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Adopting Industry 4.0 in India's Automotive Sector: Challenges, Enablers, and Policy Implications

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Abstract **- This paper examines the adoption of Industry 4.0 technologies within the Indian automotive sector, summarizing the transition towards smart manufacturing and identifying key challenges and enablers. This study employed a qualitative literature review method, organizing the findings into meaningful segments using the ABCD framework to distil large volumes of data into core insights. The framework categorizes the advantages, benefits, constraints, and disadvantages associated with Industry 4.0. The research highlights several key barriers to adoption, including high implementation costs, a lack of a skilled workforce, and cybersecurity risks. Government initiatives, such as the Make in India campaign, play a crucial role in enabling transformation but require better alignment with industry needs. This study relies on secondary data sources, which limits its ability to capture real-time developments and sector-specific nuances. The absence of primary data collection restricts a deeper exploration of emerging trends. This research provides a structured evaluation of the impact of Industry 4.0 on the automotive industry in India. It captures the essence of digital transformation in manufacturing and offers actionable policy recommendations, reflecting the challenge of summarizing complex trends and transformations into concise takeaways for academic and practical use.**

Keywords: **Industry 4.0, Automotive Sector, Smart Manufacturing, Barriers to Adoption, Digital Transformation**

I. INTRODUCTION

Industry 4.0, also referred to as the Fourth Industrial Revolution, is reshaping global manufacturing and exerting substantial influence on the automotive sector. This technological shift encompasses automation, AI, IoT, robotics, and cloud computing, which facilitate the creation of "smart factories" [1]. These advancements aim to boost operational efficiency, reduce downtime, and enable data-driven decision-making, with countries such as Germany and Japan spearheading technological integration [2]. The automotive industry, renowned for its swift embrace of innovative technologies, utilizes robotics and IoT for predictive maintenance and production enhancement [3].

In the Indian context, firms like Tata Motors are incorporating Industry 4.0 technologies, bolstered by governmental programs such as "Make in India," to maintain global competitiveness [4]. However, adoption rates vary considerably, with larger firms progressing more swiftly than SMEs due to resource constraints [5]. These obstacles are mirrored across various Indian industries, as evidenced by studies in resource-limited sectors such as livestock and casting, which emphasize similar barriers to technological progress and worker engagement [6]. Despite its vast potential, the widespread implementation of Industry 4.0 faces obstacles, including substantial investment costs, cybersecurity risks, and a shortage of skilled workers [7]. Government intervention is crucial for tackling these challenges by developing policies that enhance technological infrastructure and promote workforce upskilling [8]. Moreover, sustainable adoption requires collaboration between industry stakeholders and academic institutions to address the skill gap and drive innovation [9]. This study explores the implementation of Industry 4.0 in the Indian automotive sector by analyzing key case studies, comparing global benchmarks, and assessing the impact of government initiatives in promoting technological transformation. Insights from related industries, such as livestock and casting, further highlight the necessity for a unified approach to overcome adoption hurdles and realize the full potential of Industry 4.0 [10].

II. OBJECTIVES OF THE STUDY

This study aims to explore the adoption and impact of Industry 4.0 technologies in the Indian automotive industry. The primary objectives are:

1. To examine the extent of Industry 4.0 adoption by Indian automotive manufacturers.
2. To identify key applications, including IoT-based predictive maintenance, AI-driven optimization, and robotics in production processes.
3. To evaluate the challenges and barriers, such as high costs, workforce skill gaps, and cybersecurity risks, that hinder adoption.
4. To assess the role of government policies and initiatives in facilitating Industry 4.0 adoption.

III. LITERATURE REVIEW

A. Global Perspective on Industry 4.0 in Automotive

Industry 4.0 technologies, such as IoT, AI, CPS, and cloud computing, are being rapidly embraced by the global

automotive industry. Nations such as Germany and Japan are spearheading this transformation, utilizing these innovations to boost production efficiency and sustain their competitive advantage [11], [12]. The implementation of smart factories, which incorporate real-time data analysis and predictive maintenance, has become essential in modern automotive manufacturing, leading to reduced downtime and optimized workflows [12].

