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Digital Technology Integration for Intelligent Industrial Decision-Making: An Empirical Investigation

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Abstract: *The emergence of Industry 4.0, which is characterised by the incorporation of state-of-the-art technology developments into the manufacturing sector, has resulted in significant changes to the global industrial landscape. This thorough essay explores the key ideas, cutting-edge advancements, difficulties, and potential effects of Industry 4.0 with academic clarity and rigour. It highlights how manufacturing practices are greatly impacted by cyberphysical networks, the web, the (IoT), substantial data analysis, (AI), and contemporary robotics. The impact of Industry 4.0 on businesses, employees, consumer satisfaction, society at large, and SMMEs is also examined in the paper. The research thoroughly examines upcoming challenges, including cybersecurity vulnerabilities, data privacy concerns, and the requirement to upskill workers to adapt to shifting demands. The paper concludes with predictions on likely future trends and paths that will guide Industry 4.0's ongoing development, ushering in a new era of innovative thinking and advancement in the manufacturing sector. The quick adoption of digital technologies has drastically changed how decisions are made in contemporary industrial systems. This study uses empirical research to examine how automation, intelligent systems, and data analytics might improve the effectiveness of industrial decision-making. The influence of digital technology adoption on operational performance and resource utilisation is assessed by analysing real-world industrial data. The findings show that decision outcomes are now more accurate, responsive, and sustainable. The results offer useful information to sectors looking to use smart digital solutions for wise and efficient decision-making*

Keywords: Integration of Digital Technology; Intelligent Decision-Making; Industrial Systems; Data Analytics; Automation; Smart Manufacturing; Industry 4.0

I. INTRODUCTION

Before the License Raj was implemented in 1991 and the manufacturing sector was allocated a "quota" for output targets, India's market was closed. Overproduction was punished for the Indian market, and imports from other countries were subject to high taxes that made them economically useless (Iyer, 2018). The fourth wave of industrialisation, known as Industry 4.0, has been adopted worldwide. The terms "smart manufacturing" and "advanced manufacturing" are occasionally used interchangeably with "digital transformation" (López-Robles et al., n.d.). It is projected that this development expectation, supported by financial contributions, government initiatives, and a proactive approach by private companies in India, will attract multinational manufacturing companies to expand throughout the nation and promote competition (2020). Businesses are undoubtedly racing to acquire digital capabilities in this day and age (2019). Electrification was a crucial aspect of the second industrial age (Industry 2.0), as steel, petroleum, and electricity were widely used to develop mass manufacturing.

