A Review of Manufacturing Technologies on the Industry: Categories, Integration and Impacts

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Abstract – This study examines the progression of manufacturing technology over a span of fifty years and their substantial influence on the industry. The manufacturing industry has been significantly influenced by technological advancements like 3D printing, the Internet of Things (IoT), artificial intelligence, virtual reality and Industrial Internet of Things (IIoT). These advancements have had a profound impact on manufacturing processes, resulting in many notable outcomes. Among them include the capacity to make predictions, cut down on errors, speed up operations, increase accuracy and safety, and decrease manufacturing costs. Traditional manufacturing, Intelligent manufacturing, cloud-based smart manufacturing, reconfigurable manufacturing, Internet of Things-based smart manufacturing, and flexible manufacturing are all defined in the research. Each group has its own set of benefits and challenges, which are highlighted by the remark. The study also examines the shift from conventional manufacturing to smart manufacturing, with a particular emphasis on the tactics and management procedures driven by novel concepts and potential prospects. This study examines the effects of the Fourth Industrial Revolution (4IR) on several aspects including productivity, supply chain management, efficiency, quality management, revenue growth, sustainability, employment, and energy efficiency. This research sheds light on the far-reaching consequences of manufacturing technology and the bright future possibilities for advancements in the industry.

Keywords – Internet of Things, Fourth Industrial Revolution, Industrial Internet of Things, Supply Chain Management, Smart Manufacturing.

I. INTRODUCTION

The next age of industrial development, often referred to as Industry 4.0, is anticipated to bring about enhanced production flexibility, as well as the potential for mass customization, higher product quality, and greater productivity. Therefore, it allows organizations to effectively address the difficulties associated with manufacturing goods that are becoming more customized, while still meeting tight deadlines for market release and maintaining superior quality. The integration of intelligent manufacturing is of significant importance within the context of Industry 4.0. Conventional resources undergo a transformation into intelligent entities, enabling them to perceive, take action, and exhibit behavior within a technologically advanced environment. In the manufacturing and supply chain sectors, the term "smart manufacturing" refers to the broad and intense usage of networked information-based technology. The key technological aspects include cyber-physical-workface needs, time, integrated performance measurements, and synchronization.

Smart Manufacturing is a paradigm that elicits a fundamental and significant alteration in business operations, focusing on demand-driven economics centered around customers, general public, and partners [1]. It encompasses various aspects, including extensive workforce participation, enterprise performance, demand-driven supply chain services, variability management, rapid qualification, and real-time integrated computational materials engineering. Information technology-enabled supply networks and Smart factories have the potential to enhance their responsiveness to strategic imperatives and national interests, therefore revitalizing the industrial sector. This may be achieved via the facilitation of global competitiveness and exports, the provision of sustainable employment opportunities, significant improvements in performance, and the promotion of manufacturing innovation.

The implementation of an intelligent/smart factory necessitates the integration of several elements, including man, machine, material, technique, technologies, and energy, as described in existing literature. This complete convergence model and the pursuit of continuous improvement are of utmost importance in the context of intelligent/smart manufacturing. Numerous scholars have recognized the concept of Industry 4.0 (sometimes referred to as 4IR) within various sectors, including manufacturing, pharmaceuticals, agriculture, and others. The advancements have garnered appreciation from many individuals, who have also emphasized the significant influence of the technical driver on the chain of supply. The whole potential of Fourth Industrial Revolution can only be completely actualized via their integration into the manufacturing supply chain (MSC). However, there is a dearth of study pertaining to the modern and physical aspects that constitute the core of the MSC. Prajogo and Olhager [2] have examined the integration of many technologies, including blockchain, RFID, IoT, Big Data analysis and cloud computing, within the context of supply chain and manufacturing operations.

This study will examine the effects of various manufacturing technologies, including conventional manufacturing, intelligent manufacturing, reconfigurable manufacturing, cloud-based smart manufacturing, and flexible manufacturing, , on the industry. This paper will examine the impact of these technologies on the manufacturing sector, namely in terms of cost reduction, enhanced accuracy and safety, increased operational speed, error reduction, and the ability to make prognoses. This study will further examine the merits and drawbacks of conventional manufacturing in comparison to smart manufacturing, with particular emphasis on the notion of opportunity and the incorporation of diverse systems. Furthermore, this study will analyze the effects of the Fourth Industrial Revolution (4IR) on several aspects of the manufacturing sector, including productivity, SCM, efficiency, quality management, revenue growth, sustainability, employment, and energy efficiency.

