# Chapter 2
# Smart Manufacturing: A Review Toward the Improvement of Supply Chain Efficiency, Productivity, and Sustainability

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**Abstract** Smart manufacturing is an innovative approach to creating a more agile supply chain process capable of adapting to changing market demands and conditions to improve efficiency, productivity, and sustainability. These technologies successfully optimize their factories to decrease material waste, save money on equipment, supplies, and upkeep, and boost supply chain performance. Owing to these facts, this study reviewed how smart manufacturing systems make a revolution by monitoring and tracking production processes in real-time, providing manufacturers with valuable data that improved and optimized operations and reduced downtime, waste, and energy usage. This study aims to examine the existing research on the effects of smart manufacturing on developing the supply chain and to pinpoint the significant developments, problems, and possibilities in these fields. This systematic review covered how these areas' latest research and developments relinquish manual operations and embrace automation and smart technologies for supply chain transformation. The study included a comprehensive search of relevant databases following the PRISMA guidelines for reporting systematic reviews. The review critically investigated data management, privacy, security problems, and the possibilities and obstacles related to deploying these technologies in the real world. In advance, this study reappraised that smart manufacturing allows manufacturers to manage their supply chains better, reducing the time and resources required to coordinate and manage suppliers, logistics, and inventory. At long last, these reviewed data and insights will aid decision-making to reduce waste, improve productivity, and increase overall profitability in the supply chain literature.

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## 2.1 Introduction

Smart manufacturing is a rapidly evolving field that has the potential to transform the manufacturing industry by increasing efficiency, improving product quality, and reducing costs. Additionally, these organized efforts ensure a productive manufacturing environment for an effective, adaptable, and sensible supply chain (Dey et al. 2021). Likewise, supply chain mechanism enables organizations to rapidly adapt to vicissitudes in the market, consumer preferences, and emerging trends (Jawahar et al. 2020). In addition, this amalgamation ensures reducing lead times (Correia et al. 2021), increasing production speed (Chen et al. 2020), and improving delivery times, including closing ties with suppliers, customers, and partners to ensure the supply chain efficiency and effectiveness by identifying and addressing potential bottlenecks (Lin et al. 2016). So, this process comprises a combination of strategies, technologies and techniques that allow companies to respond to changes in demand and supply quickly, even in supply chain disruptions.

In addition, smart manufacturing enhances manufacturing operations (Kalsoom et al. 2020) via cutting-edge technology like artificial intelligence (AI), the Internet of Things (IoT), and machine learning (ML) with efficiency (Felstead 2019). Using advanced technologies, manufacturing systems gather and analyze vast amounts of data on production processes, equipment performance, and product quality (Ambrogio et al. 2022). With a comprehensive approach to data collection, these systems monitor every facet of the production process, from the raw materials used to the finished products produced (Alkhader et al. 2021), ultimately leading to greater profitability for manufacturers (Khan et al. 2022), even for innovation (Lin et al. 2016). As a result, these systems proactively identify potential issues and anomalies in real-time, even before they arise, as Wu et al. (2023) highlighted. As technology continues to evolve, smart manufacturing will likely become even more advanced, offering new opportunities for innovation and growth in the manufacturing sector.

Smart manufacturing enables closed-loop recycling systems, where materials are recycled and reused within the same production process (Sadeghi et al. 2022). This would reduce the need for new raw materials and minimize waste (Chien et al. 2022) while reducing the manufacturing carbon footprint (Nazir et al. 2021). To further ensure supply chain sustainability, smart manufacturing enables transparency and traceability throughout the supply chain (Kalsoom et al. 2020; Wu and Zhang 2022). This would allow consumers to track products' origin and production process, ensuring that they are ethically sourced and manufactured (Dutta et al. 2020). However, smart manufacturing transformed by producing customized products on a large scale (Adel 2022b), catering to individual customer preferences and needs by optimizing production processes and reducing energy consumption (Versino et al.

2023) despite the implementation challenges (Terry et al. 2020). Smart manufacturing technology could help ensure supply chain sustainability by reducing waste, optimizing resource usage, and enabling transparency and traceability throughout the supply chain.

## 2.2 Smart Manufacturing and Agile and Flexible Supply Chain Process

During the COVID-19 pandemic, smart manufacturing technologies enabled many manufacturers to quickly pivot their supply chain operations to produce essential medical equipment and supplies (Diaz-Elsayed et al. 2020). As a result, the company responded rapidly to changes in customer demand and reduced lead times significantly (Nazir et al. 2021). For instance, IBM improved its supply chain operations by implementing smart manufacturing technologies (Oh and Jeong 2019). The company used IoT sensors to monitor the temperature and humidity of its products during shipping, reducing the risk of spoilage (Wu et al. 2023). In contrast, AI algorithms optimize logistics operations, reducing transportation costs and improving delivery times (Shamsuddoha et al. 2023; Nath 2021). Using AI algorithms, manufacturers identify potential supply chain disruptions and plan for alternative routes or suppliers to lessen the effects of supply chain interruptions and keep business continuity. Hence, more manufacturers are embracing smart manufacturing technologies to create a more responsive and flexible supply chain.