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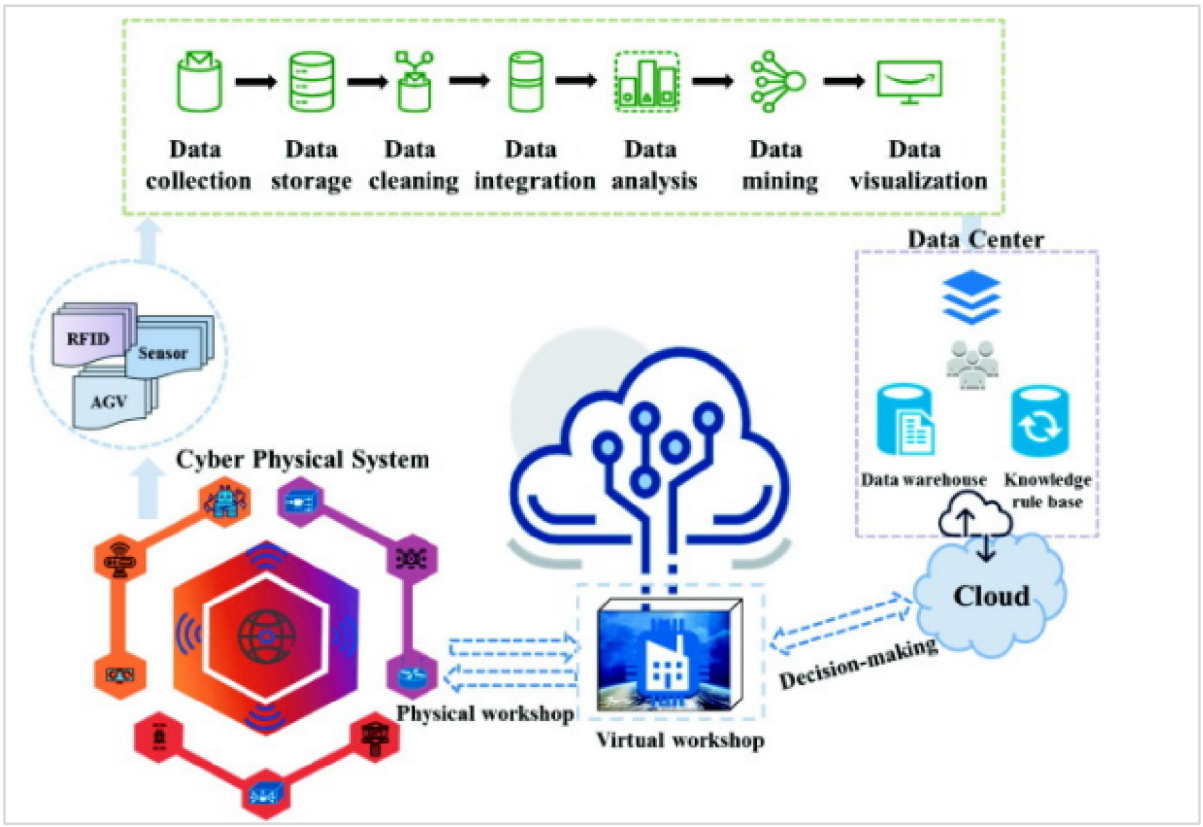

Figure 1: Industrial big data-driven technology serves as the conceptual foundation for intelligent decision-making analysis.

Industry 3.0, or the Third Industrialisation, was characterised by the employment of electronic devices in production processes and the transition to renewable energy sources. The Fourth Industrial Revolution, often known as Industry 4.0 (2020), combines technology from biology, computer technology, and physics. Industry 4.0 began appeared in the early years of the twenty-first century (2019). Cyber-physical systems, or the networking of the physical world, are its essential elements. The fourth industrial revolution is being created by a variety of digital and physical technologies, including cloud computing, augmented reality, adaptive robotics, artificial intelligence (IoT), and the Internet of Things (Ustundag & Cevikcan, n.d.). Digitalisation has changed how people connect and communicate with their surroundings in Figure 1. Computers, smartphones, self-driving cars, and wearable technology are examples of innovative gadgets and technology that have fundamentally altered how we exchange and obtain knowledge (2020). The fourth industrial revolution has begun as a result of the disruption caused by the rapid growth of technology, which is seen as a powerful catalyst for change in the modern world (2020). The term "industry 4.0," which refers to the fourth industrial revolution, was first used in 2011 during the Hannover Fair of Industrial Technologies (2020). For a more comprehensive explanation, consider that Industry 4.0 (2020) is made possible by nine technologies, or "pillars," as well as a significant shift in how manufacturing and human resource management are conducted. This fourth revolution is having a big impact on business thanks to advancements made possible by digital technologies like 5G networks, quantum computing (QC), artificial intelligence (AI), and machine learning (ML). It is changing not just how businesses operate internationally, the relationship between suppliers and customers, but also the products that are produced and what customers expect from them (2020). When we discuss digitalisation in intelligent manufacturing, we are referring to the application of the most advanced IDT, such as Additive Manufacturing, Augmented Reality, Industrial Internet of Things, and computer-assisted design (CAD), as well as Manufacturing powered by High-Performance Computing, Blockchain technology, cloud-based computing, big data analysis, and Industrial Simulation

