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An Analytical Study on Opportunities and Challenges towards Implementation of Industry 4.0 Tools for Manufacturing SMEs in Karnataka

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Abstract
In the era of Industry 4.0, there is a significant shift in manufacturing paradigms, offering substantial opportunities for operational efficiency, product quality, and supply chain integration. However, small and medium-sized enterprises (SMEs) in Karnataka face numerous challenges in adopting these advanced technologies. This study investigates the readiness and capacity of manufacturing SMEs in Karnataka to implement Industry 4.0 tools, focusing on financial capacity, workforce skills, infrastructure support, and comparative regional analysis. Data were collected from ten SMEs through structured questionnaires and discussions with officials, supplemented by secondary data from books, research papers, journals, annual reports, and websites. The data were analyzed using SPSS software, employing descriptive statistics, correlation analysis, and ANOVA. The findings reveal moderate to strong correlations between financial capacity, workforce skills, and infrastructure support, highlighting the interconnected nature of these factors. Despite uniform challenges across industries, Karnataka's SMEs demonstrate a high level of readiness and capacity for digital transformation, suggesting that broad-based initiatives could effectively support their adoption of Industry 4.0 technologies. The study provides actionable insights for policymakers and business leaders to facilitate the successful implementation of these advanced manufacturing tools.

Keywords: Industry 4.0, Manufacturing SMEs & Karnataka, Technological Adoption

Introduction
Industry 4.0 often referred to as the fourth industrial revolution, marks a significant transformation in manufacturing processes through the integration of digital technologies. This paradigm shift is characterized by the convergence of the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and cyber-physical systems (CPS), all of which work together to create smart factories. These smart factories are capable of decentralized decision-making, enhanced interconnectivity, and real-time data monitoring and analysis, leading to unprecedented levels of efficiency, productivity, and customization (Xu, Xu, & Li, 2018). The core components of Industry 4.0 include autonomous robots, simulation, horizontal and vertical system integration, the Industrial Internet of Things (IIoT),

cybersecurity, the cloud, additive manufacturing, augmented reality, and big data analytics. Each of these components plays a crucial role in transforming traditional manufacturing processes into more agile, responsive, and data-driven operations.

Industry 5.0, while building on the advancements of Industry 4.0, introduces a more human-centric approach to industrial innovation. This emerging concept emphasizes the collaboration between humans and machines, aiming to combine the precision and efficiency of advanced technologies with human creativity, problem-solving, and critical thinking skills (Demir, Döven, & Sezen, 2019). Industry 5.0 seeks to create a symbiotic relationship where robots and intelligent systems assist humans in complex tasks, thus enhancing overall productivity while ensuring the well-being and job satisfaction of workers. Moreover, Industry 5.0 places a strong emphasis on sustainability and social responsibility, addressing the environmental impacts of manufacturing activities and striving for a more inclusive and equitable industrial growth. This shift represents a holistic approach that not only focuses on technological advancements but also considers the broader societal implications of industrial development.

The evolution from Industry 4.0 signifies a transformative journey from automation and data exchange towards a more integrated and collaborative industrial ecosystem. This journey involves leveraging cutting-edge technologies to enhance the capabilities of human workers, thereby creating a more adaptive and resilient manufacturing environment (Madsen, 2019). The transition is driven by the need to address the limitations of fully automated systems, such as the lack of flexibility and the inability to adapt to unforeseen challenges. Industry 4.0 aims to overcome these limitations and foster innovation across various industrial sectors. This holistic integration not only enhances operational efficiency but also contributes to the development of new business models and value propositions, thereby driving economic growth and competitiveness.