The paper is structured into the following parts. Section II presents a discussion of previous literature works on smart manufacturing and its related technologies. Section III presents a methodology employed in composing this article. Section IV focusses on the categories of manufacturing technologies, which include intelligent manufacturing, IoT-enabled manufacturing, cloud-based smart manufacturing, flexible manufacturing systems, reconfigurable manufacturing systems, and traditional manufacturing. Section V presents a discussion of the integration of the technology for innovative industries. Section VI discusses the various impacts of smart manufacturing in the current business world. Lastly, Section VII presents a conclusion to the article.

II. LITERATURE REVIEW

According to Voss [3], the field of manufacturing technology encompasses a wide range of machinery and tools necessary for the production of finished goods. These tools span from basic handheld devices, such as lathe machines, grinders, and milling machines, to advanced computerized numerical control (CNC) machines and other complex equipment. Naturally, the manufacturing process encompasses several procedures that need detailed examination. Notable examples include casting, forging, alloying, welding, soldering, and brazing, among others. Each of these strategies has distinct benefits and limits, constituting specialized domains of knowledge in their own respective fields.

According to Lee, Bagheri, and Kao [4], term "Industry 4.0" refers to the process of adopting new systems that integrate physical and digital technology in order to link a growing number of engaged consumers. The first mention of the Fourth Industrial Revolution (4IR) can be traced back to a scholarly study published in 1985 by Syam and Sharma [5]. In this work, Rostow used the Kondratieff Cycle and long-term cyclical patterns in activities that enhance resources to explore the significance of the 4IR. The adoption of this project took place in November 2011 as part of the 2020 High Technology Plan. The German government has embraced it as a strategic effort [6].

According to Wan et al. [7], the advancement of Fourth Industrial Revolution (4IR) developing technologies is anticipated to provide novel prospects for the growth and development of emerging economies. There will be an improvement in both the quality of life and per capita income. Numerous scholarly investigations have been undertaken to examine the economic and societal implications of the 4IR on industrial sustainability, lean management systems in manufacturing, the development of industrial products, industrial production control, and the measurement of industrial performance management and global value chains. These studies aim to explore the various impacts of these subjects within the academic realm. According to Weking, Stöcker, Kowalkiewicz, Böhm, and Krcmar [8], the 4IR is expected to facilitate more collaborations via the use of digital platforms. This development is anticipated to provide an equitable environment for developing economies to collaborate in managing their resources supply chain and asserting their sovereignty.

According to Chakrabarti and Singh [9], the advent of Industry 4.0 engenders a comprehensive revolution including cultural and operational aspects. By integrating and establishing connections among people, information, and resources, one may unlock a vast array of possible enhancements and efficiencies. **Table 1** presents the instances whereby Industry 4.0 technologies are enhancing efficacy, transparency, and environmental responsibility within the realm of manufacturing and supply networks.

According to Li, Liang, and Wang [17], the notion of smart manufacturing encompasses a wide range of applications and technologies. The primary enabling technologies included under the realm of IoT are big data, embedded systems, cloud computing, and wireless sensor networks. Furthermore, this idea encompasses enhanced methodologies or procedures that may be used to adjust the industrial process, hence mitigating emissions and enhancing efficiency. The objective of smart manufacturing is to optimize factory profitability, mitigate the occurrence of accidents, and attain emission-free production processes. The fundamental framework of smart manufacturing encompasses many key components, including machinery, resources or facilities, cloud computing, a communication network, and control or monitoring interfaces.

According to Chan and Childress [18], machines engage in the transmission of information, while sensors facilitate the transmission of signals across the network to the cloud during their operational state. Data on the cloud undergoes concurrent analysis using information technologies or machine learning, after which the outcomes or forecasts are sent to terminals to facilitate decision-making. In this procedure, the manufacturing is improved in order to get high efficiency and performance. In addition to optimizing output, the operational parameters of each machine are continuously monitored, enabling the prediction of probable failures or faults in the cloud. This allows managers to proactively make modifications to the facility, therefore reducing the risk of accidents and minimizing energy wastage.

