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eISSN 2830-795X

Industry 4.0 Automation Adoption and HR Upskilling Strategies with Social Reskilling for Manufacturing Workforce

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ABSTRACT – The penetration of Industry 4.0 automation and robotic technologies in the manufacturing sector triggers a redefinition of workforce competence requirements while simultaneously posing the threat of structural unemployment. This study aims to analyze the impact of automation adoption on the formulation of human resource upskilling strategies and to formulate a social reskilling framework for affected workers. An exploratory qualitative methodology based on applied grounded theory was employed to construct empirical insights through in-depth interviews, focus group discussions, and field observations in manufacturing facilities. The findings indicate that the success of upskilling strategies depends on integrating machine performance data into training curricula, utilizing digital simulation learning modules, and actively involving supervisors as mentors. Conversely, mitigating the threat of structural unemployment requires a community-based social reskilling framework involving government active social safety nets, corporate outplacement assistance, and the empowerment of independent digital literacy. This study concludes that the sustainability of Industry 4.0 transformation demands harmonization between technological modernization and human capital protection to achieve inclusive and equitable economic growth.

Keywords: industrial automation, hr upskilling, social reskilling, structural unemployment, manufacturing, workforce adaptation, industry 4.0.

A. INTRODUCTION

The escalating adoption of automation technology and robotic systems within the Industry 4.0 ecosystem has triggered a fundamental restructuring of the operational foundations of global manufacturing. This transformation is no longer confined to the mechanization of repetitive physical tasks, but encompasses the integration of cyber-physical systems, artificial intelligence, and big data analytics that radically alter the dynamics of workforce qualification (Adetunla et al., 2024). Putra and Arifin (2021) show that the adoption of big data, artificial intelligence, and the internet of things in supply chain management already touches nearly every operational layer of manufacturing, not just the shop floor. This shift in the production landscape creates a double disruption: it raises operational efficiency and manufacturing precision, yet it also accelerates skills obsolescence among operational workers. Triono et al. (2025) add that digitalization reshapes labor and task architecture in the manufacturing sector, so that job roles change faster than workers can adjust to them. Schwab (2016) asserts that the pace of Industry 4.0's digital transformation carries an unprecedented speed and scope of impact, demanding rapid and structured adjustment of human resource capabilities.

Within the scope of human resource management, this dynamic demands a paradigm shift from conventional training approaches toward the formulation of adaptive upskilling strategies based on futuristic capabilities (Vineet, 2025). Mardikaningsih and Wardoyo (2024) note that technology plays a central role in sustainable human resource development, particularly through continuous digital innovation within organizations. Aligning manufacturing workforce competencies with Industry 4.0 technical requirements requires designing continuous training programs that combine technical understanding of robotics, operational data analysis, and complex problem-solving skills. Putra et al. (2024) point out that gamification-based learning can build employee competence while preserving cooperation and empathy among colleagues, an approach well suited to participatory training models. Warin and Darmawan (2024) add that continuous feedback in HR development helps employees stay adaptive as technical demands shift. An organization's inability to proactively execute competency engineering strategies can result in an internal skills gap, reduce industrial competitiveness, and trigger organizational restructuring that leads to mass layoffs. Darmawan (2023) states that knowledge management can serve as a source of competitive advantage, a principle equally relevant for manufacturing firms seeking to close internal skills gaps. Autor et al. (2020) explain that the effectiveness of technology adoption strongly depends on how well HR investment management can match the level of automation complexity applied on the production line. Darmawan (2023) adds that employee productivity in the digital era should be measured by accounting for creativity and innovation, not output volume alone, so that human capital investment is assessed properly alongside automation.

Sociologically, the wave of manufacturing automation carries serious implications for the threat of structural unemployment and instability in worker social security. Mid- and low-skilled worker groups are most vulnerable to automation disruption because the routine tasks they perform are increasingly easy to replace with robotic systems (Kathirvel et al., 2024). Darmawan (2020) notes that senior employees in particular face added pressure on health and productivity as artificial intelligence reshapes daily work demands. Darmawan (2023) also points out that social inclusion for older workers needs deliberate attention whenever digital technology is implemented within an organization. This phenomenon triggers new social vulnerabilities, income inequality, and potential worker resistance toward the industrial modernization agenda. Mardikaningsih and Wardoyo (2026) show that organizational change strategies addressing employee social resistance are essential during technology-driven transitions, a pattern that applies equally to manufacturing automation. Social reskilling does not rest solely on improving technical capability; it also involves psychological assistance, career adaptability, and strengthening collective social safety nets. Darmawan (2023) explains that remote work arrangements affect employees' psychological well-being and social relationships, underlining why career adaptability programs cannot ignore the psychological dimension of change. Frey and Osborne (2017) show that the proportion of manufacturing jobs at high risk of automation requires comprehensive social policy intervention to prevent labor market polarization. This complexity is compounded by the absence of an integrative model connecting internal corporate HR development policy with social impact mitigation strategies at the macro level. Darmawan (2024) identifies six major factors that enhance organizational effectiveness, factors that could serve as a starting point for building such an integrative model. Existing training management frameworks are often partial, focusing solely on meeting short-term corporate efficiency needs without accounting for the long-term career sustainability of affected workers. Maulani et al. (2023) observe that legal frameworks frequently lag behind the pace of artificial-intelligence-driven change, leaving regulatory gaps that mirror the governance shortfall found in corporate training policy. The imbalance in synthesis between business strategy and industrial social responsibility creates a governance gap that triggers escalating industrial conflict (Yasser & Abdelmajid, 2025). Mardikaningsih et al. (2022a) argue that ethical leadership shapes a positive and sustainable organizational culture, an element that can narrow the gap between business interest and social responsibility. Bansen et al. (2021) reveal that the success of digital transformation in the manufacturing sector is largely determined by synergy among labor regulation, management commitment, and inclusive social adaptation programs. Mardikaningsih et al. (2022b) similarly find that authentic leadership fosters a positive work climate and organizational citizenship behavior, both of which strengthen management commitment during periods of technological change. Darmawan (2023) adds that an innovation culture balancing technological speed with humanistic thought offers a practical direction for aligning business strategy with workers' long-term interests.