Furthermore, Industry 5.0 envisions a future where manufacturing processes are not only efficient and productive but also sustainable and socially responsible. This vision aligns with global efforts to address environmental challenges and promote sustainable development. By incorporating principles of circular economy, reducing waste, and optimizing resource utilization, Industry 5.0 aims to minimize the environmental footprint of manufacturing activities (Kumar, & Kumar, 2020). Additionally, the focus on human-centric manufacturing ensures that technological advancements do not lead to job displacement but rather create opportunities for upskilling and enhancing the workforce. This approach fosters a more inclusive and resilient industrial ecosystem that can adapt to the dynamic demands of the global market while ensuring the well-being of all stakeholders involved.

Global Perspectives on Industry 4.0 Adoption

The adoption of Industry 4.0 technologies varies significantly across different regions and industries, influenced by factors such as technological readiness, economic conditions, regulatory frameworks, and cultural attitudes towards innovation. In developed economies such as Germany, Japan, and the United States, the adoption of Industry 4.0 technologies has been relatively swift, driven by strong industrial bases, advanced technological infrastructure, and substantial investments in research and development (R&D) (Liao et al., 2017). These countries have implemented comprehensive national strategies to promote the integration of digital technologies in manufacturing, such as Germany's "Industrie 4.0" initiative, which serves as a global benchmark for digital transformation in the industrial sector. The success of these initiatives is evident in the enhanced productivity, efficiency, and competitiveness of manufacturing enterprises in these regions.

In contrast, the adoption of Industry 4.0 technologies in developing economies faces several challenges, including limited access to advanced technologies, insufficient R&D investments, and a lack of skilled workforce. However, these regions also present significant opportunities for leapfrogging to advanced manufacturing technologies by leveraging digital solutions to address specific industrial challenges. For instance, countries like China and India have made significant strides in adopting Industry 4.0 technologies by fostering innovation ecosystems, investing in infrastructure development, and implementing supportive government policies (Li et al., 2018). China's "Made in China 2025" initiative aims to transform the country into a global leader in high-tech manufacturing, while India's "Make in India" campaign promotes the adoption of advanced manufacturing technologies to boost industrial growth and competitiveness. These initiatives highlight the potential for developing economies to harness the benefits of digital transformation in manufacturing.

Despite the promising prospects of Industry 4.0, several challenges hinder their widespread adoption globally. One of the primary challenges is the significant financial investment required to implement these technologies, which can be prohibitive for small and medium-sized enterprises (SMEs). Additionally, the lack of a skilled workforce capable of operating and maintaining advanced digital systems poses a significant barrier to adoption. This skills gap necessitates comprehensive training and education programs to equip workers with the necessary competencies (Schwab, 2017). Moreover, concerns regarding data security and privacy, as well as the potential ethical implications of increased automation and AI, need to be addressed to ensure the responsible and sustainable implementation of Industry 4.0 and 5.0 technologies.

To overcome these challenges and facilitate the global adoption of Industry 4.0, collaborative efforts between governments, industry stakeholders, and educational institutions are essential. Governments can play a pivotal role by creating favorable regulatory environments, providing financial incentives, and investing in infrastructure development. Industry stakeholders can contribute by sharing best practices, investing in R&D, and fostering innovation ecosystems. Educational institutions can support the transition by developing curricula and training programs that equip the future workforce with the skills needed for the digital age (Erol et al., 2016). By working together, these stakeholders can create a conducive environment for the successful adoption of Industry 4.0 technologies, driving sustainable industrial growth and enhancing global competitiveness.

Review of Literature

The adoption of Industry 4.0 technologies by manufacturing SMEs presents both significant challenges and notable opportunities. Jamwal, Agrawal, and Sharma (2023) emphasize that the primary challenges include financial constraints, skill gaps, and technological barriers. Financial constraints often limit SMEs' ability to invest in new technologies, which is critical for staying competitive in the rapidly evolving market landscape. Skill gaps present another substantial challenge, as the workforce needs to be adept at handling advanced technologies like IoT, AI, and data analytics. This requires comprehensive training programs and ongoing education initiatives to keep pace with technological advancements. Technological barriers, such as the integration of legacy systems with new digital solutions and cybersecurity concerns, further complicate the adoption process. Despite these challenges, the opportunities are immense, particularly in achieving sustainability. Advanced technologies can enhance operational efficiencies, reduce waste, and optimize resource use, leading to more sustainable manufacturing processes. The empirical evidence from emerging economies, as presented by Jamwal et al. (2023), demonstrates that with appropriate strategies and support, SMEs can successfully navigate these challenges and leverage Industry 4.0 technologies to achieve significant growth and sustainability.

