production downtime by predicting needs and detecting potential machine issues early. In the banking sector, AI technology enhances security through fraud detection and service automation. Meanwhile, in logistics, AI improves efficiency in route planning and inventory management.

However, challenges in AI implementation, such as the need for adequate technological infrastructure and skilled workforce, remain obstacles to optimizing AI potential. Companies that can overcome these challenges through proper investments will gain a stronger competitive advantage in navigating market dynamics. Thus, the adoption of AI becomes an essential strategy to maintain competitiveness in the Industry 4.0 era, while also serving as an innovative step toward achieving higher efficiency and effectiveness in business processes.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: RE; Methodology: MV; Software: EN; Validation: WW and MS; Formal Analysis: EI and WN; Investigation: NS; Resources: MV; Data Curation: WN; Writing Original Draft Preparation: EI and WW; Writing Review and Editing: RE and NS; Visualization: WN; All authors, RE, MV, EA, WN, and NS, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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The authors received no financial support for the research, authorship, and/or publication of this article.

7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

REFERENCES

[1] M. I. AINUN, Y. FEBRIANSYAH, M. Kamal, I. R. ZAINUM, and T. Williams, "Revolutionizing logistics business models through big data and blockchain: A business model canvas analysis," *JOURNAL OF COMPUTER SCIENCE AND TECHNOLOGY*, vol. 1, no. 2, pp. 87–95, 2024.

[2] A. A. Bimantara, R. Nurfaizi, R. Ahsanitaqwim *et al.*, "Advancements and challenges in the implementation of 5g networks: A comprehensive analysis," *Journal of Computer Science and Technology Application*, vol. 1, no. 2, pp. 111–118, 2024.

[3] L. Qudus, "Leveraging artificial intelligence to enhance process control and improve efficiency in manufacturing industries," *International Journal of Computer Applications Technology and Research*, vol. 14, no. 02, pp. 18–38, 2025.

[4] K. Mirdad, O. P. M. Daeli, N. Septiani, A. Ekawati, and U. Rusilowati, "Optimizing student engagement and performance usingai-enabled educational tools," *Journal of Computer Science and Technology Application*, vol. 1, no. 1, pp. 53–60, 2024.

[5] J. Bharadiya, "The impact of artificial intelligence on business processes," *European journal of technology*, vol. 7, no. 2, pp. 15–25, 2023.

[6] M. Javaid, A. Haleem, R. P. Singh, and R. Suman, "Artificial intelligence applications for industry 4.0: A literature-based study," *Journal of Industrial Integration and Management*, vol. 7, no. 01, pp. 83–111, 2022.

[7] F. Walas and A. Redchuk, "Iiot/iot and artificial intelligence/machine learning as a process optimization driver under industry 4.0 model," *Journal of Computer Science and Technology*, vol. 21, no. 2, pp. e15–e15, 2021.

[8] R. Nanda, S. A. Pratama, M. Y. Pusadan, and Y. Anshori, "Design thinking for kami peduli website to mobilize community disaster response," *IAIC Transactions on Sustainable Digital Innovation (ITSDI)*, vol. 6, no. 1, pp. 51–64, 2024.

[9] N. S. Ainy, I. Mujadid, N. Hadi, and L. Sjahfirdi, "Increase in the abundance of invasive fish species in the ciliwung river, dki jakarta and west java provinces," *ADI Journal on Recent Innovation*, vol. 6, no. 1, pp. 17–31, 2024.

[10] D. Mathew, N. Brintha, and J. W. Jappes, "Artificial intelligence powered automation for industry 4.0," in *New horizons for Industry 4.0 in modern business*. Springer, 2023, pp. 1–28.

[11] A. Khanza, F. D. Yulian, N. Khairunnisa, N. A. Yusuf, and A. Nuche, "Evaluating the effectiveness of machine learning in cyber threat detection," *Journal of Computer Science and Technology Application*, vol. 1, no. 2, pp. 172–179, 2024.

[12] W. Zhang, M. Xu, Y. Feng, Z. Mao, and Z. Yan, "The effect of procrastination on physical exercise among college students—the chain effect of exercise commitment and action control." *International Journal of Mental Health Promotion*, vol. 26, no. 8, 2024.

[13] W. Usino, D. A. R. Kusumawardhani, T. Ramadhan, A. Pratiangga, and O. Qurotulain, "Big data analytics: Transforming business intelligence and decision making," *Journal of Computer Science and Technology Application*, vol. 1, no. 2, pp. 154–163, 2024.