Table 1. Instances where I4.0 technologies enhance efficacy, transparency, and environmental responsibility in smart manufacturing

Scenario	Explanation	Literature
Collaborative Design Platforms	Industry 4.0 promotes the creation of collaborative design platforms to make it easier for stakeholders, product designers, and R&D teams throughout your organization to share design data and insights.	Stelzle, Jannack, and Noennig [10]
Predictive maintenance	Using data analytics and IoT, factories can track the condition of their machines in real time. In order to decrease downtime by as much as 50 percent and increase asset lifetime by as much as 40 percent, predictive maintenance algorithms may help you anticipate probable breakdowns.	Su and Huang [11]
Supply chain optimization	With the help of Industry 4.0, you can see your whole global supply chain from beginning to finish. Logistics can be optimized, supply and demand balanced, orders fulfilled more quickly, and manufacturing efficiency increased with the use of customer demand, real-time data from suppliers, production schedules, inventory levels, internal teams, and much more.	Junge [12]
Agile manufacturing	Real-time consumer insights and feedback from channels like as customer care, online reviews, and social media encounters may be gleaned with the use of artificial intelligence and sophisticated analytics.	Cheng, Harrison, and Pan [13]
Quality Control and Defect Detection:	With the help of IoT sensors and machine learning algorithms, you can monitor your manufacturing processes in real time. Businesses can stay on top of product quality by monitoring every stage of the manufacturing and production process in order to spot any deviations, pinpoint the source of any quality concerns, and implement immediate fixes.	Wang, Yang, and Moghaddam [14]
Circular Economy Practices	Circular economies, which aim to minimize waste while boosting material reuse, refurbishing, and recycling, are promoted by Industry 4.0. Big Data analytics and IoT networks enable the tracking of product lifecycles, implementation of reverse logistics for product returns, and optimization of the recovery of priceless resources.	Ünal, Urbinati, and Chiaroni [15]
Carbon Footprint Monitoring and Optimization	With the use of Industry 4.0 tools, businesses can monitor their carbon footprint in real time by tracking their energy use, transportation emissions, and other metrics.	Lai [16]

This study will examine the influence of several manufacturing technologies, including conventional manufacturing, intelligent manufacturing, reconfigurable manufacturing, flexible manufacturing, and IoT-based smart manufacturing, on the industry. This article will analyze the effects of these technologies on the manufacturing industry, namely in the areas of lowered prices, better precision and safety, accelerated operations, fewer mistakes, and forecasting capabilities. Focusing on the idea of opportunity and the inclusion of varied systems, this research will go on to compare and contrast traditional manufacturing with intelligent manufacturing. Additionally, this research will examine how the Fourth Industrial Revolution (4IR) has influenced a variety of metrics pertinent to the manufacturing industry, such as output per worker, revenue growth, employment, sustainability, energy efficiency, quality management, and supply chain management.

III. RESEARCH METHODOLOGY

Each piece of literature that was uncovered was evaluated using a systematic literature review methodology. This method employs theoretical synthesis within a certain subject and its relevant subfields to promote the enrichment and consolidation of knowledge. A search was used to kick off the process of review. Only one publicly available database, Google Scholar, was searched for this study. "Autonomous car," "supply chain" and "manufacturing," were the terms used in the inquiry. Combinations such as "additive manufacturing" and collaborative" and "supply chain" and "IoT and "advanced robotics "and "IIoT and supply chain" and "manufacturing" and "supply chain and manufacturing" and "manufacturing" and "AI /deep learning" was renamed "logistic 4.0" in certain sections of the probe, and terms like "cloud manufacturing and big data "were considered in this article.

Subsequently, a comprehensive examination of the literature discovered during the search was conducted. The results derived from the comprehensive analysis were simply described and effectively communicated. During the process of doing the literature search, the investigation focused on three topics simultaneously. The subjects under discussion include the individual enablers, conventional manufacturing, and supply chain management that have been emphasized in the research report. Subsequently, the focus of the investigation was restricted to the MSC, while maintaining all other search criteria. The selection of articles was refined by excluding internet pages and book chapters. Therefore, the findings were restricted to review papers, published publications, articles in press, and conference proceedings. The examination of the conclusion and abstract sections of each article enabled the confirmation of relevance and the prevention of duplication. Consequently, a definitive compilation of publications was generated for the purpose of the review, with a specific emphasis on the correlation between the MSC and enabling technologies.