The application of cutting-edge technologies, including big data and IoT, not only tackles manufacturing issues but also enhances customer confidence by improving operational efficiency and transparency [13]. Research has further emphasized the significance of adopting data-driven strategies, particularly highlighting the crucial role of predictive maintenance in reducing operational disruptions [14]. The value of Industry 4.0 in elevating quality and safety standards is demonstrated through comparative analyses of materials and processes, such as those employed in brake systems [15]. Additionally, frameworks for hybrid investment casting processes provide opportunities to enhance manufacturing precision and efficiency [16].

The significance of Industry 4.0 technologies in addressing complex supply chain issues is evident in the global challenges faced by logistics operations, particularly in third-party logistics (3PL) [17]. Logistics networks benefit from increased transparency and reduced inefficiencies through the application of technologies such as IoT and CPS. Moreover, Industry 4.0's focus on sustainable and energy-efficient production processes aligns with advancements in renewable energy systems, as exemplified by solar drying technology [18].

By incorporating Industry 4.0 technologies, the global automotive sector not only tackles conventional manufacturing hurdles but also establishes itself as an innovation leader, thereby safeguarding its competitiveness in a rapidly changing industrial environment.

B. India's Adoption of Industry 4.0 in Automotive

The adoption of Industry 4.0 technologies in India is on the rise, primarily driven by government programs such as "Make in India." Leading automotive manufacturers, including Tata Motors and Mahindra, have incorporated intelligent manufacturing techniques to enhance product customization and operational productivity [4].

While larger enterprises are spearheading this transformation, smaller suppliers encounter substantial obstacles, including financial limitations and restricted access to advanced technology. The Indian automotive industry has begun to utilize predictive maintenance and real-time data analysis; however, widespread implementation has been hindered by cybersecurity issues and a dearth of skilled workers. To fully realize the potential of Industry 4.0, it is crucial for industries and educational institutions to collaborate to address the existing skills gap.

C. Technological and Strategic Challenges in India

As India moves toward Industry 4.0, it encounters numerous obstacles, such as substantial expenses associated with implementing new technologies, insufficient digital infrastructure in smaller urban areas, and potential cybersecurity threats. Smaller enterprises face difficulties in competing with larger corporations because of limited resources. The uneven adoption of technologies across supply chain partners hinders smooth integration [14]. In the automotive sector, Indian companies are investigating the use of artificial intelligence (AI), IoT, and machine learning to boost sustainability and enhance resource efficiency. To overcome these challenges, greater investment in digital infrastructure and programs for workforce skill development are essential [19].

D. Government Initiatives and Policies Supporting Industry 4.0

Initiatives like "Digital India" and "Make in India" are instrumental in encouraging the implementation of Industry 4.0 technologies within the automotive industry. These schemes aim to boost a sector's international competitiveness by offering support and incentives for technological progress [20]. However, the efficacy of these programs hinges on companies' ability to synchronize their strategies with emerging technologies and invest in upskilling their workforce to adapt to new technological environments.

Research has emphasized the necessity of crafting long-term digital transformation strategies to fully capitalize on government support and maintain growth in the era of Industry 4.0 [21]. Moreover, the incorporation of cutting-edge technologies has been demonstrated to enhance not only operational efficiency but also customer confidence and satisfaction, as evidenced in other industries such as retail [22].

To optimize the advantages of these initiatives, businesses must take a proactive stance toward technological adoption, encompassing strategic planning, staff training, and collaborative efforts with policymakers. This holistic approach will ensure that government schemes like "Digital India" and "Make in India" fulfill their intended goals of driving innovation and promoting sustainable development in the automotive sector.

E. Comparison with Global Trends

While Industry 4.0 has made strides, India's automotive industry lags behind global leaders such as Germany and Japan, who have achieved higher levels of automation and data-centric operations through substantial investments in digital infrastructure [11]. To sustain its competitive advantage in international markets, Indian firms must accelerate the implementation of cutting-edge technologies and reduce reliance on foreign technology suppliers by fostering local innovation and R&D capabilities [23].