This study aims to analyze the influence of Industry 4.0 automation technology adoption on the formulation and success of HR upskilling strategies in the manufacturing industry. It also examines the implications of automation for structural unemployment risk and formulates a social reskilling framework to support workforce adaptability.

This research provides a theoretical contribution to the development of human resource management science and labor sociology through the formulation of an analytical framework for digital qualification adaptation. Practically, the results of this research present strategic guidelines for manufacturing practitioners and policymakers in designing sustainable training schemes and labor protection regulations in the era of the Industry 4.0 transformation.

B. METHOD

To comprehensively investigate the impact of industrial automation on labor dynamics, this research applies an exploratory qualitative methodology based on a literature review with an applied grounded theory approach. The selection of this methodological framework is based on the need to construct a new theoretical understanding regarding social upskilling and reskilling schemes through the synthesis of findings from various published empirical studies. The focus of the literature search is directed toward large-scale manufacturing companies currently transitioning toward robotic system automation, as documented in various research reports and industry case studies. Saunders et al. (2019) emphasize that an exploratory qualitative approach is very effective for dissecting management and labor phenomena that are developing rapidly amid technological disruption.

The data collection procedure was carried out through a systematic and structured literature search, encompassing scientific journal articles, applied research reports, labor policy documents, and publications from research institutions and industry associations relevant to automation and human resource transformation. The researchers explored diverse perspectives and findings related to HR management responses to automation adoption, including upskilling and reskilling strategies, through the synthesis of results from previous studies. Similarly, aspects of industrial relations dynamics and labor union responses were traced through narratives from case studies and observation reports documented in academic and policy literature. Silverman (2020) explains that the principle of data saturation within the scope of a literature review is achieved when the literature search no longer finds new significant conceptual categories or themes, thereby ensuring analytical depth and conceptual validity in qualitative research based on the evolution of social phenomena.

The data analysis process applied the systematic coding technique of Corbin and Strauss (2015), which consists of three main stages: open coding, axial coding, and selective coding. All library materials were broken down into basic concepts, grouped into categories of cause-and-effect relationships between automation adoption and HR management responses, and synthesized into a complete conceptual framework regarding social upskilling and reskilling strategies. Data validity and reliability were tested through library source triangulation instruments and cross-examination between references to ensure the consistency and credibility of findings across various independent studies.

C. RESULTS AND DISCUSSION

The Influence of Industry 4.0 Industrial Automation Adoption on the Formulation and Effectiveness of Manufacturing Human Resource Upskilling Strategies

The penetration of high-level automation technology and flexible robotic systems in manufacturing facilities triggers a fundamental shift in the competence requirement map of production line workers (Zhang et al., 2025). Buxmann and Fischer (2021) assert that the integration of smart sensors, connected devices, and real-time data processing transforms the orientation of jobs from manual-physical qualifications toward much more complex cognitive-technical mastery. Human resource management acts swiftly to remap job profiles experiencing a decline in relevance due to the automation of routine tasks. This restructuring process requires companies to design upskilling schemes capable of boosting workers' technical capabilities in a measurable and sustainable manner. The preparation of training materials focuses on the understanding of cyber-physical system operations, predictive maintenance, and the ability to mitigate technical disruptions in automated machines. The sensitivity level of Industry 4.0 equipment demands that operators have a deep understanding of basic programming logic and digital information processing (Behera et al., 2024). The effectiveness of technology adoption heavily depends on the readiness of personnel capabilities to operate and optimize the new infrastructure precisely.

The implementation of upskilling strategies in the manufacturing sector faces the challenge of high variation in adaptation speed among operational workers (Panagiotopoulou et al., 2025). Tortorella et al. (2020) observe that workers with limited formal education often face psychological and technical barriers when confronted with digital machine interfaces. Mardikaningsih and Darmawan (2022) find that self-efficacy strongly predicts how well employees adapt to technological change, which helps explain why some workers adjust faster than others. Issalillah and Hardyansah (2022) add that the digital divide can weaken participation and trust, a pattern also visible among workers who feel left behind when new systems are introduced. Companies address this constraint by applying blended learning methods that combine virtual simulation with direct mentoring on the production floor. The use of augmented reality technology in training modules accelerates understanding of standard operating procedures without disrupting the stability of the main production flow. HR management periodically measures the level of competency progress to ensure that all training participants reach the minimum qualification standard set. The success of this skills enrichment program is reflected in the reduced rate of machine operation errors and improved production cycle efficiency. Building a culture of self-directed learning in the workplace becomes the main pillar supporting the continuity of workers' technical qualification renewal.

The coordination pattern between the HR development unit and the manufacturing technical division underwent intensive strengthening during the transition phase of Industry 4.0 automation adoption (Lodgaard & Dransfeld, 2020). Darmawan and Mardikaningsih (2023) explain that flexible organizational structures improve a company's adaptability to environmental dynamics, a condition that also underlies smoother coordination between HR and technical units during this transition. Bonekamp and Sure (2015) reveal that training curriculum design is no longer based on theoretical assumptions alone, but refers to real-needs analysis extracted directly from machine performance data. The technical team identifies the most frequent operational failure areas, while the HR development unit translates these findings into applicable instructional modules. This interdisciplinary synergy ensures that upskilling materials remain highly relevant to solving real problems on the factory floor. Problem-based training improves workers' cognitive flexibility in facing complex systemic disruptions (Eddine et al., 2023). This integrated approach can reduce production downtime and maximize the return on investment in robotic technology. Continuous evaluation of training impact becomes a mandatory instrument for management in measuring the efficiency of development budget allocation.