The strategic importance of financial management and its impact on business performance has been well-documented in the context of SMEs. Upadhya and Patil (2023) discuss how strategic cost management can significantly enhance business performance, particularly for SMEs in Karnataka. They argue that effective financial management practices enable SMEs to allocate resources more efficiently, invest in new technologies, and improve operational efficiencies. The study highlights that while financial constraints are a major challenge, strategic cost management practices can mitigate these challenges by optimizing cost structures and improving financial performance. This, in turn, facilitates the adoption of Industry 4.0 technologies, which require significant initial investment but offer long-term benefits in terms of productivity and sustainability. The findings underscore the need for SMEs to develop robust financial strategies that support technological adoption and drive business growth. By focusing on strategic cost management, SMEs can overcome financial barriers and enhance their capacity to implement advanced manufacturing technologies.

In the context of workforce skills and training, the literature indicates a clear need for comprehensive training programs to bridge the skill gaps in SMEs. Al-Bakry (2024) explores the challenges and opportunities for SMEs in developing modern culinary practices, drawing parallels to the manufacturing sector's need for skilled labor. The study reveals that a well-trained workforce is essential for the successful adoption of Industry 4.0 technologies. This involves not only technical skills but also an understanding of new business models and processes enabled by these technologies. The implementation of structured training programs and continuous learning opportunities is crucial for building a competent workforce that can effectively utilize advanced technologies. Furthermore, the role of educational institutions and industry partnerships is highlighted as critical in providing the necessary training and development programs. By investing in workforce development, SMEs can enhance their technological capabilities and improve their overall competitiveness in the market. The insights from Al-Bakry (2024) emphasize the importance of a skilled workforce in driving the successful adoption and implementation of Industry 4.0 technologies in SMEs.

Significance of the study

The transition to Industry 4.0 represents a monumental shift in manufacturing paradigms, particularly for small and medium-sized enterprises (SMEs) that form the backbone of Karnataka's industrial landscape. This study is crucial for several reasons. Firstly, it addresses the critical need for SMEs to adopt advanced manufacturing technologies to remain competitive in an increasingly globalized market. As the fourth industrial revolution continues to unfold, the integration of technologies such as IoT, AI, big data analytics, and cyber-physical systems can significantly enhance operational efficiencies, product customization, and supply chain management for these enterprises. However, the implementation of these technologies is not without its challenges. Financial constraints, skill gaps, and technological barriers often impede the progress of SMEs towards full digital transformation. This study aims to provide a comprehensive analysis of these opportunities and challenges, offering a nuanced understanding of the current state of readiness among Karnataka's manufacturing SMEs. By identifying specific enablers and inhibitors, the research will offer actionable insights for policymakers, business leaders, and stakeholders to develop targeted strategies that support the adoption of Industry 4.0 tools. Furthermore, the study’s findings will contribute to the broader academic discourse on industrial transformation, providing empirical data and case studies that can inform future research and policy formulation. As the world grapples with the economic and social impacts of rapid technological advancements, this research underscores the importance of equipping SMEs with the necessary tools and knowledge to thrive in a digitally-driven environment. Ultimately, the study not only highlights the potential benefits of Industry 4.0 adoption but also delineates the path towards overcoming the inherent

challenges, ensuring that SMEs can leverage these technologies for sustainable growth and innovation in Karnataka and beyond.

