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Responsible Technological Transformation in Manufacturing Operations:

Balancing Technology and Innovation

> The future of manufacturing lies not in replacing humans with machines, but in designing systems where their strengths converge, combining precision with empathy and automation with human insights.

The global manufacturing landscape is undergoing significant changes in the 21st century. Both advanced and developing economies have a promising future in manufacturing, driven by a strong pipeline of innovative materials, cutting-edge technologies, advanced production techniques, and optimized manufacturing operations. These advancements create new opportunities to revitalize the industry.

Manufacturing operations have continuously evolved ever since industrialization began. After centuries of transformation, we are still in the early maturity stage of the 4th Industrial Revolution

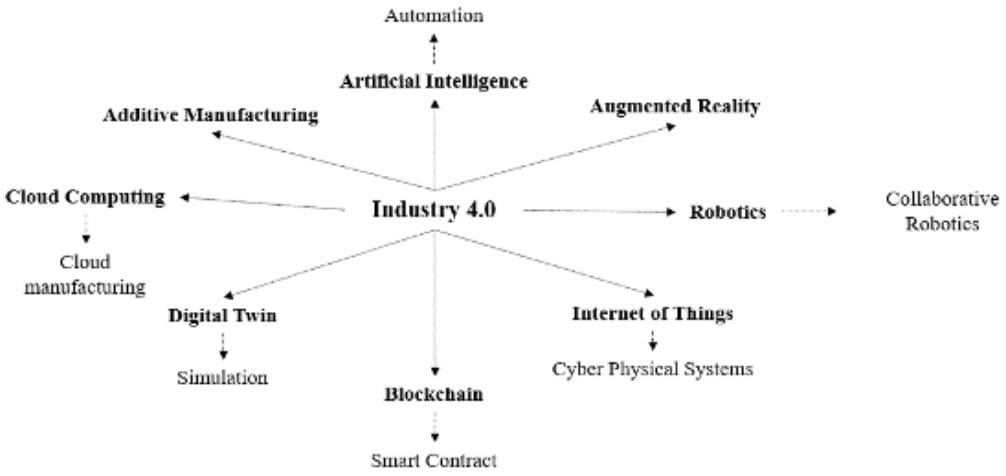

Figure 1- Main disruptive technologies & applications

(Industry 4.0), even as discussion about the transition to Industry 5.0 begins to emerge. The Sri Lankan government released their 2025 human development report in collaboration with the UNDP, titled "A Matter of Choice: People and Possibilities in the Age of AI." This report examines the paths that can be taken to advance human development in a world where disruptive technologies are thriving.

At the heart of Industry 4.0 are disruptive technologies that are reshaping manufacturing. Both academic literature and real-world applications frequently highlight key innovations such as blockchain, artificial intelligence (AI), robotics, the internet of things (IoT), additive manufacturing, digital twins, augmented reality (AR), and cloud computing [Fig. 1]. These technologies are revolutionizing manufacturing by enhancing efficiency, connectivity, and automation [1].

The integration of disruptive technologies presents significant opportunities to drive innovation, transform manufacturing processes, and enhance supply chain efficiency. In the era of rapid technological advancement, the global manufacturing sector must adapt quickly, whether by innovating, accelerating processes, or keeping pace with change. However, alongside these advancements, there are some critical concerns related to ethical applications, data privacy, environmental sustainability, and equitable access to technology.