IV. RESEARCH METHODOLOGY

This research, based on a qualitative analysis of the literature, investigates the implementation and effects of Industry 4.0 technologies in India's automotive industry. Owing to the lack of primary data from expert interviews or surveys, this study relies on secondary sources, including scholarly articles, industry reports, and government publications. The research synthesizes information from the existing literature to provide a comprehensive understanding of the adoption of Industry 4.0.

The study utilized various data sources, such as peer-reviewed journals, conference papers, and reports from industry and government, accessed through databases such as IEEE Xplore, SpringerLink, Elsevier, Emerald, Google Scholar, and Semantic Scholar repositories. Significant reports from automotive associations and initiatives like "Make in India" are also included. These sources offer insights into the current trends, challenges, and policies influencing Industry 4.0 adoption.

To analyze the data systematically, this study employs the ABCD framework, examining operational and competitive benefits, specific advantages for stakeholders, adoption challenges, and potential negative consequences, including workforce displacement and data security issues. This framework provides a thorough evaluation of Industry 4.0's impact on the Indian automotive sector.

The methodology involves a systematic review of research articles and reports to identify themes, such as technological trends, operational benefits, challenges, and policy implications. Data are coded according to the ABCD framework to ensure alignment with advantages, benefits, constraints, or disadvantages. Thematic insights were synthesized to identify patterns and develop key findings, with comparisons to global trends highlighting gaps and opportunities.

This study's reliance on secondary data limits its ability to capture real-time industry insights and is dependent on the available literature, which may not reflect recent developments. Furthermore, certain aspects, such as detailed case studies of Indian automotive firms, may be underrepresented. As this research utilized publicly available data, no ethical concerns were involved.

V. INDUSTRY 4.0 TECHNOLOGIES IN THE AUTOMOTIVE INDUSTRY IN INDIA

A. Industry 4.0 in the Global Automotive Industry

The global automotive sector is undergoing transformation through Industry 4.0, which incorporates technologies such as IoT, Big Data Analytics, AI, Robotics, Cloud Computing, Cyber-Physical Systems (CPS), 3D Printing, and Blockchain. These innovations enable more intelligent and efficient manufacturing processes, boost productivity, reduce downtime, and facilitate customization. IoT enables real-time data gathering and predictive maintenance, whereas AI and machine learning enhance quality control and risk management. CPS merges physical and digital systems, allowing seamless component communication, while 3D printing expedites prototyping and bespoke part production. Blockchain improves supply chain transparency and security, fostering trust and operational efficiency.

In India, automotive firms are increasingly embracing Industry 4.0 technologies to enhance efficiency and competitiveness. Companies like Tata Motors and Mahindra have utilized IoT for predictive maintenance and cloud-based supply chain management. Robotics and automation, in line with the "Make in India" initiative, improve precision and reduce waste. AI and Big Data Analytics streamline logistics and inventory management, minimizing lead times and operational bottlenecks. For instance, Suzuki has employed smart factory solutions to monitor energy usage and boost production capabilities.

Nevertheless, the adoption rate varies considerably between larger and smaller enterprises, with the latter often being limited by resource constraints. Government initiatives such as "Digital India" and "Make in India" play a vital role in promoting Industry 4.0 adoption by investing in digital infrastructure to establish India as a global manufacturing hub [20]. The Automotive Mission Plan 2026 aims to create a sustainable, technology-driven ecosystem; however, its success depends on the industry's ability to keep pace with technological advancements and overcome existing infrastructure challenges.

B. Challenges in Adopting Industry 4.0

Advanced technology adoption presents significant hurdles for Small and Medium Enterprises (SMEs), including substantial upfront expenses, inadequate digital infrastructure (particularly in smaller cities), threats to cybersecurity, and concerns about data protection. These issues are further complicated by skill shortages, as constantly evolving technologies necessitate ongoing workforce training. The scarcity of skilled personnel required for effective implementation is worsened by limited cooperation between industry and academia. Additionally, reluctance among employees and management to embrace change, especially in conventional manufacturing settings, impedes technological progress.