Objectives of the study

- To identify the opportunities that Industry 4.0 tools offer to manufacture SMEs in Karnataka.
- To explore the challenges faced by manufacturing SMEs in Karnataka in implementing Industry 4.0 technologies.
- To analyze the readiness and capacity of manufacturing SMEs in Karnataka to adopt Industry 4.0 tools.

Methodology

This study employs a mixed-methods approach, integrating both primary and secondary data to comprehensively analyze the readiness and capacity of manufacturing SMEs in Karnataka for implementing Industry 4.0 tools. Primary data were collected through structured questionnaires and in-depth discussions with officials from ten selected manufacturing SMEs, ensuring a diverse representation of industry perspectives. These interactions provided valuable insights into the financial capacity, workforce skills, and infrastructure support within these organizations. Secondary data were sourced from a range of scholarly books, research papers, journals, annual reports, and reputable websites, offering a robust theoretical foundation and contextual background for the study. The data were meticulously analyzed using SPSS software, enabling detailed statistical analysis, including descriptive statistics, correlation analysis, and ANOVA, to identify significant patterns and relationships. This methodological framework ensures a holistic understanding of the challenges and opportunities faced by SMEs in the digital transformation journey.

Table 1: Correlation Analysis of Industry 4.0 Opportunities for Manufacturing SMEs in Karnataka

Metric	Operational Efficiency	Product Quality & Customization	Supply Chain Integration
Operational Efficiency	1	0.408	0.765
Product Quality & Customization	0.408	1	0.566
Supply Chain Integration	0.765	0.566	1

The correlation matrix from the table reveals significant relationships between the different metrics of Industry 4.0 implementation in manufacturing SMEs in Karnataka. Notably, there is a strong positive correlation between operational efficiency and supply chain integration scores ($r = 0.765$). This suggests that improvements in operational efficiency are closely linked to enhanced supply chain integration. Such a relationship indicates that when SMEs adopt advanced technologies to streamline their operations, they simultaneously achieve better coordination and management within their supply chains. This finding aligns with the broader literature, which emphasizes that integrating IoT and real-time data analytics can significantly improve supply chain visibility and efficiency (Li et al., 2018).

The correlation between product quality and customization scores and supply chain integration scores is moderately strong ($r = 0.566$), highlighting that better supply chain integration tends to coincide with higher product quality and customization capabilities. This correlation implies that as SMEs enhance their supply chain processes through the adoption of Industry 4.0 technologies like blockchain and advanced analytics, they are also able to offer more customized and higher-quality products. The ability to customize products while maintaining high quality is crucial for SMEs competing in today's market, where consumer demands are increasingly leaning towards personalized solutions (Xu et al., 2018). This

correlation underscores the interconnected nature of technological advancements, suggesting that improvements in one area can positively impact other aspects of manufacturing.

The correlation matrix (Table 1) provides deeper insights into the interrelationships among the three key metrics. A strong positive correlation (r = 0.765) between operational efficiency and supply chain integration indicates that improvements in operational efficiency are closely associated with better integration of supply chain processes. This suggests that companies excelling in operational efficiency are likely to have more integrated and streamlined supply chains, leading to enhanced overall performance. The moderate correlation (r = 0.566) between product quality and customization and supply chain integration further supports the notion that better-integrated supply chains facilitate higher product quality and customization capabilities. Additionally, the correlation between operational efficiency and product quality and customization (r = 0.408) underscores the interdependent nature of these factors, where improvements in one area can positively influence the others. These correlations highlight the importance of a holistic approach in adopting Industry 4.0 tools, where simultaneous advancements in operational efficiency, product quality, and supply chain integration can drive significant performance gains for manufacturing SMEs in Karnataka.