IV. MANUFACTURING TECHNOLOGIES CATEGORIES

The field of manufacturing is dedicated to the development of economic capabilities that effectively address client demands, while concurrently enhancing efficiency, performance, and delivery within a given society. Manufacturing may be described as the process of enhancing the intrinsic value of raw goods by means of labor, equipment, chemicals, formulation, or biological processes, hence augmenting their worth prior to their sale. The practice of manufacturing has its origins in ancient civilizations; however, notable progress and shifts have shaped the evolving dimensions of manufacturing in the last fifty years. Advanced technologies such as 3D printing, artificial intelligence, IIoT, virtual reality, and the IoT have significantly influenced the manufacturing industry. The significant increase in data volume and storage capabilities has played a crucial role in reducing manufacturing costs, facilitating accuracy and safety measures, enhancing operational efficiency, decreasing mistakes, and enabling predictive analysis. There are six distinct categories within the realm of manufacturing: intelligent manufacturing, IoT-enabled manufacturing, cloud-based smart manufacturing, flexible manufacturing systems, reconfigurable manufacturing systems, and traditional manufacturing.

Intelligent Manufacturing

Intelligent manufacturing, commonly referred to as smart manufacturing, encompasses a comprehensive framework for product transactions and enhancing production via the use of sophisticated manufacturing and information technology. The aforementioned concept is widely recognized as a novel manufacturing paradigm that relies on technology and intelligent science to significantly enhance the many aspects of a typical product's life cycle, including production, design, management, and integration. Various data analytics, smart sensors, intelligence devices, sophisticated materials, and adaptive decision-making models may be used to effectively support the full product life cycle. According to Zhong, Xu, Klotz, and Newman [19], there will be enhancements in service level, product quality, and production efficiency.

The capacity of a manufacturing business to effectively navigate and adapt to the dynamic and volatile nature of the global market may significantly boost its competitiveness. One manifestation of this notion is the IMS, which is regarded as the manufacturing systems' next generation achieved via the incorporation of novel models, structures, and techniques to convert the conventional manufacturing system into an intelligent system. In the framework of Industry 4.0, a service-oriented architecture (SOA) that makes use of reconfigurable services to end-users, adaptability, customization, and the Internet to enable cooperative working environments is used by an Intelligent Manufacturing System (IMS). This facilitates the establishment of a deeply integrated manufacturing system that combines human and machine capabilities.

The primary objective of this extensive integration of human-machine collaboration is to create a cohesive ecosystem encompassing the many components of Intelligent Manufacturing Systems (IMS). This integration facilitates the smooth amalgamation of organizational, managerial, and technological aspects at multiple levels. One instance of IMS may be seen in the Festo Didactic cyber-physical factory, which provides technical education and certification to major suppliers, schools, and universities as a component of the strategic effort known as Platform Industry 4.0, initiated by the German government [20].

Artificial intelligence (AI) plays a crucial role inside an Intelligent Management System (IMS) by offering fundamental capabilities like decision making, reasoning, and learning. The use of artificial intelligence technology has the potential to reduce human participation in an intelligent management system. One illustration of this concept is the automated arrangement of materials and production compositions, along with real-time control and monitoring of production processes and manufacturing activities. The increasing acknowledgment of Industry 4.0 will eventually lead to the realization of autonomous sensing, intelligent decision-making, intelligent interconnecting, and intelligent learning analysis. An instance of an intelligent scheduling system has the capability to schedule tasks by using artificial intelligence approaches and problem-solving algorithms. Furthermore, this system may be made available to other users as a service via an Internet-oriented platform.

IoT-Enabled Manufacturing

The type of intelligent manufacturing is predicated upon the real-time collection and dissemination of data among personnel, machinery, and associated tasks. The use of RFID is imperative for the purpose of data collecting. RFID readers and tags are strategically integrated inside the infrastructure of retail establishments, assembly lines, and industrial machines. These devices provide prompt, precise, and reliable data on dispersed manufacturing resources, as well as fast detection of any disruptions occurring inside the structure and its various floors. In a similar vein, machine layer, workshop floor layer, and the manufacturing system layer are interconnected, facilitating the seamless flow of real-time production information. This availability of data enables informed decision-making for optimizing the manufacturing system.