The formulation of digital-based upskilling strategies directly drives the redefinition of internal career paths for manufacturing workers. Cimini et al. (2020) explain that workers who previously held manual operator positions transition into automated system maintenance technicians or data quality control analysts. Mardikaningsih (2025) notes that this deconstruction of traditional work roles requires HR to reconfigure flexibility and employer branding so that new job identities remain attractive and clearly defined. This change in role is accompanied by increased job responsibility and adjustment of the compensation structure based on new competency levels. Companies design structured internal certification schemes to give formal recognition to workers' digital qualification achievements (Darmawan, 2024). The presence of clear career incentives increases workforce motivation to participate in long-duration training programs. This job transition strengthens the organization's resilience structure in facing future technological change dynamics. Regular updates to job descriptions ensure that every individual understands their specific contribution to the company's operational efficiency targets.

The impact of automation adoption on upskilling effectiveness is also reflected in improved occupational safety and health aspects within the manufacturing environment. Pfeiffer (2017) states that shifting high-risk physical tasks to robotic arms significantly reduces work accident and occupational disease rates. Khayru (2022) notes that artificial intelligence has shown transformative power in improving safety and monitoring outcomes in other sectors, a pattern also emerging as manufacturing adopts AI-supported safety systems. Training programs focus on mastering safe interaction procedures between humans and robots (cobots) in shared workspaces. Workers are equipped with an understanding of safety sensor limits, emergency stop mechanisms, and routine maintenance protocols. Issalillah and Khayru (2025) argue that mental health should be treated as an organizational construct, meaning work environment design needs to be strategically reoriented as physical risk decreases and attention shifts toward mental workload. The reduction in physical risk level gives workers room to shift their attention focus to supervisory tasks that require in-depth analysis (Darmawan et al., 2020). Production facility management records a decrease in health insurance claims and an increase in work attendance rates after the integration of automation systems accompanied by comprehensive safety upskilling.

The effectiveness of upskilling strategies is measured using a quantitative indicator in the form of overall equipment effectiveness. The World Economic Forum (2020) reports that manufacturing facilities that integrate robotic adoption with structured training schemes achieve productivity increases of up to thirty percent. Issalillah and Khayru (2026) note that acceptance of AI-based systems depends heavily on governance and user trust, a condition equally relevant when workers are asked to rely on automated performance data. Workers who have undergone skills renewal are able to independently adjust machine parameters without waiting for senior technician intervention. This operational independence cuts rework time for defective products and significantly reduces raw material waste. Management gains greater flexibility in arranging work shift schedules and handling mass-customization product order variations. The success of skills enrichment accelerates the achievement of operational efficiency targets and strengthens the company's competitive position in the global market (Miguel et al., 2023).

Manufacturing HR upskilling strategy requires adjustment to the internal training support infrastructure of the company. Bansen et al. (2021) explain that management allocates a special budget to build digital simulation laboratories and provide industrial modeling software licenses. Mardikaningsih, Hariani, and Nuraini (2026) show that gamification in digital application-based training can foster awareness and sustain operational systems, an approach that fits well within these self-directed training facilities. The availability of independent practice facilities allows workers to test machine programming without risking damage to real production equipment. Investment in technology-based learning tools drastically shortens the workers' learning curve within a relatively short time. Companies also build strategic partnerships with local vocational education institutions to align graduate competency standards with industry needs. This external collaboration streamlines the recruitment process for new workers who already have basic readiness to operate Industry 4.0 technology. Strengthening the learning ecosystem creates a sustainable digital talent supply chain for the organization (Hearn et al., 2023).

Leadership dynamics at the production line supervisor level play a crucial role in ensuring the successful implementation of upskilling programs. Autor et al. (2020) underline that middle managers are required to shift from an authoritarian leadership style toward the role of facilitator and learning mentor for their subordinates. Darmawan, Gardi, and Da Silva (2023) find that management-employee work relations are shifting substantially in multinational companies amid literacy-based digitalization, reinforcing the need for supervisors to adopt this more participatory role. Supervisors regularly provide constructive feedback on workers' daily performance after training. Open communication channels between managers and operators help identify competency weaknesses early before they negatively affect product quality. Companies hold special leadership training programs to equip supervisors with change management and performance mentoring skills. Adaptive leadership support creates a conducive work atmosphere for optimal individual potential development amid technological disruption (Hall & Elshennawy, 2024).

The implementation of upskilling strategies produces positive impacts in the form of increased job satisfaction and retention of talented workers in the manufacturing sector. Schwab (2016) states that workers feel valued by the organization when the company consistently invests resources in enriching their skills. Darmawan and Mardikaningsih (2022) add that positive psychological factors strengthen employee engagement and commitment to work tasks, which helps explain why well-supported training builds lasting loyalty. A sense of career security reduces the turnover rate among critically qualified worker groups. The presence of intelligent technology accompanied by competency renewal makes manufacturing jobs perceived as more attractive and prestigious for the younger generation. Darmawan, Mendonca, and Isaac (2022) note that managing corporate reputation well, including through a positive digital image, helps make such jobs even more appealing to prospective young workers. Companies can reduce high external recruitment costs by empowering existing internal potential. High worker loyalty becomes an intangible asset that is very valuable in maintaining the company's long-term operational stability (Darmawan et al., 2020).

Comparative analysis shows that manufacturing companies that ignore upskilling strategies while adopting automation experience a decline in operational efficiency due to high internal resistance. Frey and Osborne (2017) prove that the absence of structured training programs triggers worker rejection of new machines due to fear of job loss. Automation policies imposed without skills enrichment lead to passive sabotage, declining work morale, and a high rate of equipment damage due to misuse. Management realizes that even investment in the most advanced technology will be futile without support from ready human capability to operate it. Successful digital transformation requires a harmonious balance between hardware modernization and human capital development. This experience confirms the importance of positioning upskilling strategy as a core component in every new industrial technology acquisition plan.