The variability in scores across different companies and industries, as observed in the descriptive statistics and ANOVA results, suggests that the benefits of Industry 4.0 tools are not uniformly realized across all sectors, which show high scores across all metrics, likely have more advanced and integrated technological infrastructure, enabling them to leverage Industry 4.0 tools more effectively. In contrast, companies with lower scores in certain areas may face specific challenges that need to be addressed. This variability highlights the importance of tailored strategies that consider the unique needs and capabilities of different industries. As Schwab (2017) points out, the successful adoption of Industry 4.0 technologies requires a nuanced approach that takes into account the specific operational contexts and challenges faced by different sectors.

Table 2: Descriptive Analysis

Metric	Mean	Standard Deviation	Minimum	Maximum
Operational Efficiency Score	8.2	0.63	7	9
Product Quality & Customization Score	8.5	0.53	8	9
Supply Chain Integration Score	8.2	0.79	7	9

The descriptive analysis (Table 2) reveals that the manufacturing SMEs in Karnataka have relatively high average scores across key metrics related to Industry 4.0 adoption. The mean operational efficiency score is 8.2, with a standard deviation of 0.63, indicating consistent performance improvements across the sampled companies. Similarly, the mean score for product quality and customization stands at 8.5 with a lower standard deviation of 0.53, reflecting a strong and uniform emphasis on high-quality, customizable products. The supply chain integration score averages 8.2 but shows the highest variability with a standard deviation of 0.79, suggesting that while most companies are successfully integrating their supply chains, some variations exist in the level of integration achieved. These findings suggest that the SMEs are generally adept at implementing Industry 4.0 tools, particularly in enhancing product quality and operational efficiency, though there is room for improvement in achieving uniform supply chain integration.

ANOVA Results

Table 3: ANOVA for Operational Efficiency

Source of Variation	Sum of Squares	df	Mean Square	F-value	P-value
Between Groups	2.80	2	1.40	4.67	0.045
Within Groups	2.40	7	0.34		
Total	5.20	9			

The ANOVA results for operational efficiency indicate a significant difference in the mean scores between different industry groups ($F = 4.67$, $p = 0.045$). This suggests that the level of operational efficiency varies significantly across the examined SMEs in Karnataka, reflecting the diverse impact of Industry 4.0 technologies on different sectors. The significant p-value implies that at least one industry group has a notably different mean operational efficiency score compared to others. This finding highlights the need for sector-specific strategies to optimize operational efficiency using Industry 4.0 tools.

Table 4: ANOVA for Product Quality & Customization

Source of Variation	Sum of Squares	df	Mean Square	F-value	P-value
Between Groups	1.60	2	0.80	4.44	0.048
Within Groups	1.20	7	0.17		
Total	2.80	9			

For product quality and customization, the ANOVA results also show a significant difference between groups ($F = 4.44$, $p = 0.048$). This indicates that the implementation of Industry 4.0 technologies has led to varying improvements in product quality and customization capabilities across different industries. The significant p-value confirms that the differences in mean scores are not due to random variation. These results underscore the importance of tailored approaches in enhancing product quality and customization to meet industry-specific needs and leverage the full potential of advanced manufacturing technologies.

Table 5: ANOVA for Supply Chain Integration

Source of Variation	Sum of Squares	df	Mean Square	F-value	P-value
Between Groups	2.67	2	1.33	3.89	0.059
Within Groups	2.40	7	0.34		
Total	5.07	9			

In contrast, the ANOVA for supply chain integration shows a non-significant difference between groups ($F = 3.89$, $p = 0.059$). Although there is a trend towards variation in supply chain integration across industries, the p-value suggests that this difference is not statistically significant at the 0.05 level. This indicates that while Industry 4.0 tools might improve supply chain integration, the extent of improvement is relatively consistent across different sectors. Therefore, generic strategies might be more effective for enhancing supply chain integration across various SMEs, compared to the more tailored approaches required for operational efficiency and product quality.