In comparison to global frontrunners such as Germany, Japan, and the United States, the Indian automotive sector lags behind in embracing Industry 4.0. While international firms benefit from well-developed digital infrastructure and government support, Indian companies grapple with infrastructure deficiencies and financial constraints. Furthermore, dependence on foreign technology suppliers creates vulnerability and restricts domestic innovation [21].

Nevertheless, India has considerable potential to become a world leader in Industry 4.0. The Indian automotive industry could fully capitalize on the advantages of Industry 4.0 through joint initiatives between the government and the private sector, coupled with rising foreign investment and an emphasis on sustainable manufacturing practices.

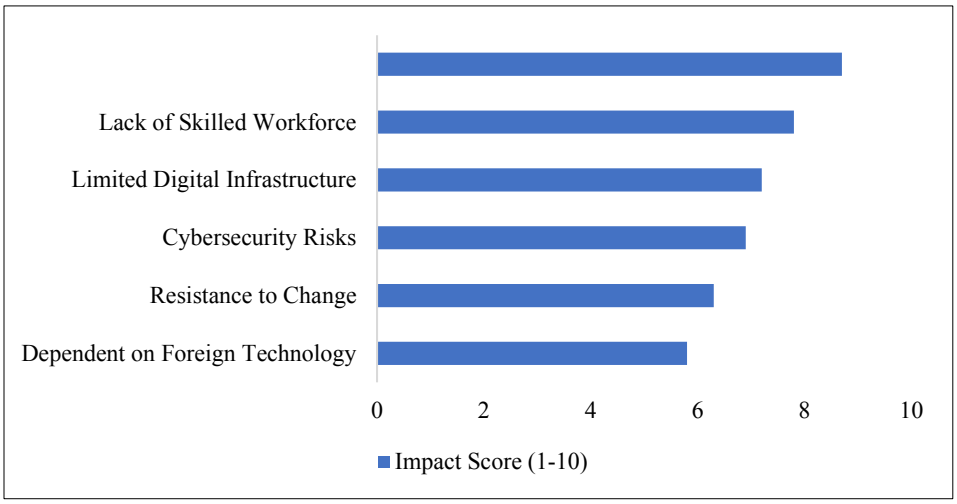

Fig. 1 Impact Scores of Key Challenges in Adopting Industry 4.0 Technologies in the Indian Automotive Sector

VI. ABCD ANALYSIS

To assess the implementation of Industry 4.0 technologies in India's automotive industry, the ABCD framework is utilized. This approach examines the Advantages, Benefits, Constraints, and Disadvantages of adoption. By employing this method, crucial factors affecting implementation were identified, offering valuable perspectives on both the potential opportunities and challenges involved in the process.

TABLE I ABCD ANALYSIS

Category	Key Aspects	Impact on Stakeholders	References
Advantages	Improved efficiency, predictive maintenance, product customization	Increases productivity, reduces downtime, improves competitiveness	(Bhatia & Kumar, 2020) [13]
Benefits	Cost savings for manufacturers, better product quality for customers, alignment with Make in India	Manufacturers: Lower costs; Customers: Quality products; Government: Economic growth	(Verma & Venkatesan, 2023) [21]
Constraints	High implementation costs, lack of skilled workforce, limited digital infrastructure, cybersecurity risks	SMEs: Adoption barriers; Workforce: Training required; Companies: Risk management essential	(Kumar *et al.,* 2020)
Disadvantages	Workforce displacement, dependency on foreign technology, integration challenges, resistance to change	Social impact: Job losses; Companies: Operational delays; Industry: Technology reliance	(Goswami & Daultani, 2021) [20]

A. Advantages

Technologies in Industry 4.0 offer numerous operational and strategic benefits to India's automotive sector.

1. *Enhanced Production Efficiency:* Automated systems and real-time monitoring enhance manufacturing processes, minimize waste, and reduce downtime [13].
2. *Increased Product Personalization:* Artificial intelligence and additive manufacturing allow producers to create customized items tailored to consumer desires.
3. *Proactive Maintenance:* IoT sensors coupled with data analysis anticipate machinery breakdowns and boost equipment reliability.
4. *Improved International Competitiveness:* By embracing Industry 4.0, Indian firms align themselves with global manufacturing benchmarks, thereby increasing their competitive edge.