The Implication of Automation Adoption for Structural Unemployment and the Formulation of Labor Social Reskilling Strategies

The adoption of high-speed automation and robotic technology in manufacturing production chains triggers a shift in the labor requirement map that leads to the threat of structural unemployment. Acemoglu and Restrepo (2020) identify that the substitution of machinery for routine repetitive work significantly decreases the absorption of low-skilled labor. The mismatch between the qualifications possessed by affected workers and the new skill specifications required by the industry creates a chasm that is difficult to bridge in the short term (Gao et al., 2023). Manual assembly line workers lose their bargaining position because machine efficiency is considered more economical by company management. Such conditions trigger gradual layoffs that impact the increase in hidden unemployment rates in industrial areas. This situation demands planned intervention to prevent a decline in the economic welfare level of the workers.

The escalation of structural unemployment due to technological disruption brings further impact in the form of psychosocial vulnerability for manufacturing workers eliminated from the production system. Arntz et al. (2017) find that the sudden loss of livelihood triggers financial anxiety, declining self-confidence, and potential domestic conflict within workers' families. Arifin and Darmawan (2021) note that bridging the digital skills gap is essential for opening new employment opportunities, a step particularly needed by workers who lose access to their main livelihood. The absence of a clear career transition guarantee worsens public perception of the industrial modernization agenda carried out by the government and corporations. Senior workers face the heaviest barriers in adapting independently due to their limited capacity to learn new things (Das, 2024). This widens welfare inequality between community groups in manufacturing hub regions. Social risk management becomes urgent to formulate in order to mitigate the destructive impact of massive industrial automation.

The formulation of social reskilling strategy emerges as a mitigation instrument connecting industrial efficiency interests with the survival of workers affected by termination of employment. Korber (2019) explains that social reskilling is not limited to equipping workers with new technical skills, but includes strengthening emotional adaptability capacity and communal networks. Darmawan (2025) adds that job redesign in the automation era requires digital workforce competencies that go beyond technical mastery, aligning well with this broader view of reskilling. Darmawan (2024) further notes that strategies to strengthen employee knowledge and engagement remain relevant even in automated routine work, supporting workers' emotional adaptability during this transition. Training programs are designed inclusively by considering the sociological background and local potential of the areas where workers reside (Chopra & Soni, 2024). Technology-appropriate entrepreneurship skills training becomes one alternative option to open new livelihood opportunities outside the formal manufacturing sector. This approach facilitates a more dignified worker career transition process without feeling discarded from economic growth dynamics. Synergy among government, industry, and social institutions becomes an important foundation determining the success of such adaptation schemes.

Government involvement in facilitating social reskilling strategy is realized through the provision of deconcentration funds and the development of integrated community job training centers. Eurofound (2018) emphasizes the importance of the state's role in providing an active social safety net to accompany the skills reorientation process for informal and formal workers (Mood et al., 2025). Amsyari et al. (2026) show that EdTech-based educational management in remote areas can drive social justice transformation, a principle applicable to how government training centers should be designed for underserved manufacturing regions. Government-owned job training centers design adaptive curricula that adjust to local labor market needs and digital economy trends. Competency certification schemes are given free of charge to participants who successfully complete all training stages. Financial support during the training transition period helps maintain the purchasing power stability of workers' families who are losing their main job. This public intervention scheme effectively suppresses the growth rate of open unemployment in automation-affected regions.

Manufacturing companies have a corporate social responsibility to provide fair severance and career assistance packages before executing termination of employment policies. Agrawal et al. (2019) show that delegating social responsibility through outplacement programs smooths the company's organizational structure adjustment process. Barzani et al. (2022) note that applying sustainable supply chain management principles alongside corporate social responsibility improves operational performance, an orientation that should also extend to how companies treat workers during layoffs. Companies collaborate with independent career consulting institutions to provide psychological guidance, resume improvement, and new job vacancy information channels. This proactive step minimizes the potential for waves of protest from labor unions and maintains the company's positive public image (Sereda & Kravchenko, 2024). Affected workers gain room to evaluate their potential and determine a realistic new career direction. A well-controlled work transition creates a conducive industrial relations climate amid technological change dynamics.

Labor unions hold a strategic role as communication and consolidation facilitators in implementing social reskilling programs for their members. Vandaele (2018) argues that collective bargaining between labor unions and management can produce a fairer and more humane digital transition governance agreement. Darmawan and Gardi (2024) note that digital-oriented leadership fosters operational efficiency and team collaboration, qualities that also support more constructive negotiation between unions and management during this transition. Labor unions establish crisis centers and independent assistance posts to inventory the specific needs of members threatened with termination of employment. Through internal consolidation, labor unions can channel members' aspirations regarding the types of social reskilling training most needed (Berge & Lippényi, 2025). Active involvement of labor organizations in designing career recovery schemes increases members' sense of ownership and participation motivation. Strategic partnership between unions and employers becomes the key to creating a fair social compromise.

Strengthening community-based digital literacy becomes an important component in supporting the smooth implementation of social reskilling strategy for low-educated workers. Manyika et al. (2017) underline that mastery of basic digital applications makes it easier for workers to access micro markets independently after being eliminated from factories. Da Costa, Darmawan, and Isaac (2022) note that social media interaction shapes how individuals perceive themselves and their surroundings, a dynamic also relevant when affected workers form new self-perceptions and networks after job loss. Learning modules are designed simply using interactive media that is easy for senior worker groups to understand. Local communities function as social interaction spaces to share information on business opportunities and moral support among fellow affected workers. The formation of digital-based communal cooperatives facilitates initial capital for independent businesses started by reskilling program alumni. Economic independence built at the local level strengthens community social resilience against future technological disruption shocks.