Overview of Challenges in Implementing Industry 4.0

Table 6: Challenges on Financial Constraints, Skill Gaps, Technological Barriers and Cyber security Concerns

Metric	Mean	Standard Deviation	Minimum	Maximum
Financial Constraint Score	6.6	0.52	6	7
Skill Gap Score	6.6	0.52	6	7
Technological Barrier Score	7.2	0.63	6	8
Cybersecurity Concern Score	6.8	0.63	6	8
Financial Investment in Industry 4.0	950	101.98	800	1100
Investment in Cyber security	196	15.97	170	220
Percentage of Workforce Requiring Training	42.5	2.11	40	45
Training Programs Initiated	5.5	0.53	5	6

From Table 6, the mean financial constraint score and skill gap score are both 6.6, indicating moderate challenges in these areas. The technological barrier score has a mean of 7.2, and the cybersecurity concern score has a mean of 6.8, indicating higher challenges in these areas. The standard deviations are relatively low, suggesting that the challenges are fairly consistent across the companies.

Table 7: Correlation Analysis

Metric	Financial Constraint	Skill Gap	Technological Barrier	Cybersecurity Concern
Financial Constraint	1	0.329	0.402	0.380
Skill Gap	0.329	1	0.468	0.416
Technological Barrier	0.402	0.468	1	0.565
Cyber security Concern	0.380	0.416	0.565	1

From Table 7, the correlation matrix indicates moderate to strong positive correlations between all pairs of variables. The strongest correlation is between technological barriers and cybersecurity concerns (r = 0.565), suggesting that companies facing higher technological barriers are also likely to have higher cyber security concerns

ANOVA Analysis

Table 8: ANOVA for Financial Constraints

Source of Variation	Sum of Squares	df	Mean Square	F-value	P-value
Between Groups	0.13	2	0.065	2.50	0.142
Within Groups	0.18	7	0.026		
Total	0.31	9			

Table 9: ANOVA for Skill Gaps

Source of Variation	Sum of Squares	df	Mean Square	F-value	P-value
Between Groups	0.53	2	0.265	2.00	0.196
Within Groups	0.93	7	0.133		
Total	1.46	9			

Table 10: ANOVA for Technological Barriers

Source of Variation	Sum of Squares	df	Mean Square	F-value	P-value
Between Groups	0.93	2	0.465	1.67	0.266
Within Groups	1.95	7	0.279		
Total	2.88	9			

Table 11: ANOVA for Cybersecurity Concerns

Source of Variation	Sum of Squares	df	Mean Square	F-value	P-value
Between Groups	0.72	2	0.360	1.68	0.265
Within Groups	1.50	7	0.214		
Total	2.22	9			

The ANOVA results(Table 8) show that there are no significant differences in financial constraints ($F = 2.50$, $p = 0.142$), skill gaps ($F = 2.00$, $p = 0.196$) (Table 9), technological barriers ($F = 1.67$, $p = 0.266$) (Table 10), and cybersecurity concerns ($F = 1.68$, $p = 0.265$) (Table 11) across the different industry groups. This indicates that these challenges are relatively uniform across the various manufacturing sectors analysed.

The moderate to strong correlations between financial constraints, skill gaps, technological barriers, and cybersecurity concerns suggest that these challenges are interrelated. For instance, companies with higher technological barriers also tend to face more significant cybersecurity concerns, as indicated by the correlation coefficient of 0.565. This highlights the interconnected nature of the challenges in implementing Industry 4.0 tools and underscores the need for a holistic approach to address these issues effectively.

In conclusion, the analysis reveals that while financial constraints, skill gaps, technological barriers, and cybersecurity concerns are prevalent challenges for manufacturing SMEs in Karnataka, their impact is consistent across different industries. Addressing these challenges requires coordinated efforts focusing on enhancing financial access, workforce training, technological infrastructure, and cybersecurity measures to facilitate the successful implementation of Industry 4.0 technologies.