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(2020). Saudi Arabia is still in the early stages of this transition, despite the fact that many countries are switching from analogue to digital production processes in business and services (2021). Manufacturing is viewed as a force multiplier since investments in it have a multiple effect on GDP growth. Manufacturing competitiveness is necessary to achieve balanced economic growth since it supports other economic sectors like services and agriculture while also promoting growth, employment, and productivity (2020). The foundations of a successful and competitive business are the production techniques and formulas that, notwithstanding their parallelism, yield equivalent results (2021). The definition of manufacturing is being altered by the combination of lean and I4.0, which may enhance the use of LM to identify and remove waste (2023). Multinational manufacturing businesses are expected to extend their presence throughout the country and boost competitiveness as a result of this development expectation, which is supported by government programs and funding in addition to a proactive attitude by private enterprises in India (2018). The new Industry 4.0, or I 4.0, paradigm, which enhances asset management, capital flow, forecasting, planning, decision-making, scalability, and information exchange and use, will revolutionise supply chains. The necessity for new SC architecture for Industry 4.0 has been emphasised by many who have concluded that the transition to intelligent production and SC will play a critical role in the ongoing industrial revolution (2023). In the upcoming years, the development of skilled labour with IT and technical domain expertise will be crucial to the building of measuring infrastructure, as will the digital transformation of technological and metrological infrastructure. It will be crucial to the Government of India's Atma Nirbhar Bharat (self-reliant) objective, Industry 4.0, smart cities, and Digital India (2021). Since the beginning of industrialisation, scientific discoveries, advancements, and revolutions have spurred several paradigm shifts. These were thereafter referred to as the "industrial revolutions." The emphasis has recently shifted to Technology 5.0, which seeks to enhance the current "Industry 4.0" strategy. Through research and innovation, it facilitates the shift to a human-centered, sustainable, and resilient industry (2022). The goal of this study is to determine how Industry 4.0's digitalisation components might be prioritised by India's small and medium-sized discrete manufacturing facilities and how they relate to other transformational indicators like increased productivity, quality, efficiency, and flexibility. The initiative began with a number of awareness-raising Industry 4.0 seminars hosted at various sites throughout India since SMMEs confront the initial issue of understanding what Industry 4.0 is and how those new technologies may enhance things.

II. LITERATURE REVIEW

Our environment has undergone a paradigm change from manual to automated processes as a result of the digital revolution brought about by the convergence of smart technology. In this era of computerized systems, technology convergence plays a crucial role in the creation and growth of embedded and smart systems (2021). Cities may now adapt to offer new products and streamline smart services thanks to the quick development of digital technologies. Digitization has altered how citizens and stakeholders live, work, interact, and communicate. Any data systems and processes required for service delivery are integrated with this disruptive change. However, the digital revolution presents opportunities for the development of smart cities. Managing the complexity and integration of data continues to be a difficulty for municipalities (2021). The concept of sustainability has been gaining traction among decision-makers, supervisors, and academics. Achieving equilibrium among the economy, society, an). The impact of the digital shift on business performance is examined using smart technologies. Academics, supervisors, and decision-makers are beginning to embrace the idea of long-term viability. Implementing strategic adjustments, especially with regard to the business model, is necessary to achieve a balance between society, the environment, and the economy (2021). Digitalisation is altering the corporate landscape, and companies must overcome challenges to grow. The first stage in offering support is to confirm that a business is prepared for digital capabilities and to establish clear improvement objectives. Evaluate seven companies' digital readiness with a self-check tool. To delve deeper into the data and identify the factors that promote, hinder, and facilitate digitalisation, a case study will be employed (2019). to become familiar with the principles of Industry 4.0, which is the shift in manufacturing technology and procedures towards data interchange and automation. Industry 4.0: We must immediately change and adapt how we do business. Therefore, the question that must be asked is: Are we ready for Industry 4.0? What challenges do you anticipate we'll encounter in the near future? Index Terms: Automation, Industry 4.0, benefits, and challenges (2020). The "responsible