B. Benefits to Stakeholders

Industry 4.0 implementation offers advantages to various parties within the automotive sector.

1. For manufacturers, automation leads to reduced workforce expenses, enhanced production rates, and uniform product standards [11].
2. Consumers benefit from intelligent manufacturing processes that enable companies to provide superior products with decreased waiting times and improved personalization options.

3. The government finds alignment between Industry 4.0 and the "Make in India" program, fostering job creation and promoting technological advancement.
4. For suppliers and supply chain collaborators, sharing real-time information enhances stock control and facilitates seamless operation throughout the supply network.

C. Constraints

Despite the numerous advantages offered by Industry 4.0, its adoption in the Indian automotive sector faces several obstacles.

1. *Substantial Initial Expenditure:* The considerable upfront investment required for cutting-edge technological infrastructure impedes adoption, particularly among smaller enterprises [21].
2. *Shortage of Qualified Personnel:* There is a dearth of workers proficient in operating new technologies, necessitating extensive training and skill enhancement programs [9].
3. *Insufficient Digital Infrastructure:* Implementation is hampered by inadequate internet and technological infrastructure, especially in smaller urban areas.
4. *Cybersecurity Concerns:* The increased reliance on digital systems exposes businesses to potential data breaches and cyber-attacks.

D. Disadvantages and Risks

While the implementation of Industry 4.0 technologies offers numerous benefits, it also brings about certain risks and disadvantages.

1. *Job Displacement:* The rise of automation could diminish the demand for unskilled workers, potentially resulting in unemployment and societal issues.
2. *Reliance on Overseas Technology:* Numerous companies depend on imported technological solutions, which may hinder local innovation and create a state of dependence.
3. *Compatibility Issues with Existing Systems:* Older infrastructure in manufacturing facilities might not be seamlessly integrated with modern technologies, potentially causing delays or increased expenses.
4. *Opposition to Change:* The reluctance of both management and staff to embrace new technologies, particularly in conventional manufacturing environments, can impede the adoption process.

VII. RESULTS AND DISCUSSION

The ABCD analysis findings offer valuable perspectives on the prospects, obstacles, and potential pitfalls associated with the implementation of Industry 4.0 in India's automotive industry. This section examines the outcomes, drawing upon significant research and implications for various stakeholders, including manufacturers and policymakers.

A. Opportunities through Advantages and Benefits

The implementation of Industry 4.0 technologies presents significant operational and strategic advantages. Predictive maintenance, enabled by IoT, AI, and Big Data Analytics, has resulted in decreased downtime and improved production efficiency [13]. Customer satisfaction has been enhanced through product customization utilizing 3D printing and AI-driven insights, thereby offering bespoke solutions. Companies adopting smart manufacturing achieve cost reductions and competitive edges through real-time monitoring and process optimization.

The "Make in India" initiative, launched by the Indian Government, complements the goals of Industry 4.0 by encouraging innovation, automation, and sustainable manufacturing practices [4]. These technological advancements benefit manufacturers by lowering costs and customers through enhanced product quality and quicker deliveries. Additionally, supply chain partners can reap the rewards of smooth data exchanges and improved coordination [20].

B. Constraints and Adoption Barriers

Although Industry 4.0 technologies offer clear benefits, their widespread adoption in India faces several obstacles. The substantial costs associated with implementation present a significant challenge, especially for small and medium-sized enterprises (SMEs), which often lack the financial resources to invest in sophisticated digital systems. This financial constraint puts smaller companies at a competitive disadvantage compared with larger manufacturers with greater access to capital and resources. Another major hurdle is the lack of skilled workers. Many organizations struggle to find employees with the necessary expertise to operate and maintain advanced technologies. Research has emphasized the importance of collaboration between educational institutions and businesses to address these skill deficits and ensure smooth implementation. Furthermore, the increased reliance on interconnected systems exposes companies to cybersecurity threats, posing additional challenges [14]. The limited digital infrastructure beyond major urban areas further impedes the adoption of Industry 4.0, making it difficult for firms in Tier 2 and Tier 3 cities to effectively utilize these advancements. Without significant investment in infrastructure, the digital divide will continue, thereby restricting the impact of Industry 4.0.