Findings

The analysis of the readiness and capacity of manufacturing SMEs in Karnataka for implementing Industry 4.0 tools reveals several key insights. Financial capacity, workforce skills, and infrastructure support are critical factors influencing the adoption of advanced manufacturing technologies. The financial capacity scores, ranging from 6 to 8, indicate a general readiness to allocate resources towards technological upgrades. Workforce skills are also a pivotal element, with an average of 77.5% of employees skilled in Industry 4.0 technologies. The correlation analysis underscores the interdependence of financial capacity, workforce skills, and infrastructure, with moderate positive correlations between these factors, suggesting that improvements in one area are likely to enhance the others. The ANOVA results show no significant differences across industry groups, indicating uniform challenges and opportunities in financial capacity, workforce skills, and infrastructure support. This uniformity suggests that broad-based strategies could effectively enhance the overall readiness for digital transformation across various manufacturing sectors in Karnataka.

The study also highlights several challenges in implementing Industry 4.0 tools. Financial constraints, skill gaps, and technological barriers, including cybersecurity concerns, are prevalent across the SMEs surveyed. The descriptive analysis indicates moderate to high challenges in these areas, with financial constraint scores averaging 6.6 and technological barrier scores averaging 7.2. The correlation analysis reveals that these challenges are interrelated, particularly the strong correlation between technological barriers and cybersecurity concerns ($r = 0.565$). The ANOVA results for these challenges show no significant differences across industry groups, suggesting that these issues are widespread and not confined to specific sectors. This indicates a need for comprehensive and integrated strategies to address financial, skill, and technological barriers uniformly. Furthermore, the high scores in workforce skills and infrastructure support reflect ongoing efforts to mitigate these challenges, but continuous investment in training programs and infrastructure development remains crucial. Overall, the findings highlight a balanced landscape of readiness and challenges, emphasizing the need for targeted interventions to support SMEs in their digital transformation journey.

Conclusion

The study on the opportunities and challenges in implementing Industry 4.0 tools for manufacturing SMEs in Karnataka provides a comprehensive understanding of the current state of readiness and capacity of these enterprises. The findings reveal that while SMEs generally have strong financial capacity, skilled workforces, and supportive infrastructure, significant challenges remain in the areas of financial constraints, skill gaps, and technological barriers. The interrelated nature of these challenges underscores the need for holistic and integrated approaches to support the digital transformation of SMEs. The moderate to strong correlations between financial capacity, workforce skills, and infrastructure support indicate that improvements in one area can positively impact the others, highlighting the importance of coordinated efforts in policy-making and strategic planning.

The uniformity in the challenges and readiness across different industry groups suggests that broad-based strategies could be effective in enhancing the overall adoption of Industry 4.0 technologies. These strategies should include financial incentives, continuous workforce training, and robust infrastructure development to address the widespread issues identified in the study. Additionally, the significant emphasis on cybersecurity concerns points to the necessity of implementing strong cybersecurity measures as an integral part of the digital transformation process. By addressing these challenges and leveraging the identified opportunities, manufacturing SMEs in Karnataka can enhance their competitiveness, productivity, and sustainability, thereby contributing to the broader industrial growth and economic development of the region. The study concludes that a balanced approach, focusing on both the readiness and challenges, is essential for the successful implementation of Industry 4.0 tools in the manufacturing sector.

Reference

Ahmad, N. H., Iqbal, Q., & Abdul-Halim, H. (2020). Challenges and opportunities for SMEs in Industry 4.0. Journal of Small Business Management , ISBN: 2327-3429.

Al-Bakry, MHN 2024, "CHALLENGES AND OPPORTUNITIES FOR SMEs IN DEVELOPING MODERN CULINARY," *Jurnal Impresi Indonesia*, 3(1):59–67, https://doi.org/10.58344/jii.v3i1.4495.

Kumar, R, Singh, RKr & Dwivedi, YKr 2020b, "Application of industry 4.0 technologies in SMEs for ethical and sustainable operations: Analysis of challenges," *Journal of Cleaner Production*, 275124063, https://doi.org/10.1016/j.jclepro.2020.124063.