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production and consumption" SDG number twelve is addressed by researchers, who also provide manufacturing groups with some recommendations. Research on eco-innovation (EI), digitisation (DT), and smart technologies (ST) is still lacking. Even with SDS and EI, businesses cannot achieve SSCP without DT and cutting-edge technologies. Therefore, it is recommended that managers employ DT and ST to make sure they are pursuing sustainable performance and contributing to the SDGs (2022). How a business's digital transformation can improve relationship performance and power intelligent technology. The results of a survey of 280 small and medium-sized enterprises (SMEs) in Finland show that intelligent technology and digital transformation must be coupled to enhance relationship performance. This suggests that smart technology completely mediates the relationship between relationship performance and digital change (2020). the applicability of digital maturity frameworks for assisting manufacturers of smart devices in their digital transformation journeys and provide a number of recommendations to improve the tool's usability in this specific scenario. This is accomplished by applying several design principles to the unique circumstances of smart device manufacturers by looking at a variety of seven maturity models. The model's recommendations, which are based on the most relevant findings, deal with the need for a prescriptive condition, a broad business perspective, and a greater tool scope when establishing the dimensions (2020). The creation of smart cities, the main trend in contemporary urbanisation, is based on the fourth industrial revolution. 4.0. However, Industry 4.0 technologies result in completely new "smart city" infrastructure. The management of resource consumption and energy efficiency enhancements, the organisation of urban production, and the control of population changes in megacities are all made possible by these new technologies (2019). Digital transformation is crucial to survival in the Industry 4.0 era because it makes industries more competitive and helps them to make the best choices possible at every step of their operations. Industry 4.0 and IoT have some genuine, ROI-verified benefits (Dr. N. Venkateswaran). Manufacturing companies, especially SMEs, have benefited from Industry 4.0 tools and technologies. By combining the pillars of technology tools, advantages, and constraints of their application in the manufacturing sector, the proposed model employs a multi-criteria decision support model, specifically AHP, a needs assessment framework based on the Quality Function Deployment approach (2019). To investigate the functional areas that could profit from Industry 4.0 technology and support the modernization of India's manufacturing facilities. It does this in accordance with the objectives of India's small and medium-sized discrete manufacturing enterprises (SMME) to deploy digital technology for the specified functional areas. The Indian SMME community's self-evaluation states that manufacturing and design modifications following operational measurements constitute the ideal transformation cycle (2020). The use of Industry 4.0 technology in current maintenance procedures and the resulting prospects for improvements in factory management and maintenance tactics (2020). Legislators and decision-makers are examining the potential of Industry 4.0 as a smart technology to create a green economy in order to achieve the European Greener Deal by reevaluating rules for the supply of clean energy. Industry 4.0 will eventually impact every aspect of life, but in order for a digital revolution to be sustainable, it is critical to understand the barriers to its adoption. The largest barrier to Industry 4.0 adoption among the fourteen issues mentioned is "resistance to change," which is followed by "governmental support" (2021). Since the digital transformation required by Industry 4.0 is complex and resource-intensive, small and medium-sized businesses must follow a strategic digitalisation guideline in order to succeed in the change. The current study aims to provide manufacturing medium-sized firms (SMEs) with a path for successful digital transformation with the aid of Industry 4.0. -Eleven success elements are critical to the digital transformation efforts of SMEs. For example, the findings indicated that operational technology readiness is the most challenging issue affecting SMEs' performance in their digital transformation, with outside finance for digitalisation being the first step towards accomplishing this aim (2021). Knowledge management (KM) and decision-making, KM and innovation ecosystems, KM and frontier technologies, and KM and Industry 4.0 are some of the research clusters in an organized review of literature (SLR) that describes the connections, relationships, and interdependencies between KM, DT, and Industry 4.0 (2022). The two primary factors that operate as stepping stones in the implementation of data and digital technology (IDT) of smart manufacturing are perceived benefits and managerial collaboration. It's critical to recognise and evaluate these components. The findings should aid academics, businesspeople, and legislators in developing a comprehensive understanding of the surroundings and procedures that facilitate the digitalisation of production in the Industry 4.0 era and the transformation of smart manufacturing (2020). According to Nayyar and Kumar (n.d.), Industry 4.0, or the fourth industrial revolution, is a