C. Risks and Social Implications

The implementation of Industry 4.0 brings forth various challenges, including the potential displacement of workers due to increased automation. As machines take over low-skilled tasks, numerous employees may face unemployment, which could lead to social instability and require extensive retraining programs [23]. Additionally, both workers and managers, particularly in conventional manufacturing settings that rely heavily on human labor, may resist

technological advancements. Another concern is the reliance on foreign-made technologies. Numerous firms depend on imported equipment and software, which hinders local innovation and creates vulnerabilities in the event of supply chain disruptions or international conflicts [4]. Furthermore, difficulties in integrating new technologies with existing legacy systems complicate the adoption process, often resulting in setbacks and higher operational expenses [11].

D. Comparative Analysis: India vs. Global Trends

In comparison to global frontrunners such as Germany, Japan, and the United States, India's implementation of Industry 4.0 technologies remains in its early stages. Although Indian firms are making progress, they must expedite investments in infrastructure, workforce training, and cybersecurity to meet international standards. By contrast, developed economies enjoy the advantages of well-established digital ecosystems and superior policy frameworks, facilitating swifter adoption. Notwithstanding these obstacles, India possesses considerable potential to emerge as a world leader in Industry 4.0 if it can surmount existing limitations. Enhanced cooperation among industry, government, and academia is essential for constructing a robust ecosystem capable of supporting sustained growth over the long term.

VIII. POLICY RECOMMENDATIONS

Drawing from the insights gleaned from the ABCD analysis, as well as the outcomes and deliberations, a set of policy suggestions is put forward to encourage the implementation of Industry 4.0 technologies within India's automotive industry. These proposals are aimed at crucial stakeholders, including government bodies, industry executives, academic institutions, and supply chain collaborators.

A. Recommendations for Government

1. *Promote Technological Advancement:* Offer fiscal benefits, financial assistance, and subsidies to car manufacturers, especially small and medium-sized enterprises, to encourage investment in Industry 4.0 technologies [13]. Broaden the scope of funding under the "Make in India" and "Digital India" programs to bolster technological infrastructure growth in secondary and tertiary urban centers.
2. *Enhance Digital Networks:* Boost investment in high-bandwidth Internet and 5G infrastructure to ensure smooth connectivity for Internet of Things-enabled manufacturing systems. Robust cybersecurity protocols should be established to safeguard interconnected production facilities from data theft and online attacks.
3. *Foster Academic-Industrial Partnerships:* Support collaborations between automotive companies and educational institutions to create curricula that align with the requirements of Industry 4.0. Initiate programs for skill enhancement and retraining to address the current skills gap.

B. Recommendations for Automotive Manufacturers

1. *Prioritize Workforce Upskilling and Enhancement:* Establish ongoing training initiatives to equip staff with expertise in robotics, data analytics, and the IoT. Emphasize change management tactics to mitigate employee resistance and facilitate a seamless shift toward automated systems.
2. *Emphasis on Domestic Innovation:* Reduce dependence on foreign technologies by allocating resources to R&D and nurturing innovation within the local ecosystem [4]. Engage with emerging businesses and technology firms to create cost-effective, India-centric Industry 4.0 solutions.
3. *Embrace Eco-friendly Practices:* Utilize Industry 4.0 technologies to enhance energy efficiency and minimize waste, in line with worldwide sustainability objectives. Implement predictive maintenance for longevity.

C. Recommendations for Educational Institutions

1. *Craft Industry-Aligned Educational Programs:* Establish courses centered on cutting-edge manufacturing techniques, the Internet of Things, artificial intelligence, and data analysis, customized to meet automotive industry requirements [9]. Set up innovation centers and collaborative spaces to promote research into Industry 4.0 applications within automotive production.
2. *Implement Workforce Upskilling Initiatives:* Partner with businesses to provide vocational training and work placements, ensuring students acquire hands-on experience. Organize community-based learning schemes to enhance the skills of the current workforce, particularly in emerging technologies and Industry 4.0. This holistic strategy addresses the skill shortage in the automotive sector by cultivating a workforce capable of embracing and propelling technological advancements in the industry.