Cloud-Based Smart Manufacturing

Manufacturing that is based on the cloud is a paradigm that encompasses several modern manufacturing technologies, such as networked and decentralized systems. These technologies provide computing capabilities and service-oriented frameworks to support manufacturing processes. The integration of intelligent computing, IoT, and virtualization further enhances the capabilities of these technologies. Cloud-based manufacturing, sometimes referred to as a service-oriented and knowledge-based manufacturing system, effectively runs by using cloud computing technology. The use of cloud-based smart manufacturing has shown its advantageous impact in the domains of health care, robotics, and blockchain. In order to operate effectively, Cloud-based smart manufacturing equipment must include a context-aware metering system, intelligence, and connectivity. The cloud-based smart manufacturing architecture has three levels, namely cloud servers, local servers, and physical resources. The local and physical servers, including both software and hardware components necessary for the production process, are interconnected with the industrial network. In contrast, the cloud servers used in this context are reliant on internet connectivity and are situated external to the physical confines of the smart factory. Cloud-based smart manufacturing offers many advantages, including enhanced flexibility, improved cost-efficiency, and increased product scalability.

Flexible Manufacturing Systems

Flexible manufacturing processes (FMS) include the ability of production facilities to effectively manage uncertainty by enabling the modification or, in some instances, the reversal of choices taken in preceding periods. After customers have communicated their information requirements, organizations may modify their operations to align with future production demands. The system's capacity for resilience enables it to adapt in response to any changes. Modifications may manifest as stringent operational prerequisites, a reduction in the lifespan of the product, the redistribution of capacity to an alternative manufacturing procedure without the need for equipment substitution or significant retooling, and an expansion in the assortment of items provided.

Continuous flexible manufacturing is made possible by the use of intelligent sensors, which provide the essential data required for the implementation of the self-optimization procedure. The capacity to adjust to fluctuating circumstances is facilitated by the ongoing execution and self-improvement of operations in relation to factors such as effectiveness, accessibility, energy use, dependability, adaptability, and computational demands. The system is overseen by workers who possess advanced skills, and they are responsible for ensuring that problem-solving abilities are effectively used to autonomously handle any system failures. Additionally, these workers supervise the process of machine and robot renewal. One of the primary benefits of FMS is its capacity to effectively control and coordinate time, machinery, and robotics in a highly adaptable manner. Additionally, it has the capability to provide bulk customization and enhance demand response.

Reconfigurable Manufacturing Systems

These systems integrate the advantages of specialized production lines with flexible manufacturing systems (FMS). The term “Reconfigurable manufacturing systems” is formally defined as follows: The initial design of an RMS incorporates the ability to undergo swift modifications in its structure, hardware, and software components. This enables the system to promptly adapt its production functionality and capacity for a specific group of parts, in response to unforeseen shifts in market conditions or regulatory demands. The RMS exhibits six fundamental characteristics, which are succinctly outlined in **Table 2.** The six fundamental qualities of Reconfigurable Manufacturing Systems (RMS) serve to decrease the duration and expenses associated with system reconfiguration, thus augmenting the responsiveness of the system. Currently, these technologies are extensively used in several sectors such as the automobile, aerospace, and food and beverage industries inside the United States.

The RMS principles are developed with the help of RMS's primary characteristics. The following are some of the guiding concepts of RMSs (Resource Management Systems): 1) Scalability, or the ability to meet growing demand, should be built into the production system from the start. 2) The manufacturing system has to be flexible enough to produce new goods for consumers. Thirdly, the production systems should contain optimal integration of product quality inspection to improve diagnostic capabilities. 4) A product family should act as a foundation for the manufacturing system's layout, allowing for bespoke production. Reorganizing processes and reassigning jobs to machines are two ways to boost system productivity, which brings us to point number five. Maximizing machine uptime and system output requires the use of best maintenance practices.

The first four guidelines focus on methodologies for system design that use the characteristics of “modularity” and “integrability” to aid in the creation of cost-effective solutions. Each machine serves as a component in the larger system, and they all work together via the utilization of gantries and conveyors. concepts 5 and 6 include system operating concepts that aim to enhance both the productivity and dependability of the system. at accordance with Principle 5, the ERC-RMS developed system-balancing software which was deployed at 22 manufacturing facilities operated by General Motors and Chrysler, resulting in significant cost reductions [21]. As an example, Mr. Brian Harlow, Vice President of Chrysler, said that the use of the ERC-RMS line-balancing software resulted in a noteworthy reduction of 10% in the operational expenses associated with engine assembly lines at the Mac Avenue Engine Plant in Detroit. This achievement has considerable importance. Mathematical definitions have been presented in the literature to describe the essential aspects of the RMS, with particular emphasis on scalability, convertibility, and an integrated multi-attribute reconfigurability index. The design of various types of RMS, including as material handling systems, machining systems, assembly systems, and fixturing systems, incorporates a range of features and principles (see **Table 2**). This is achieved via the use of diverse techniques and models.