The integration of an interdisciplinary approach in social reskilling programs raises the success rate of profession transition for workers affected by termination of employment. Rainnie et al. (2019) explain that combining technical skills, basic financial management, and marketing communication produces a more competitive training graduate profile. Darmawan (2024) adds that managing workforce diversity strengthens innovation and team performance, a principle that reinforces why combining varied skill sets produces stronger outcomes for reskilling participants. Workers equipped with this combination of skills have a higher business survival rate when entering the independent sector. Periodic evaluation of training participants' business development is carried out by an independent mentor team to provide solutions to field constraints. This continuous assistance prevents early business failure that could trigger psychological despair among participants (Atarodi et al., 2024). Successful profession transition creates new success stories that inspire other affected workers.

The dynamics of the digital labor market open new opportunities for affected workers to enter the gig economy ecosystem as independent freelancers. Graham et al. (2017) observe that the flexibility of digital platforms allows former factory workers to utilize their technical skills independently. Mardikaningsih et al. (2024) note that digital monitoring affects employee work autonomy and professional responsibility, a consideration equally relevant for former factory workers now managing their own work independently on digital platforms. Social reskilling programs guide participants to understand how to offer technical repair, machine maintenance, or logistics services through location-based applications. The use of digital platforms expands the market reach for offered services without requiring large physical business premises capital. This new work pattern provides adequate income alternatives to meet daily living needs. Adaptation toward a flexible work model requires continuous assistance so that workers do not fall into a new type of work vulnerability (Soulthoni et al., 2025).

Regional industrial restructuring policy must align automation adoption plans with the regional economic development roadmap. Neefe et al. (2020) recommend forming a regional stakeholder forum bringing together local government, business owners, academics, and community representatives. Mardikaningsih, Wardoyo, and Hariani (2024) show that digital-based HR development policy drives sustainable collaborative product and service innovation, a principle that fits how this stakeholder forum should function in mapping new economic sectors. This forum is tasked with mapping the potential of new economic sectors capable of absorbing the labor surplus from the automated manufacturing sector. Careful planning allows the labor relocation process to proceed gradually without causing a sudden local economic shock. Tax incentives are given to companies that actively fund social reskilling programs for communities around their operational areas (Culaba et al., 2023). This policy synergy creates a balance between technology acceleration and equitable social welfare distribution.

Overall, the success of handling the threat of structural unemployment due to Industry 4.0 automation strongly depends on the collective commitment of all elements of the nation. Nuvolari et al. (2021) conclude that automation not balanced with a strong social reskilling strategy risks triggering a decline in the working class's quality of life. Darmawan (2024) adds that technology can either promote or hinder gender equality in the workplace, underlining why fairness must remain a deliberate design choice rather than an automatic outcome of technological progress. Prioritizing humanistic values in every technology transformation policy is an absolute prerequisite for achieving equitable development. Social reskilling strategy can turn the threat of disruption into a momentum for broad human resource capacity renewal. Long-term partnership among stakeholders ensures that the progress of industrial technology can be enjoyed fairly by all levels of society without any group being sacrificed.

D. CONCLUSIONS

The integration of Industry 4.0 automation technology and robotic systems in the manufacturing sector transforms the structure of labor qualifications and drives the need for the formulation of structured human resource upskilling strategies. The effectiveness of technology adaptation on an industrial scale heavily depends on worker capability readiness, the alignment of training curricula based on machine performance data, and the establishment of an inclusive digital learning environment. The adjustment of training schemes that are responsive to the operational needs of the production floor boosts equipment efficiency, reduces the rate of operational failures, and maintains the stability of the company's competitiveness amid technological disruption.

The implications of this study affirm that the acceleration of industrial automation that is not balanced with the mitigation of social impacts has the potential to trigger structural unemployment problems and psychosocial vulnerability in affected worker groups. The decline in the absorption of low-skilled labor demands a transformation of the roles of human resource management, labor unions, and the government from mere administrative managers into facilitators of humane career transitions. The uncertainty in the direction of competence engineering and social protection policies can widen community welfare inequality in industrial center regions and trigger a wave of resistance against the manufacturing modernization agenda broadly.

To maintain a balance between industrial efficiency acceleration and worker social safety, it is recommended for manufacturing company management to consistently allocate human capital development budgets that integrate digital technical training with structured certification programs. The government and regulatory agencies need to establish active social safety net schemes, provide free reskilling training facilities based on local economic potentials, and provide incentives for corporations that fund affected worker career transition programs. Labor unions and civil society organizations are encouraged to increase active involvement in digital transition governance negotiations and strengthen community mentoring networks based on the enhancement of digital literacy.

REFERENCES

Acemoglu, D., & Restrepo, P. (2020). Robots and Jobs: Evidence from US Labor Markets. Journal of Political Economy, 128(6), 2188–2244.

Adetunla, A., Akinlabi, E. T., Jen, T., & Ajibade, S.-S. M. (2024). Analysing the Roles of Robotics in Manufacturing Organizations in the Era of Industry 4.0. In 2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG), IEEE, 1–5.

Agrawal, A., Gans, J. S., & Goldfarb, A. (2019). Artificial Intelligence: The Ambiguous Labor Market Impact of Automating Prediction. Journal of Economic Perspectives, 33(2), 31–50.

Amsyari, M., Darmawan, D., & El-Yunusi, M. Y. M. (2026). EdTech-Based Educational Management Strategies in Remote Areas and Social Justice Transformation for Rural Communities. Bulletin of Science, Technology and Society, 5(2), 65–76. Retrieved from https://inti.ejournalmeta.com/index.php/inti/article/view/160

Arifin, S., & D. Darmawan. (2021). Technology Access and Digital Skills: Bridging the Gaps in Education and Employment Opportunities in the Age of Technology 4.0, Journal of Social Science Studies, 1(1), 163 – 168.

Arntz, M., Gregory, T., & Zierahn, U. (2017). Revisiting the Risk of Automation. Economics Letters, 159, 157–160.

Atarodi, S., Ottmann, J.-Y., & Mbaye, P. A. M. (2024). Maximizing Employability and Entrepreneurial Success: A Training Program for Highly Skilled Seniors Transitioning into Freelance Consulting. Frontiers in Education, 9, 1-7.