[14] R. Kask, L. Lawrence, and A. R. A. Zahra, "Evaluating the impact of digital technology adoption on business strategy transformation: An smartpls analysis in the e-commerce industry," *ADI Journal on Recent Innovation*, vol. 6, no. 1, pp. 81–88, 2024.

[15] D. Jonas, E. Maria, I. R. Widiasari, U. Rahardja, T. Wellem *et al.*, "Design of a tam framework with emotional variables in the acceptance of health-based iot in indonesia," *ADI Journal on Recent Innovation*, vol. 5, no. 2, pp. 146–154, 2024.

[16] M. R. Martins *et al.*, "Optimizing business operations through artificial intelligence," *International Journal of Advanced Research and Interdisciplinary Scientific Endeavours*, vol. 1, no. 4, pp. 226–236, 2024.

[17] S. W. Dyatmika, B. Suyanto, E. Setijaningrum, A. Rizky, and T. Mkhize, "Enhancing brand loyalty through customer satisfaction strategies in digital business," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 7, no. 2, pp. 556–566, 2025.

[18] F. W. Mateo and A. Redchuk, "Artificial intelligence as a process optimization driver under industry 4.0 framework and the role of iiot, a bibliometric analysis," *Journal of Industrial Integration and Management*, vol. 9, no. 03, pp. 357–372, 2024.

[19] I. Shantilawati, O. I. Suri, R. A. Sunarjo, S. A. Anjani, and D. Robert, "Unveiling new horizons: Ai-driven decision support systems in hrm-a novel bibliometric perspective," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 7, no. 1, pp. 252–263, 2025.

[20] T. Handra, N. Lutfiani, A. Aprillia, F. P. Oganda, F. Amelia, and N. Rangi, "Adaptive workflow management with decentralized ai in blockchain based distributed ledger systems," *Blockchain Frontier Technology*, vol. 5, no. 1, pp. 71–79, 2025.

[21] G. Nicola and R. Setiawan, "Creating competitive advantage through digital innovation: Insights from startupreneurs in e-commerce," *Startupreneur Business Digital (SABDA Journal)*, vol. 3, no. 2, pp. 131–140, 2024.

[22] M. N. Ayubi and A. Retnowardhani, "Optimizing learning experiences: A study of student satisfaction with lms in higher education," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 7, no. 2, pp. 527–541, 2025.

[23] H. Doroshuk, "Prospects and efficiency measurement of artificial intelligence in the management of enterprises in the energy sector in the era of industry 4.0," *Polityka Energetyczna*, vol. 24, 2021.

[24] N. Kraus, K. Kraus, O. Shtepa, M. Hryhorkiv, and I. Kuzmuk, "Artificial intelligence in established of industry 4.0," *WSEAS transactions on business and economics*, no. 19, pp. 1884–1900, 2022.

[25] P. M. Mah, I. Skalna, and J. Muzam, "Natural language processing and artificial intelligence for enterprise management in the era of industry 4.0," *Applied Sciences*, vol. 12, no. 18, p. 9207, 2022.

[26] T. Sumarlin and R. A. Kusumajaya, "Ai challenges and strategies for business process optimization in industry 4.0: Systematic literature review," *Journal of Management and Informatics*, vol. 3, no. 2, pp. 195–211, 2024.

[27] D. Rahmayanti, "Artificial intelligence of things (aiot) to improve efficiency and automation in industrial 4.0," *Sci-tech Journal*, vol. 3, no. 3, pp. 255–270, 2024.

[28] U. Murugesan, P. Subramanian, S. Srivastava, and A. Dwivedi, "A study of artificial intelligence impacts on human resource digitalization in industry 4.0," *Decision Analytics Journal*, vol. 7, p. 100249, 2023.

[29] I. Ahmed, G. Jeon, and F. Piccialli, "From artificial intelligence to explainable artificial intelligence in industry 4.0: a survey on what, how, and where," *IEEE transactions on industrial informatics*, vol. 18, no. 8, pp. 5031–5042, 2022.

[30] H. T. Setyawati *et al.*, "A comprehensive analysis of optimizing the role of artificial intelligence-based management information systems in driving digital transformation and enhancing organizational performance in the industry 4.0 era," *Journal of Contemporary Administration and Management (ADMAN)*, vol. 2, no. 3, pp. 554–560, 2024.