Table 2. Core features of RMS

Characteristics	Integration	Literature
Integrability (interfaces for rapid integration)	The speed and accuracy with which modules may be integrated via hardware and software interfaces	Chen et al [22]
Scalability (design for capacity changes)	Adaptability is "the capacity to transform the capacity of production by adding, withdrawing, or adjusting resources and/or system components."	Holmes and Rahe [23]
Convertibility (Adaptive Functionality Design)	Adapting preexisting infrastructure and machinery to meet emerging needs in production	Mayers [24]
Diagnosability (plan with diagnostics in mind)	The capacity to monitor product quality in real time and pinpoint the sources of any defects found	Smircich [25]
Customization (Family-member-only adaptability)	Customizable adaptability within a component family achieved via system or machine flexibility	Kotha [26]
Modularity (modular components)	The division of work into manageable chunks that can be switched around between various production models.	Jones, Keating, and Porter [27]

Traditional Manufacturing

In conventional manufacturing, there is a clear segregation of automated procedures, which results in the need for frequent human interventions to facilitate the transitions between different stages. Due to the absence of interconnectivity among machines and across the process of entrepreneurship, human interventions within the manufacturing sector are required to analyze disparate datasets and provide reports in order to detect issues and find possible avenues for improvement. Traditional industrial applications have a disconnected nature. According to Kumar, Zindani, and Davim [28], conventional manufacturing methods lack the capacity to effectively monitor and regulate automated processes, as well as provide enough functionality, scalability, sophisticated production capabilities, and efficient connection with demand and supply chains. The ramifications of adhering to conventional manufacturing practices on a substantial level include the closure of factories, implementation of decreased work hours, diminished output and demand, disruption of supply material networks, and eventual closures. The practice of reusing the same system is unattainable within the realm of conventional production.

The typical production line is characterized by a widespread occurrence of recurring malfunctions in older instruments, leading to an escalation in maintenance expenses. Within this particular system, there exists a restricted level of visibility pertaining to the operating systems and data related to productivity. One example of a conventional manufacturing method is the DMS, which involves the development of a specialized production structure that is tailored to efficiently produce a certain product. The DMS (Document Management System) is not specifically designed to effectively address diverse requirements and unexpected surges in demand.

V. INTEGRATION FOR INNOVATIVE INDUSTRIES

The advent of the Fourth Industrial Revolution (4IR) has precipitated a notable transformation within several sectors, characterized by a change in prevailing ideas. This transition entails the abandonment of some ideas while concurrently embracing novel concepts. The fundamental strength of any intelligent manufacturing system is in its capacity to facilitate and enhance the integration of diverse systems, foster cooperation among different robots, and promote interoperability across companies. The aforementioned attributes indicate that the effectiveness and practicality of contemporary product development processes are not only reliant on internal company operations, but rather depend on the integration of activities across organizational boundaries. This method is widely used by enterprises worldwide.

The three primary characteristics that may be regarded as facilitating the implementation of the Fourth Industrial Revolution (4IR) are shown in **Table 3** below.

Table 3. Characteristics facilitating I4.0 application

Characteristics	Explanation	Literature
Horizontal Integration	Horizontal integration is the automatic fusion of numerous IT systems in several production phases across businesses in various locations. They could provide same or comparable services. It is ideal for horizontal integration to work on the system and the process simultaneously until the product is finished.	Dietzenbacher, Smid, and Volkerink [29]
Vertical Integration	To create a functional management system (FMS) and a reliable management system (RMS), organizations often resort to vertical integration. The goal of vertical integration is expansion via the purchase of complementary businesses, often in the supply chain or manufacturing sector. Big data, IoT, AI, and cloud computing are heavily integrated with IT and automation in vertical integration.	Robertson and Langlois [30]

End-to-End Digital Integration	A well-established value chain may support end-to-end engineering integration, which in turn can facilitate the development of individualized and automated goods and services. The sequence of events may start with a client making a request, continuing with maintenance, product submission, delivery, approval, production engineering, design, production planning, and development.	Uhlmann and Frazzon [31]