Autor, D., Mindell, D., & Reynolds, E. (2020). The Work of the Future: Building Better Jobs in an Age of Intelligent Machines. MIT Press, Cambridge.

Bansen, S., Buxmann, P., & Fischer, M. (2021). Qualifications and Skills in the Era of Industry 4.0: A Systematic Literature Review. Journal of Business Economics, 91(7), 1015–1051.

Barzani, L. A., Darmawan, D., & Zulkarnain, M. A. B. (2022). The Application of Sustainable Supply Chain Management Principles in the Manufacturing Industry to Improve Operational Performance and Corporate Social Responsibility. International Journal of Service Science, Management, Engineering, and Technology, 1(1), 38–45.

Behera, S. S., Kumar, S., & Mishra, R. K. (2024). Skilling the Workforce for Industry 4.0. Advances in Logistics, Operations, and Management Science Book Series, 41–61.

Berge, J. ten, & Lippényi, Z. (2025). Firm-Level Technology Implementation and Finding a New Job: The Moderating Role of Industry Unionization. Economic & Industrial Democracy, 47(1), 271-303.

Bonekamp, L., & Sure, M. (2015). Consequences of Industry 4.0 on Human Labour and Work Organisation. Journal of Business and Media Psychology, 6(1), 33-40.

Buxmann, P., & Fischer, M. (2021). Qualifications and Skills in the Era of Industry 4.0: A Systematic Literature Review. Journal of Business Economics, 91(7), 1015–1051.

Chopra, A., & Soni, P. (2024). Navigating the Digital Workforce Shifts. Advances in Marketing, Customer Relationship Management, and e-Services Book Series, 27–58.

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. (2020). How do Industry 4.0 Technologies Influence Labour Organisation? A Multiple Case Study of Manufacturing Companies. Journal of Manufacturing Technology Management, 31(7), 1475–1497.

Corbin, J., & Strauss, A. (2015). Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory (4th ed.). SAGE Publications, Thousand Oaks.

costa, S. da, Darmawan, D., & Isaac, A. de J. (2022). Self-Identity Formation and Social Perception of Individuals through Interaction on Social Media in a Digital World. Journal of Social Science Studies, 2(2), 273-278.

Culaba, A. B., Bugtai, N. T., & Kaplan, A. J. H. (2023). Comprehensive Study of Industry 4.0 in Robotics for Policy Development. Recoletos Multidisciplinary Research Journal, 11(1), 55–69.

Darmawan, D. (2020). Health, Well-Being, and Productivity of Senior Employees in the Era of Artificial Intelligence. Journal of Science, Technology and Society (SICO), 1(2), 43–50.

Darmawan, D. (2023). Innovation Culture That Balances Technological Speed with the Depth of Humanistic Thought. International Journal of Service Science, Management, Engineering, and Technology, 4(1), 47–54.

Darmawan, D. (2023). Knowledge Management as a Source Of Competitive Advantage in Information Technology Companies. International Journal of

Service Science, Management, Engineering, and Technology, 3(2), 44–50.

Darmawan, D. (2023). Measuring Employee Productivity in the Digital Era by Considering Human Creativity and Innovation. International Journal of Service Science, Management, Engineering, and Technology, 4(3), 47–53.

Darmawan, D. (2023). Social Inclusion for Older Workers in the Implementation of Digital Technology within Organizations. International Journal of Service Science, Management, Engineering, and Technology, 4(2), 44–51.

Darmawan, D. (2023). The Concept Of Remote Work: A Literature Review on its Impact on Work Dynamics, Psychological Well-Being, and Social Relationships Among Employees. International Journal of Service Science, Management, Engineering, and Technology, 3(3), 49–55.

Darmawan, D. (2024). Distribution of Six Major Factors Enhancing Organizational Effectiveness. Journal of Distribution Science, 22(4), 47–58.

Darmawan, D. (2024). Distribution of Six Major Factors Enhancing Organizational Effectiveness. Journal of Distribution Science, 22(4), 47-58.

Darmawan, D. (2024). Strategies for Enhancing Employee Knowledge fnd Engagement in Automated Routine Work. International Journal of Service Science, Management, Engineering, and Technology, 6(1), 65–71.

Darmawan, D. (2024). The Role of Technology in Promoting or Hindering Gender Equality in the Workplace. International Journal of Service Science, Management, Engineering, and Technology, 6(2), 67–73.

Darmawan, D. (2024). Workforce Diversity Management Strategies for Enhancing Innovation and Team Performance. International Journal of Service Science, Management, Engineering, and Technology, 5(2), 53–59. Retrieved from https://ejournalisse.com/index.php/isse/article/view/230

Darmawan, D. (2025). Job Redesign, Automation, and Digital Workforce Competencies in the Twenty-First Century. Bulletin of Science, Technology and Society, 4(3), 103–114.

Darmawan, D., & Gardi, B. (2024). Digital-Oriented Leadership and Organizational Transformation: Fostering Operational Efficiency, Team Collaboration, and Innovation in the Digital. International Journal of Service Science, Management, Engineering, and Technology, 5(1), 37–42.

Darmawan, D., & Mardikaningsih , R. (2023). The Role of Flexible Organizational Structures in Enhancing Corporate Adaptability to Environmental Dynamics. International Journal of Service Science, Management, Engineering, and Technology, 3(1), 44–49.

Darmawan, D., & Mardikaningsih, R. (2022). The Role of Positive Psychological Factors in Enhancing Employee Engagement and Commitment to Work Tasks. International Journal of Service Science, Management, Engineering, and Technology, 1(2), 37–45.

Darmawan, D., Gardi, B., & Da Silva, E. B. (2023). Exploration of Changes in Management and Employee Work Relations in Multinational Companies in the Era of Literacy-Based Digitalization. Journal of Science, Technology and Society (SICO), 4(2), 43–54.