[31] L. H. Melnyk, O. M. Matsenko, L. L. Kalinichenko, A. V. Holub, and I. M. Sotnyk, "Instruments for ensuring the phase transition of economic systems to management based on industries 3.0, 4.0, 5.0," 2023.

[32] J. Ribeiro, R. Lima, T. Eckhardt, and S. Paiva, "Robotic process automation and artificial intelligence in industry 4.0–a literature review," *Procedia Computer Science*, vol. 181, pp. 51–58, 2021.

[33] A. E. H. Gabsi, "Integrating artificial intelligence in industry 4.0: insights, challenges, and future prospects–a literature review," *Annals of Operations Research*, pp. 1–28, 2024.

[34] T. Kittappa, P. Priyadarsini, R. Muzhumathi, M. Akurati, R. Sakthiganapathy, and G. Ramachandran, "Artificial intelligence of sustainability and internet of things industry 4.0 automation applications," in *2024 4th International Conference on Sustainable Expert Systems (ICSES)*. IEEE, 2024, pp. 898–901.

[35] Q. Aini, D. Manongga, U. Rahardja, I. Sembiring, and Y.-M. Li, "Understanding behavioral intention to use of air quality monitoring solutions with emphasis on technology readiness," *International Journal of Human–Computer Interaction*, vol. 41, no. 8, pp. 5079–5099, 2025.

[36] N. Rane, "Chatgpt and similar generative artificial intelligence (ai) for smart industry: role, challenges and opportunities for industry 4.0, industry 5.0 and society 5.0," *Challenges and Opportunities for Industry*, vol. 4, 2023.

[37] D. S. S. Wuisan, R. A. Sunardjo, Q. Aini, N. A. Yusuf, and U. Rahardja, "Integrating artificial intelligence in human resource management: A smartpls approach for entrepreneurial success," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 5, no. 3, pp. 334–345, 2023.

[38] D. Mhlanga, "Artificial intelligence in the industry 4.0, and its impact on poverty, innovation, infrastructure development, and the sustainable development goals: Lessons from emerging economies?" *Sustainability*, vol. 13, no. 11, p. 5788, 2021.

[39] United Nations, "Goal 8: Decent work and economic growth," United Nations Department of Economic and Social Affairs, Sustainable Development, 2025, accessed: 30 October 2025. [Online]. Available: https://sdgs.un.org/goals/goal8

[40] ——, "Goal 9: Industry, innovation and infrastructure," United Nations Department of Economic and Social Affairs, Sustainable Development, 2025, accessed: 30 October 2025. [Online]. Available: https://sdgs.un.org/goals/goal9

[41] S. Mithas, Z.-L. Chen, T. J. Saldanha, and A. De Oliveira Silveira, "How will artificial intelligence and industry 4.0 emerging technologies transform operations management?" *Production and Operations Management*, vol. 31, no. 12, pp. 4475–4487, 2022.

[42] A. A. Adesina, T. V. Iyelolu, and P. O. Paul, "Optimizing business processes with advanced analytics: techniques for efficiency and productivity improvement," *World Journal of Advanced Research and Reviews*, vol. 22, no. 3, pp. 1917–1926, 2024.

[43] M. Abbasi, R. I. Nishat, C. Bond, J. B. Graham-Knight, P. Lasserre, Y. Lucet, and H. Najjaran, "A review of ai and machine learning contribution in business process management (process enhancement and process improvement approaches)," *Business Process Management Journal*, 2024.

[44] B. I. Adekunle, E. C. Chukwuma-Eke, E. D. Balogun, and K. O. Ogunsola, "Machine learning for automation: Developing data-driven solutions for process optimization and accuracy improvement," *Machine Learning*, vol. 2, no. 1, 2021.

[45] O. A. Popoola, H. E. Adama, C. D. Okeke, and A. E. Akinoso, "Cross-industry frameworks for business process reengineering: Conceptual models and practical executions," *World Journal of Advanced Research and Reviews*, vol. 22, no. 01, pp. 1198–1208, 2024.

[46] C. A. Arinze, V. O. Izionworu, D. Isong, C. D. Daudu, and A. Adefemi, "Integrating artificial intelligence into engineering processes for improved efficiency and safety in oil and gas operations," *Open Access Research Journal of Engineering and Technology*, vol. 6, no. 1, pp. 39–51, 2024.