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compelling and significant transition in the industry as the production process becomes more digital for the current generation. The software and automotive industries may be the most equipped to adopt Industry 4.0 technology, while the construction project management industry may be the least fit, according to the study's ten firms. Professionals from each of the ten companies outline the common barriers to Industry 4.0 technology adoption. Aversion to change, unclear financial rewards, and problems with collaboration and coordination are these three typical barriers (2022). Industry 4.0 is beginning to be adopted by Indian industries. If it embraces Industry 4.0, the Indian engineering sector, which has the largest market share, has a lot of promise. The Indian engineering sector may be transformed to produce intelligent goods and services by putting Industry 4.0 into practice (2020). Industry 4.0 aims to create intelligent factories that will revolutionise manufacturing and production by utilising intelligent machines to produce intelligent and clever products. It shows that financial aid, continuing specialised skill development, and government-provided Internet connection at a reduced cost are the primary facilitators because they have a substantial driving force (2020). The Indian government's 2011 National Manufacturing Policy has been revised to include Industry 4.0 ideas. Initiatives to reorganize and boost India's manufacturing capabilities are being launched by the government and business community. There are several intriguing results from the maturity survey. The Indian SMME community's self-evaluation indicates that manufacturing and design modifications following operational measurements constitute the intended transformation cycle. They must first collect real-time machine data, analyse it, and then consider the insights obtained when making decisions regarding production and design because manufacturing and design strategies rely on performance indicators (Dutta et al., 2020a, 2020b). Investigates India's current efforts to adapt its supply chain ecosystem to smarter technology in preparation for the Fourth Industrial Revolution. With a score of 0.44 (most ready) on a scale of 0 to 1, India's preparedness is just above the world average. Government and start-up culture have been found to be significant transformation elements, even though cybersecurity, regulations, and digital infrastructure are the areas most in need of development (2023). Describe how Industry 4.0 (I4.0) technology impact lean tools using a conceptual model. Additionally, it prioritises I4.0 technologies for the digital transformation of lean factories. The findings indicate that while cyber-security and big data analytics impact 93% and 74% of the lean tools, respectively, lean manufacturing, simulation, the industrial web of things, horizontal and vertical integration, and cloud manufacturing all have an impact on 100% of the lean instruments (2023). A substantial body of research shows how industry 4.0 (I4.0) technologies gives businesses a competitive advantage and reduces disruptive emergency circumstances. Manufacturing companies must be more open about how they use I4.0 technologies to digitally transition in order to remain competitive in both routine and emergency scenarios. This study outlined the function, definition, and procedure of creating MS4.0 and offered a framework to help practitioners with the process (2023). The business improves the quality of its 4.0 performance based on the degree of significance of these variables, comprehension of these variables, and sub-factors to prioritise them. The AHP model shows that "Committed Leadership" is acknowledged as the most important organizational characteristic and is ranked highest, followed by quality culture and collaboration, which are created at a higher level. These important organisational factors and their subcategories' priority are contributing attributes (2022).

III. RESEARCH GAP

The situations covered in the preceding sections aid in the conceptualisation of Industry 4.0 in relation to Indian SMMEs. However, it was noted that the majority of earlier studies focused more on the IT representation of the relevant technology, that is, the isolated capabilities of the cutting-edge technologies that are available for both product and procedure definition, confirmation, interfacing, data generation, and data exchange. Industry 4.0 technologies should be prioritised and implemented by SMMEs. One of the primary shortcomings in the literature review is the absence of sufficient information for SMMEs to prioritise the implementation of Industry 4.0 components. In order to effect change, SMMEs must be able to identify the most important areas where Industry 4.0 technologies may be implemented and develop a comprehensive picture of the digitalised value chain throughout their businesses. It is important to recognise that every SMME is unique because of its industry, the market's prevailing forces, and the organisational values it seeks to establish and preserve. From this perspective, before implementing smart manufacturing techniques, SMMEs in particular must identify their unique process change needs and prioritise the most

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impactful areas of implementation to establish organisational preparation based on current maturity levels. The actual transformation journey, encompassing planning, short-term target selection, continuous monitoring, and action, is not well understood, despite several researches on Industry 4.0 and its benefits for business. The absence of study on the transformation process and the dynamic perspective of advantages earned during such a journey is also another significant gap identified in the literature assessment. Furthermore, it was noted that although previous international scholarly study has explored the components of Industry 4.0 and disruptive technologies, it has not adequately addressed the Indian context due to the paucity of Indian-focused research in this field. It is necessary to create a clear roadmap with success criteria in order to motivate Indian SMMEs to adopt Industry 4.0. In order to facilitate organisational transformation, it is necessary to close the labour and talent gaps. Since new skills are needed at all levels, including technical, managerial, and supervisory, manpower is a significant concern for the impending industrial revolution. Therefore, another important gap found in the literature review is the absence of an Indian setting within the body of research material currently published.