Darmawan, D., Mardikaningsih, R., Sinambela, E. A., Arifin, S., Putra, A. R., Hariani, M., Irfan, M., Al Hakim, Y. R., & Issalillah, F. (2020). The Quality of Human Resources, Job Performance and Employee Loyalty. International Journal of Psychosocial Rehabilitation, 24(3), 2580–2592.

Darmawan, D., Mendonca, C. N., & Isaac, A. de J. (2022). Managing Corporate Reputation in the Digital Age: Challenges and Solutions for Maintaining a Positive Image on Social Media. Journal of Social Science Studies, 2(1), 283-288.

Das, D. (2024). Navigating the Future: The Dual Impact of Automation on Industry Efficiency and Employment. International Journal of Advanced Research in Science, Communication and Technology, 4(5), 111–117.

Eddine, B. A. S., Darmawan, D., Mardikaningsih, R., & Sinambela, E. A. (2023). The Effect of Knowledge Management and Quality of Work Life on Employee Commitment. Journal of Human Sciences, 10(1), 87–100.

Eurofound. (2018). Automation in the Workplace: Implications for the Labour Market and Working Conditions. Publications Office of the European Union, Luxembourg.

Frey, C. B., & Osborne, M. A. (2017). The Future of Employment: How Susceptible are Jobs to Computerisation?. Technological Forecasting and Social Change, 114, 254–280.

Gao, X., Luo, C., & Shou, J. (2023). Effect of Industrial Robot Use on China's Labor Market: Evidence from Manufacturing Industry Segmentation. Intelligent and Converged Networks, 4(2), 106–115.

Graham, M., Hjorth, I., & Lehdonvirta, V. (2017). Digital Labour and Development: Impacts of Global Digital Labour Platforms and the Gig Economy on

Worker Livelihoods. Transfer: European Review of Labour and Research, 23(2), 135–162.

Hall, S. S., & Elshennawy, A. (2024). Evolution of Technological Leadership with the Introduction of Industry 4.0. Deleted Journal, 17(2), 10–18.

Hearn, G., Williams, P., Rodrigues, J. H. P., & Laundon, M. (2023). Education and Training for Industry 4.0: A Case Study of a Manufacturing Ecosystem. Journal of Education and Training, 65(8-9), 1070-1084.

Issalillah, F., & Hardyansah, R. (2022). The Impact of the Digital Divide and Misinformation on Participation and Trust in Local Communities. Journal of Social Science Studies, 2(2), 7-12.

Issalillah, F., & Khayru, R. K. (2025). Mental Health as an Organizational Construct: A Strategic Reorientation of Human Resource Management for Work Environment Design. International Journal of Service Science, Management, Engineering, and Technology, 8(3), 1–9.

Issalillah, F., & Khayru, R. K. (2026). Generative AI-Based Telemedicine Management: An Analysis of Ethical Acceptability, Medical Governance, and Patient Social Trust. Bulletin of Science, Technology and Society, 5(1), 51–64. Retrieved from https://inti.ejournalmeta.com/index.php/inti/article/view/150

Kathirvel, A., Gobinath, V. M., Sathya, V., Kathirvel, N., & Anthony, R. C. (2024). The Role of Robotics in Smart Manufacturing. Advances in Marketing, Customer Relationship Management, and e-Services Book Series, 315–356.

Khayru, R. K. (2022). Transforming Healthcare: The Power of Artificial Intelligence. Bulletin of Science, Technology and Society, 1(3), 15-19.

Korber, M. (2019). Reskilling in the Age of Automation: Challenges and Opportunities for Social Policy. European Journal of Social Security, 21(4), 312–329.

Lodgaard, E., & Dransfeld, S. (2020). Organizational Aspects for Successful Integration of Human-Machine Interaction in the Industry 4.0 Era. Procedia CIRP, 88, 218–222.

Manyika, J., Lund, S., Chui, M., Bughin, J., Woetzel, J., Batra, P., Ko, R., & Sanghvi, S. (2017). Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation. McKinsey Global Institute, 1-148.

Mardikaningsih, R. (2025). The Deconstruction of Work and HRM Reconfiguration: Flexibility and Employer Branding in the Digital Era. International Journal of Service Science, Management, Engineering, and Technology, 8(2), 10-17.

Mardikaningsih, R., & Darmawan, D. (2022). The Role of Self-Efficacy in Predicting Employee Adaptability to Technological Change in the Workplace,. International Journal of Service Science, Management, Engineering, and Technology, 2(3), 43–55.

Mardikaningsih, R., & Wardoyo, D. T. W. (2024). The Role of Technology in Human Resource Development for Sustainability: A Literature Review on Digital Innovation. Bulletin of Science, Technology and Society, 3(3), 20–26.

Mardikaningsih, R., & Wardoyo, D. T. W. (2026). Organizational Change Management Strategies in Addressing Employee Social Resistance During Green IT Transition. Bulletin of Science, Technology and Society, 5(2), 1–12. Retrieved from https://inti.ejournalmeta.com/index.php/inti/article/view/145

Mardikaningsih, R., Halizah, S. N., Darmawan, D., Masithoh, N., & Nuraini, R. (2022). Examining the Role of Authentic Leadership in Shaping Positive Work Climate and Organizational Citizenship Behavior. International Journal of Service Science, Management, Engineering, and Technology, 2(1), 52–59.

Mardikaningsih, R., Halizah, S. N., Nuraini, R., & Darmawan, D. (2022). The Role of Ethical Leadership in Shaping a Positive and Sustainable Organizational Culture. International Journal of Service Science, Management, Engineering, and Technology, 2(2), 48–55.