D. Recommendations for Supply Chain Partners

Utilize blockchain technology to enhance transparency and traceability in supply chain management. Incorporate IoT systems to monitor inventory, logistics, and production processes in real time, thereby minimizing delays and inefficiencies. Foster robust partnerships with Industry 4.0 technology providers to ensure seamless adoption of new technologies. Suppliers should be encouraged to engage in training initiatives to promote alignment across the supply chain and bolster collaborative efforts.

IX. CONCLUSION

The implementation of Industry 4.0 technologies offers a substantial opportunity for India's automotive sector to boost productivity, reduce costs, and enhance its global market position. These innovations enable manufacturers to refine their production methods, deliver customized products, and streamline operations through automated processes and

predictive data analysis. Nevertheless, the journey toward complete adoption is not without hurdles. Substantial implementation expenses, a shortage of skilled workers, and cybersecurity concerns present significant obstacles, particularly for smaller firms. Concerted efforts are crucial to overcoming these challenges. The government must continue to invest in digital infrastructure and offer financial support to aid businesses in embracing new technologies. Concurrently, companies must allocate resources to workforce development to ensure their staff can manage advanced systems. Partnerships between industry and educational institutions are vital in addressing skill shortages, promoting innovation, and encouraging the uptake of emerging technologies. Although the Indian automotive industry still lags behind global frontrunners, its growth potential is vast. With appropriate policies, investments, and strategic alliances, India can establish itself as a global center for automotive innovation. Embracing Industry 4.0 technologies will not only improve productivity and sustainability but also help the sector achieve enduring resilience and success in the international market.

REFERENCES

[1] D. Smolka and Z. Papulová, "Industry 4.0 technologies implementation in the automotive sector," *Human Interaction & Emerging Technologies (IHIET 2023): Artificial Intelligence & Future Applications*, 2023. [Online]. Available: https://doi.org/10.54941/ahfe1004101.

[2] M. Prause, "Challenges of Industry 4.0 technology adoption for SMEs: The case of Japan," *Sustainability*, vol. 11, no. 20, p. 5807, 2019. [Online]. Available: https://doi.org/10.3390/su11205807.

[3] A. S. Sitar, V. Dimovski, and K. Ljubi, "Investigating challenges to Industry 4.0 technology transition in automotive and mobility industries from multi-stakeholder perspective," in *2023 IEEE 28th International Conference on Emerging Technologies and Factory Automation (ETFA)*, 2023, pp. 1–4. [Online]. Available: https://doi.org/10.1109/ETFA54631.2023.10275634.

[4] M. Khanna, H. J. S. Sidhu, and R. Bansal, "Industry 4.0: A study of India's readiness as preferred investment destination in automotive and auto-component industries," in *2020 Sixth International Conference on Parallel, Distributed and Grid Computing (PDGC)*, 2020, pp. 557–560. [Online]. Available: https://doi.org/10.1109/PDGC50313.2020.9315751.

[5] A. Raj, G. Dwivedi, A. Sharma, A. B. L. S. Jabbour, and S. Rajak, "Barriers to the adoption of Industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective," *International Journal of Production Economics*, vol. 224, p. 107546, 2020. [Online]. Available: https://doi.org/10.1016/j.ijpe.2019.107546.

[6] M. M. Ali, "Emerging prospective of Indian livestock: A study on poultry industry," *Asian Journal of Managerial Science*, vol. 4, no. 1, pp. 33–39, 2015. [Online]. Available: https://doi.org/10.51983/ajms-2015.4.1.1171.

[7] S. A. Suha and T. F. Sanam, "Challenges and prospects of adopting Industry 4.0 and assessing the role of intelligent robotics," in *2022 IEEE World Conference on Applied Intelligence and Computing (AIC)*, 2022, pp. 524–529. [Online]. Available: https://doi.org/10.1109/AIC55036.2022.9848946.

[8] T. Menkhoff and G. Surianarayanan, "How Singapore's manufacturing small and medium size enterprises embrace Industry 4.0," *Human Aspects of Advanced Manufacturing*, 2023. [Online]. Available: https://doi.org/10.54941/ahfe1003516.