VI. IMPACT OF SMART MANUFACTURING

The emergence of the Fourth Industrial Revolution (4IR) is yielding varied impacts across several sectors within the manufacturing industry. By considering the main application areas and the existing enabling technologies that make up the ecosystem of the Fourth Industrial Revolution, its consequences may be evaluated. Several elements might potentially influence the outcome of the 4IR. The elements include production services and processes, industry dynamics, business models, governance mechanisms, market dynamics, organizational structures, as well as the social and natural environments within which enterprises function. The immediate consequences include enhanced job opportunities and social equity, expedited economic expansion, and advantages in industrial efficiency for both the sector and its broader supply chain. This section presents a comprehensive analysis of the extensive implications of smart manufacturing.

Revenue Growth (Profitability)

The impact of the Fourth Industrial Revolution (4IR) on various regions in the manufacturing sector varies significantly. The assessment of its potential effect may be conducted by an analysis of the ecosystem that underpins the Fourth Industrial Revolution, including its primary domains of implementation and the current technologies facilitating them. The impact of the 4IR may be further understood by examining many elements that contribute to its development. These variables include production services and processes, environmental considerations, business models, organizational structures, market dynamics, industry trends, and governance mechanisms. The immediate ramifications include enhanced employment prospects and economic advancement, equitable social conditions, and additional benefits in terms of industrial output for both the supplier chain and the whole firm. The following paragraphs outline the overarching effects of smart manufacturing.

Employment

Despite the proliferation of automation and robots in the realm of smart manufacturing, it is evident that workers continue to possess substantial prospects for active engagement within the production environment. It is certain that many low-skilled occupations would be rendered obsolete as a result of the 4IR. The successful implementation of the smart factory's aims and ambitions will need the expertise and contribution of a new working class. A significant number of employees will need training in modern and information technologies, artificial intelligence, data analytics, cybernetics, virtual reality, virtual reality, and Edge/Fog/Cloud computing. The imminent realization of Industry 5.0 is anticipated to be facilitated by the collaborative integration of robots and humans.

The emergence of novel business prospects for enterprises engaged in the direct or indirect advancement of intelligent technologies to generate innovative goods and services is anticipated to result in a rise in employment possibilities. It is plausible that individuals with limited skills may use this chance to progress in their professional trajectories. The use of smart technology to develop novel goods and services is anticipated to generate employment opportunities. Nevertheless, the methods by which this objective may be achieved within the context of smart manufacturing remain uncertain, notwithstanding the potential for professional progression. A method of transition from conventional to smart manufacturing may be used, which involves a stable implementation guided by change in management.

Supply Chain Management

The current approach to Supply Chain Management (SCM) is grounded on conventional practices, which have failed to effectively tackle significant challenges such as the departure of crucial suppliers and the lack of availability of necessary machine components. The exclusive dependence on the deterministic method for managing the supply chain has not produced optimal outcomes, particularly in the COVID-19 pandemic context. The observed poor performance may be attributed to the absence of a recurring pattern in social behavior patterns, rendering them unpredictable. Due to the dynamic and complex nature of the global landscape, relying just on examining exit supply networks and the choices made by forward-thinking supply chain managers is inadequate as a basis for progress. Smart manufacturing has many benefits, including the potential for cost reduction, more visibility into processes, optimization of procurement procedures, and improved flexibility, particularly within the realms of production and SCM. The term “smart supply chain” is used to describe a newly established, all-encompassing business system that includes several applications on varying scales, from internal, company-specific procedures to a worldwide network. This implementation makes use of smart methods and procedures. In smart supply chain management, the system always works to organize and improve its own processes without any human intervention. Connectivity, smart decision making, real-time communication, accurate data collection, and agile operations are just some of the major advantages of the system.

Energy Efficiency and Sustainability

Sustainability is the adoption of a strategic strategy meant to guarantee the long-term maintenance of industrial capacity and the value chain. The concept of sustainability involves the conversion of resources into commercially valuable items via the use of environmentally conscious practices. Several strategies have been implemented to enhance energy conservation and mitigate the adverse effects associated with energy use, which significantly influence society, the economy, and the environment. The potential courses of action include the implementation of energy saving measures, the promotion of sustainable practices, and adherence to the Kyoto Protocol. As shown in the preceding section, there has been a tendency to use the terms "energy conservation" and "energy efficiency" interchangeably, leading to confusion and misunderstanding. Energy conservation refers to the conscious efforts and behaviors of customers to minimize their energy use or abstain from it altogether.