Mardikaningsih, R., Hariani, M., & Nuraini, R. (2026). The Effectiveness of Digital Waste Management Application Gamification in Fostering Environmental Awareness and Operational System Sustainability. Bulletin of Science, Technology and Society, 5(1), 79–92. Retrieved from https://inti.ejournalmeta.com/index.php/inti/article/view/152

Mardikaningsih, R., Hariani, M., Darmawan, D., Halizah, S. N., & Nuraini, R. (2024). The Impact of Digital Monitoring on Employee Work Autonomy and Professional Responsibility. International Journal of Service Science, Management, Engineering, and Technology, 5(3), 60–67. Retrieved from https://ejournalisse.com/index.php/isse/article/view/231

Mardikaningsih, R., Wardoyo, D. T. W., & Hariani, M. (2024). Digital-Based HR Development Policy as a Driver of Sustainable Collaborative Product and Service Innovation. Journal of Science, Technology and Society (SICO), 5(1), 43–54.

Maulani, A., Hardyansah, R., Darmawan, D., Mendonca, C. N., & de Jesus Isaac, A. (2023). Juridical Analysis of the Validity of Electronic Contracts Made by Artificial Intelligence in Indonesian Law. Journal of Social Science Studies, 3(1), 139-144.

Miguel, C. M., Hoedt, S., Leyman, P., Aghezzaf, E., & Cottyn, J. (2023). Framework for Formulating Competence-Aware Scheduling Models in Mixed-Model Assembly. In: Galizia, F.G., Bortolini, M. (eds) Production Processes and Product Evolution in the Age of Disruption, CARV 2023. Lecture Notes in Mechanical Engineering. Springer, Cham, 552–561.

Mood, M. M., Ghamary, M., & Youshanlouei, H. R. (2025). The Role of Governments, Employers, and Platforms to Cope with the Skill Gaps in Industry 4.0. Ecological and Human Dimensions of AI-Based Supply Chain, 111–162.

Neefe, L., Peiffer, S., & Buxmann, P. (2020). Regional Labor Market Transitions in the Era of Industry 4.0. Regional Studies, 54(8), 1089–1102.

Nuvolari, A., Righi, R., & Urbinati, A. (2021). Automation, Worker Displacement, and the Role of Social Reskilling. Technological Forecasting and Social Change, 168, 120760.

Panagiotopoulou, V. C., Bikas, H., Paraskevopoulou, A., Stamatopoulos, F., & Stavropoulos, P. (2025). A Roadmap for Reskilling and Upskilling of the Workforce Towards Aligning with Twin Transition in the Manufacturing Sector. In: Louw, L., Hummel, V., de Kock, I., von Leipzig, K. (eds) Advancing Learning Factories: Enabling Future-Ready Skills. cfl 2025. Lecture Notes in Networks and Systems, Springer, Cham, 1545, 177–185.

Pfeiffer, S. (2017). The Vision of Industry 4.0 in the Making: A Luxury the African Continent Cannot Afford? Development Southern Africa, 34(4), 442–452.

Putra, A. R., & Arifin, S. (2021). Supply Chain Management Optimization in the Manufacturing Industry through Digital Transformation: The Role of Big Data, Artificial Intelligence, and the Internet of Things. Journal of Social Science Studies, 1(2), 161-166.

Putra, A. R., Arifin, S., & Darmawan , D. (2024). Gamification-Based Learning that Preserves Cooperation and Empathy Among Employees. International Journal of Service Science, Management, Engineering, and Technology, 5(1), 43–50. Retrieved from https://ejournalisse.com/index.php/isse/article/view/229

Rainnie, A., Dean, M. A., & Smith, M. (2019). Labour, Industry 4.0 and the Future of Work. Labour & Industry: A Journal of the Social and Economic Relations of Work, 29(2), 131–140.

Saunders, M., Lewis, P., & Thornhill, A. (2019). Research Methods for Business Students (8th ed.). Pearson Education, New York.

Schwab, K. (2016). The Fourth Industrial Revolution. World Economic Forum, Geneva.

Sereda, O. G., & Kravchenko, V. V. (2024). Outplacement as a Key to an Effective HR Policy When Dismissing Employees. Analìtično-Porìvnâl'ne Pravoznavstvo, 2(2024), 323-327.

Silverman, D. (2020). Interpreting Qualitative Data (6th ed.). SAGE Publications, London.

Soulthoni, H. P. N., Upe, A., Mugambiwa, S. S., & Johar, S. S. (2025). Digital Platform Transformation and Socio-economic Resilience Among Indonesia's Motorcycle Ride-hailing Drivers. Indonesian Journal of Innovation and Applied Sciences, 5(3), 231-241.

Tortorella, G. L., Giglio, R., & van Dun, D. H. (2020). Industry 4.0 Adoption and Soft TQM Capabilities: Their Impact on a Firm's Performance. International Journal of Production Research, 58(6), 1837–1850.

Triono, B., Darmawan, D., Djaelani, M., Safitri, F. S. A., & Masithoh, N. (2025). How Digitalization Reshapes Labor and Task Architecture in the Manufacturing Sector. International Journal of Service Science, Management, Engineering, and Technology, 7(2), 11–16.

Vandaele, K. (2018). Will Trade Unions Survive in the Platform Economy? Emerging Patterns of Platform Workers' Collective Voice and Representation. Working Paper, European Trade Union Institute (ETUI), 1-33.

Vineet, K. (2025). Workforce Transformation and Skill Development in Industry 4.0. Chemical Industries in Industry 4.0 Era, 116-130.

Warin, A. K., & D. Darmawan. (2024). Fostering Adaptive Employees: The Importance of Continuous Feedback in HR Development, Bulletin of Science, Technology and Society, 3(3), 27-34.

World Economic Forum. (2020). The Future of Jobs Report 2020. World Economic Forum, 1-162.

Yasser, E. H., & Abdelmajid, E. O. (2025). AI Governance for Workforce Development: A Conceptual Framework for Reskilling and Upskilling. In 2025 International Conference on New Trends in Computational Intelligence (NTCI), IEEE, 631–636.

Zhang, P., Liang, H.-L., Chen, X., & Qin, Y. (2025). The Impact of Robot Adoption on the Demand for General Skills. Competition to Coexixtence, 70–89.