IV. METHODOLOGY

The study's recommended research methodology for understanding Industry 4.0's fundamental ideas and the potentially revolutionary effects of disruptive technologies on small and medium-sized enterprises (SMMEs) is a calculated reaction to a significant issue that Indian SMMEs face. Many of these businesses currently struggle with a lack of employees with the necessary skills, which calls for proactive steps to raise awareness of the importance of Industry 4.0 in progressing their business endeavours. These steps include aligning conceptual frameworks with Industry 4.0 requirements and conducting maturity self-assessments to identify differences between organisational values and aspirational goals. An in-depth understanding of Industry 4.0 technologies within the particular context of manufacturing enterprises, with an emphasis on Indian SMMEs, has been made possible by the existing literature research. In addition to providing a knowledge base to be shared with representatives of Indian SMMEs, this literature review has helped to raise awareness by contextualising the ongoing research on digital transformation. As a result, this program has enabled SMMEs to envision focused projects that complement their business goals. The research methodology developed for this study begins with a thorough analysis of the current literature regarding the technologies supporting Industry 4.0, intelligent manufacturing paradigms, and the current business imperatives and challenges facing Indian and international Small and Medium-Sized Enterprises (SMMEs), both now and in anticipation of future trends. This thorough review of the literature provides a comprehensive knowledge of the technological components of Industry 4.0, clarifies its implications for Indian SMMEs, points out important research gaps, and defines the parameters of the current study. This literature review's main goal is to methodically gather and compile relevant information, setting the stage for further stages of the investigation.

V. RESULT AND ANALYSIS

The results of the maturity assessment were methodically gathered, classified, and thoroughly examined in an Excel dataset, making it easier to identify broad patterns concerning the seven functional areas. To create a cohesive viewpoint on the differences between the current situation and the ambitious solutions in each of the seven functional areas, a simple methodological approach was developed. Given that the response dataset was non-probabilistic, making it impossible to draw probabilistic conclusions, these insights are crucial for directing practical actions. Digital technologies that encourage teamwork can speed up program management, which includes synthesising client requirements, creating specifications and detailed designs, closely monitoring project budgets and timelines, and successfully completing tasks within specified budgetary, temporal, and quality constraints. It appears that most Indian small and medium-sized enterprises (SMMEs) have a common goal of moving up the value chain from their current position as component producers to that of system suppliers. SMMEs hope to collaborate with an integrated manufacturing bill of process (IMBP), which outlines resource allocation and process plans in line with the final product design, in their production planning efforts. Automation of decision-making procedures, verification of robotic and CNC program implementations, and virtual commissioning of PLCs and controllers for modelling and verifying manufacturing process designs are all crucial aspects of production engineering duties. A key strategy for improving

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asset utilisation and guaranteeing optimal production output from the start is the integration of Industry 4.0 components. Additionally, the client-facing post-sales services department hopes to use the Internet of Things (IoT) for smooth integration with maintenance procedures in order to achieve customer service level agreements (SLAs) through predictive maintenance based on real-time data obtained from the field. When utilising various automation technologies and programmed machinery, such PLCs, CNC machines, and robots, there is a discernible disparity between actualisation and expectations on the factory floor. Adopting offline computing and integrating Industry 4.0 simulation components can greatly improve operational efficiency, velocity, and precision in order to close this gap. This stands in sharp contrast to the traditional method, which is based on a trialand-error methodology and is typified by computer programming or machine learning. Alternative evaluations in the field of design and production scheduling functions are another notable area where a significant aspirational shortage is apparent. In order to identify the best design solution, modern designers equip themselves with the capacity to evaluate several alternative designs using performance simulations. Alternative assessments in the industrial planning function promote process innovation. By modelling, evaluating, and validating multiple process alternatives, modern production planners select the optimal solution. Production quality, equipment utilisation, and overall efficiency all rise as a result. Indian small and medium-sized enterprises (SMMEs) are clearly inclined to prioritise the integration of connected machines, data collecting, and analytics within their Industry 4.0 adoption plan, according to the results of the maturity assessment study. The Internet of Things (IoT), cloud computing, connected machines, and big data analytics are the key components of Industry 4.0 deployment in this context. These components are made possible by thorough systems integration, design improvements, and production interventions. In order to optimise design, quality, and production processes and produce insightful data, various technologies must be integrated. Additionally, in order to maintain traceability and guarantee regulatory compliance, all functions must use digital documentation. By closely tracking both process and product costs, including change-related expenses, integrated product costing systems are essential to sustaining profitability. Precise control and increased productivity are made possible by the use of measurements for capacity and usage. Industrial technical solutions that enable flexible automation are essential for meeting the demands of a dynamic shop floor and unanticipated order variations. They improve process transparency and provide real-time monitoring and diagnostics at several stages, including machine, cell, line, and plant levels, through efficient human-machine interfaces.