Energy conservation requires little or negligible technical involvement in comparison to energy efficiency methods in order to achieve energy savings. According to Anastasi, Conti, Di Francesco, and Passarella [32], this option has been widely recognized as a highly used and economically efficient approach for enhancing energy conservation in several nations. Some straightforward examples of energy saving are actions such as switching off lamps during daytime hours, minimizing the usage of air conditioning or thermostats, and disconnecting electronic devices when they are not in use. Sustainability is often used as an alternative approach to tackle energy-related challenges. Sustainability is often defined as the capacity to use existing resources, such as water and energy, in a more efficient manner, with the aim of preventing future generations from experiencing resource depletion. Sustainable development practices include several factors, among which sustainable consumption is included as a means to attain this objective.

Sustainable development emphasizes the advancement of human civilization via conscientious economic growth while minimizing negative impacts on the natural ecosystem. As shown by Saxena, Ramaswamy, Beale, Marciniuk, and Smith [33], the United Nations (UN) has introduced SDG (sustainable development goals) as a means to guide countries towards achieving sustainability by 2030 via the implementation of sustainable development practices. This blueprint offers a more structured and comprehensive approach for nations to pursue sustainable development. The plan has a total of 17 interconnected objectives that aim to tackle the worldwide concerns. These objectives are intended to be accomplished by the 193 Member States in order to attain sustainability and guarantee inclusivity for all individuals.

Quality Management

The use of smart manufacturing processes enables the automation of production lines, hence presenting an advantageous prospect for quality monitoring. Real-time production quality entails making prompt judgments on client requests. The enhancement of quality management is facilitated by three distinct kinds of integration, namely horizontal, vertical, and end-to-end integrations. Quality control in intelligent manufacturing is achieved by the use of integrated forms, which leads to a reduced need for post-process quality inspection. The use of quality management practices leads to an increased demand for products and a reduction in the period that goods remain in the market.

VII. CONCLUSIONS

Industry 4.0 denotes a paradigm shift in industrial advancement with the objective of augmenting production adaptability, facilitating mass customization, improving product quality, and enhancing overall productivity. The process encompasses the incorporation of intelligent manufacturing and smart technology throughout the supply chain industry and manufacturing. Smart manufacturing comprises a range of applications and technology, including traditional manufacturing, reconfigurable manufacturing, intelligent manufacturing, flexible manufacturing, IoT-based smart manufacturing, and cloud-based smart manufacturing. The utilization of these technologies has substantial implications for the industry, including the decrease of costs, improved precision and safety, heightened operational efficiency, diminished errors, and the capacity to provide forecasts. The Fourth Industrial Revolution (4IR) has the capacity to rejuvenate the industrial sector via the facilitation of global competitiveness, exports, sustainable job prospects, substantial enhancements in performance, and the promotion of manufacturing innovation. The aforementioned phenomenon presents innovative opportunities for the advancement and expansion of developing economies, hence enhancing both the standard of living and the income per individual.

The incorporation of intelligent manufacturing technologies, like AI, big data, cloud computing, and IoT facilitates the enhancement of production processes, the refinement of decision-making capabilities, and the augmentation of operational efficiency. The system provides assistance for several academic areas such as carbon footprint monitoring and optimization, collaborative design platforms, circular economy techniques, predictive maintenance, quality control, agile manufacturing, and supply chain optimization. Nevertheless, the adoption of smart manufacturing also gives rise to several obstacles. These include the need for a novel labor force equipped with proficiency in information and digital technologies, the possibility of job displacement, and the uncertainty surrounding the mechanisms for effectively integrating robots and people. In general, smart manufacturing has the capacity to fundamentally transform the manufacturing sector, resulting in heightened revenue expansion, enhanced operational effectiveness, and augmented productivity. Additionally, it provides prospects for the promotion of sustainable development, enhancement of energy efficiency, and implementation of quality management. However, it is essential to engage in thorough analysis and strategic preparation in order to effectively tackle the obstacles and facilitate a seamless progression toward the Fourth Industrial Revolution.

Data Availability
No data was used to support this study.

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