The rapid development of AI-driven automation in manufacturing operations has exacerbated unemployment and labor replacements, particularly in low-income countries. If not handled responsibly, this may result in socio-economic inequalities, despite its potential for cost savings, smarter data-driven decision-making, and improved process visibility. In addition, blockchain can function as a means to achieve enhanced transparency in supply chains, which results in improved visibility, ethical sourcing, and sustainable operational practices. However, there have been cases where technology's unchangeable characteristics have caused data privacy concerns and led to staff layoffs by minimizing manual processes in manufacturing operations. Similarly, the improper implementation of robots in the workplace can pose safety risks and highlight the importance of responsible practices to ensure workers' safety while achieving productivity

Industry 5.0 is rapidly evolving to strike a balance between humans and machines, with increasing human concerns arising through Industry 4.0. Innovative technologies are now opening a new era of automation for manufacturers, where humans and machines will increasingly collaborate [2]. The collaboration between humans and machines in manufacturing involves a synchronized effort of both parties working towards a shared objective in the management of manufacturing operations. As a result, human-machine collaboration (HMC) has become a key driver of responsible technological transformation (RTT) in global manufacturing.

The key indicators of HMC include its involvement in the organization's decision-making process, engagement in the organization's problem-solving process, participation in the organization's information identification and evaluation process, and contribution to the recognition of organizational problems, opportunities, or risks [3]. Understanding these driving forces, particularly the role of HMC in manufacturing operations, is essential for ensuring RTT.

Recent research and industry experts indicate that embracing disruptive technologies while adhering to principles of responsible transformation positively contributes to economic growth, environmental sustainability, and social well-being. There is a lack of focused research on the multidimensional view of RTT in global manufacturing operations. Therefore, the requirement for a comprehensive framework that prioritizes RTT is becoming increasingly pertinent. This approach ensures technological transformation benefits society by considering privacy, security, equity, and environmental sustainability while fostering innovation and efficiency. It is crucial to develop and implement technology-driven frameworks that emphasize ethical practices and sustainability while enhancing the resilience and agility of global manufacturing operations. Understanding the impact of RTT on supply chain resilience and agility is essential, as these factors directly influence manufacturing performance. Supply chain resilience refers to the ability of a supply chain to withstand, adapt to, and recover from disruptions [3], while supply chain agility is the capacity to respond quickly and effectively in a rapidly changing and uncertain environment [4]. In the highly volatile landscape of supply chains and manufacturing operations, disruptions have become a significant challenge. Technology plays a crucial role in building resilient and agile supply chains to enhance a firm's performance. Research suggests that technological transformation positively influences supply chain resilience and agility and manufacturing performance. Moreover, there is a notable research gap regarding the specific effects of RTT on these supply chain factors. We must strike a balance between technology and innovation, while also giving priority to ethical standards, environmental sustainability, social well-being, and economic viability. As we move forward, maintaining this balance will be critical to long-term success in both academic and industry practices. Therefore, our study looks at how RTT affects supply chain resilience, agility, and performance by using Partial Least Squares Structural Equation Modeling (PLS-SEM) in manufacturing operations. PLS-SEM facilitates a rigorous analysis of these relationships, which is essential, as mentioned in the existing literature and industry practices, to foster sustainable, adaptive, and high-performing supply chains in an era of rapid technological advancements. The study focuses specifically on manufacturing mobility equipment in Sri Lanka, and the results are expected to be reported in upcoming publications. The University of Moratuwa research investigates the incorporation of Digital Twin technology into coconut manufacturing processes in Sri Lanka. Preliminary simulations indicate improved visibility, collaborative planning between humans and automated systems, and more agile decision-making, consistent with RTT and Industry 5.0. A human-centered approach that links technological advancement with sustainability, ethical principles, and long-term economic benefits is essential for ensuring a responsible transition in disruptive technologies. As manufacturers adopt RTT to enhance resilience, agility, and performance, they must prioritize employee reskilling, transparent governance, and innovative sustainability practices to ensure that technological progress enhances productivity without exacerbating social inequalities. Furthermore, collaboration among industry leaders, policymakers, and educational institutions can facilitate the development of regulatory frameworks and best practices that guide responsible technology adoption. By emphasizing ethical AI, sustainable automation, and equitable access to technology, manufacturers can build a resilient, adaptable, and future-oriented manufacturing operation that drives business growth while benefiting employees and society as a whole.

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