Notably, these technologies detect, measure, and identify aspects that affect production efficiency, which eventually makes shop floor decision-making easier to understand and more flexible. In conclusion, these strategic priorities represent the group effort to promote Industry 4.0 adoption inside the SMME.

VI. CONCLUSION

By visualizing Industry 4.0, we hope to highlight the innovative technology, business opportunities, social challenges, and human resource needs associated with this revolutionary paradigm change. (2022). This study's objectives were to rate I4.0 technologies based on a survey of industry experts and investigate how each I4.0 digital technology influences lean tools in a theoretical framework. The MS 4.0 conceptual framework, which is a useful tool for developing a plan to integrate Industry 4.0 technologies into the manufacturing sector, is the study's primary theoretical contribution. The digital revolution of Industry 4.0 and the AI it integrates allow for the creation of Smart Factories that depend on CPPS (2021). Additionally, by simplifying the implementation of smart and intelligent technology, this framework helps to ease problems in both ordinary and emergency situations. Given India's sizable SMME population, it can be deduced from the aforementioned study that research on Industry 4.0 specifically for the country is now in the defining and awareness-raising stages. Innovation and mass customization are accelerated by Industry 4.0, which makes it necessary to assess and modify methods for particular applications. The growing pool of skilled individuals in the manufacturing workforce, which has emerged as a crucial factor in determining success in the journey towards Industry 4.0 adoption, must be appropriately taken into account in India's strategic approach. Since the current research project is an early and innovative attempt to develop a workable plan for the digitisation of manufacturing businesses through the lens of production strategy, it has significant potential to influence both the academic community and professionals in the industry. Giving Indian Small and Medium-Sized Enterprises (SMMEs) precedence in the area of Industry 4.0

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components is the main goal of this study. Eight of the eight aspects of integrating Industry 4.0 systems are disruptive technologies that can be chosen and integrated, and one has been designated as a "priority" strategic project that Indian SMMEs should undertake. Understanding the distinct organisational principles that underpin disruptive innovations is essential to their adoption and prioritisation, hence this study has also included an investigation of these principles. The conceptual nature of the proposed framework might be further clarified in light of the knowledge gained from implementing the framework. The current study identified prospects for future investigation. There are certain issues with the existing strategy that will need to be resolved in the future. Even though the evaluation survey results were clear about the maturity definitions, more investigation is needed to ascertain whether this methodology can be used more widely to assess the adoption of Industry 4.0 maturity. Factual and perceptual evaluations are also required to ascertain an organization's level of maturity. The results obtained will also validate the measures used to examine the benefits of putting Industry 4.0 components into practice. However, one of the long-term goals of the research is to standardize the maturity evaluation method. Case studies including the application of the suggested MS 4.0 framework are highly recommended for future research projects. Further research and understanding are necessary to achieve cost-effective process visibility, automated data collection, process orchestration for increased throughput, utilisation, and efficiency, and, most importantly, to identify areas of improvement both upstream and downstream that can improve business value and benefit the Indian industries. Consideration should also be given to the industry 5.0 concept, which prioritises human centricity, sustainability, and resilience (2022).

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