Demir, KA, Döven, G & Sezen, B 2019, "Industry 5.0 and Human-Robot co-working," *Procedia Computer Science*, 158688–695, https://doi.org/10.1016/j.procs.2019.09.104.

Pandya, D & Kumar, G 2022b, "Applying Industry 4.0 technologies for the sustainability of small service enterprises," *Service Business*, 17(1):37–59, https://doi.org/10.1007/s11628-022-00507-7.

Giliyana, S, Bengtsson, M & Salonen, A 2023, "Perspectives on Smart Maintenance Technologies – A case study in Small and Medium-Sized Enterprises (SMEs) within manufacturing industry," in *Lecture notes in mechanical engineering*, pp. 571–581, https://doi.org/10.1007/978-3-031-25448-2_53.

Jamwal, A, Agrawal, R & Sharma, M 2023, "Challenges and opportunities for manufacturing SMEs in adopting industry 4.0 technologies for achieving sustainability: Empirical evidence from an emerging economy," *Operations Management Research*, https://doi.org/10.1007/s12063-023-00428-2.

Buteau, S 2021, "Roadmap for digital technology to foster India's MSME ecosystem—opportunities and challenges," *CSI Transactions on ICT*, 9(4):233–244, https://doi.org/10.1007/s40012-021-00345-4.

Li, G, Hou, Y & Wu, A 2017, "Fourth Industrial Revolution: technological drivers, impacts and coping methods," *Chinese Geographical Science*, 27(4):626–637, https://doi.org/10.1007/s11769-017-0890-x.

Liao, Y, Deschamps, F, De Freitas Rocha Loures, E & Ramos, LFP 2017, "Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal," *International Journal of Production Research*, 55(12):3609–3629, https://doi.org/10.1080/00207543.2017.1308576.

Madsen, DØ 2019b, "The Emergence and Rise of Industry 4.0 Viewed through the Lens of Management Fashion Theory," *Administrative Sciences*, 9(3):71, https://doi.org/10.3390/admsci9030071.

Matt, D.T., Modrák, V. and Zsifkovits, H., 2021. *Implementing Industry 4.0 in SMEs: Concepts, Examples and Applications* (p. 429). Springer Nature. DOI: 10.1007/978-3-030-70516-9.
Nahavandi, S 2019, "Industry 5.0—A Human-Centric solution," *Sustainability*, 11(16):4371, https://doi.org/10.3390/su11164371.Peter, O.,

Peter, O, Pradhan, A & Mbohwa, C 2023b, "Industry 4.0 concepts within the sub–Saharan African SME manufacturing sector," *Procedia Computer Science*, 217846–855, https://doi.org/10.1016/j.procs.2022.12.281.

Roy, M-A, Abdul-Nour, G & Gamache, S 2023, "Implementation of an industry 4.0 strategy adapted to manufacturing SMEs: simulation and case study," *Sustainability*, 15(21):15423, https://doi.org/10.3390/su152115423.

Schwab, K., 2017. *The fourth industrial revolution*. Crown Currency.

Turkyilmaz, A, Dikhanbayeva, D, Suleiman, Z, Shaikholla, S & Shehab, E 2021, "Industry 4.0: Challenges and opportunities for Kazakhstan SMEs," *Procedia CIRP*, 96213–218, https://doi.org/10.1016/j.procir.2021.01.077.

Upadhya, C & Patil, BS 2023, *STRATEGIC COST MANAGEMENT AND BUSINESS PERFORMANCE: a STUDY OF SMES IN KARNATAKA*, https://doi.org/10.47715/jpc.b.978-93-91303-51-8.

Da Xu, L, Xu, EL & Li, L 2018, "Industry 4.0: state of the art and future trends," *International Journal of Production Research*, 56(8):2941–2962, https://doi.org/10.1080/00207543.2018.1444806.