[9] S. S. Azrot, B. Singh, and I. A. Khan, "Industry 4.0 implications for industries-academia collaboration in India," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 2022. [Online]. Available: https://doi.org/10.46254/in02.20220335.

[10] L. P. Singh, "An investigation into work postures of workers engaged in casting industry: A study in India," *Asian Journal of Managerial Science*, vol. 1, no. 1, pp. 17–22, 2012. [Online]. Available: https://doi.org/10.51983/ajms-2012.1.1.1099.

[11] F. Arcidiacono, A. Ancarani, and D. Mauro, "Where the rubber meets the road: Industry 4.0 among SMEs in the automotive sector," *IEEE Engineering Management Review*, vol. 47, no. 3, pp. 86–93, 2019. [Online]. Available: https://doi.org/10.1109/EMR.2019.2932965.

[12] P. Sundari and M. Ramalakshmi, "Global leaders in Industry 4.0: A comparative analysis," *Journal of Industrial Automation*, vol. 22, no. 3, pp. 78–88, 2018.

[13] M. S. Bhatia and S. Kumar, "Critical success factors of Industry 4.0 in automotive manufacturing industry," *IEEE Transactions on Engineering Management*, vol. 69, pp. 2439–2453, 2020. [Online]. Available: https://doi.org/10.1109/TEM.2020.3017004.

[14] K. Markov and P. Vitliemov, "Logistics 4.0 and supply chain 4.0 in the automotive industry," *IOP Conference Series: Materials Science and Engineering*, vol. 878, 2020. [Online]. Available: https://doi.org/10.1088/1757-899X/878/1/012047.

[15] V. Gupta, K. Saini, A. K. Garg, G. Krishan, and O. Parkash, "Comparative analysis of disc brake model for different materials investigated under tragic situations," *Asian Review of Mechanical Engineering*, vol. 5, no. 1, pp. 18–23, May 2016.

[16] P. Kumar, R. Singh, and I. P. S. Ahuja, "A framework for developing a hybrid investment casting process," *Asian Review of Mechanical Engineering*, vol. 2, no. 2, pp. 49–55, Nov. 2013.

[17] D. J. Hiran Gabriel and M. Parthiban, "A literature review on global challenges for third-party logistics (TPL or 3PL)," *Asian Review of Mechanical Engineering*, vol. 9, no. 2, pp. 27–30, Nov. 2020.

[18] M. M. Sharikmaslat and C. G. Harge, "A glance on solar drying technology: A review," *Asian Review of Mechanical Engineering*, vol. 8, no. 1, pp. 44–47, May 2019.

[19] Raghavendra and K. Aparna, "Factors influencing unified payments interface adoption among hawkers in Mangaluru: An extended technology acceptance model approach," *Asian Journal of Managerial Science*, vol. 13, no. 2, pp. 45–51, 2024. [Online]. Available: https://doi.org/10.70112/ajms-2024.13.2.4250.

[20] M. Goswami and Y. Daultani, "Make-in-India and Industry 4.0: Technology readiness of select firms, barriers, and socio-technical implications," *The TQM Journal*, 2021. [Online]. Available: https://doi.org/10.1108/tqm-06-2021-0179.

[21] A. Verma and M. Venkatesan, "Workforce implications of Industry 4.0 in the Indian automotive industry: A review," *Technology Analysis & Strategic Management*, vol. 35, no. 10, pp. 1241–1249, 2023. [Online]. Available: https://doi.org/10.1080/09537325.2021.2007875.

[22] Raghavendra and M. G., "Integrating advanced technologies in retail: A conceptual framework for enhancing consumer experience and trust," *International Journal of Engineering Technologies and Management Research*, vol. 11, no. 10, pp. 26–36, 2024.

[23] Raghavendra and K. Sheethal, "Exploring the synergies between digital transformation, environmental proactivity, and green innovation for sustainable business practices," *Asian Journal of Managerial Science*, vol. 13, no. 2, pp. 31–37, 2024. [Online]. Available: https://doi.org/10.70112/ajms-2024.13.2.4248.