By using these technologies, manufacturers create a more responsive and agile supply chain that quickly adapts to changes in demand or supply. For example, IoT sensors track the operation of manufacturing machinery in real-time (Tuffnell et al. 2019). This data be analyzed to identify potential issues before they cause downtime (Sadeghi et al. 2022). Similarly, machine learning (ML) algorithms optimize production schedules based on machine capacity, material availability, and customer demand (Touckia et al. 2022). Smart manufacturing faces certain limitations in terms of its flexible supply chain despite its involvement in the industry. One of the major shortcomings is the absence of a comprehensive framework that integrates all the manufacturing technologies and systems. Though various individual technologies and systems have been developed, manufacturers still require a cohesive framework that can assist them in making informed decisions regarding which technologies to implement and how to integrate them effectively. Moreover, smart manufacturing requires improved data analytics and management tools. With the exponential growth of data generated by smart manufacturing systems, there is a pressing need for advanced data analytics tools that can help manufacturers comprehend this data and utilize it to optimize their operations. Additionally, superior data management tools are essential to ensure data reliability, accuracy and security.

Table 2.1 shows that smart manufacturing uses advanced technologies like the IoT, AI and ML to automate and optimize manufacturing processes with greater

**Table 2.1** Smart manufacturing system and operations optimization

| Smart manufacturing systems | How they make revolution |
|---|---|
| Real-time monitoring and tracking (Bourke 2019; Tuffnell et al. 2019) | Smart manufacturing systems gather data from different production phases in an instantaneous fashion using cutting-edge sensors and tracking tools. They then use AI and ML algorithms to spot trends, anticipate problems, and improve processes |
| Predictive maintenance (Adel 2019; Sadeghi et al. 2022; Sun et al. 2022) | Smart manufacturing systems use real-time equipment and machinery monitoring to predict maintenance requirements and schedule necessary maintenance tasks. This proactive approach helps to minimize unexpected downtime, extend equipment lifespan, and prevent costly repairs |
| Quality control (Terry et al. 2020; Zhang et al. 2021) | Real-time monitoring allows for the immediate detection of quality issues, allowing for corrections to be made before the production process is completed |
| Resource optimization (Jha and Siano 2021; Pu et al. 2020) | For optimization of resource consumption, such as consumption of energy, water and raw material, smart manufacturing utilizes monitoring and tracking resource usage in real-time |
| Visibility (Lin et al. 2016; Liu et al. 2022) | Intelligent manufacturing systems enable real-time tracking, which facilitates inventory level optimization, minimizes wait times, and enhances the overall effectiveness of the supply chain |
| Enhanced flexibility (Dey et al. 2021; Nazir et al. 2021) | Smart manufacturing systems quickly adapted to demand or production requirements changes for more agile production processes and excellent responsiveness to customer needs |
| Automation (Bellavista et al. 2021; Kang et al. 2016; Nguyen et al. 2021) | Automation, a core component of smart manufacturing, improves efficiency and consistency in manufacturing processes, reducing lead times and increasing production speed and greater flexibility in production to adjust to changes in demand |
| Data analytics (Bourke 2019; Chung et al. 2018; Touckia et al. 2022) | Smart manufacturing generates vast amounts of data that be analyzed to identify patterns and trends to optimize production processes, identify inefficiencies, and improve the supply chain by reducing costs and increasing efficiency |

(continued)

**Table 2.1** (continued)

| Smart manufacturing systems | How they make revolution |
|---|---|
| Collaborative robotics (Adel 2022b; Butdee et al. 2022; Sun et al. 2022) | Collaborative robots or cobots work alongside humans for repetitive or dangerous tasks with a quickly reprogrammable option |
| Digital twins (Frankó et al. 2020; Nguyen et al. 2021) | Digital twins are digital representations of physical assets, such as machines or production lines to simulate production processes to reduce downtime and improve efficiency |

efficiency, flexibility, and agility in manufacturing operations and flexible supply chain process (Terry et al. 2020). However, in today's fast-paced and competitive manufacturing industry, data-driven decision-making is crucial to optimizing manufacturing operations (Liu et al. 2022). By providing manufacturers with valuable data, it is possible to make informed decisions about production schedules, inventory management, equipment maintenance, and quality control (Dzhuguryan and Deja 2021; Versino et al. 2023; Vieira 2016) and identify the root causes of defects and implement corrective actions (Jawahar et al. 2020). For instance, relevant data on inventory levels, demand forecasts, and lead times are used to optimize inventory management, such as inventory levels and demand, adjust production schedules, and reduce inventory carrying costs (Brooks et al. 2021). So, as the manufacturing industry continues to become more data-driven, the ability to analyze and use data becomes a critical factor for supply chain success.

## 2.3 Smart Technologies and Supply Chain Transformation

By embracing smart manufacturing, manufacturers possibly create a more competitive supply chain (Pu et al. 2020) and meet the demands of an ever-changing market with improved efficiency (Jha et al. 2022), reduced costs (Lei et al. 2022), and increased production speed (Alkhader et al. 2021; Bajracharya et al. 2020; Dzhuguryan and Deja 2021; Nazir et al. 2021; Wu and Zhang 2022). So, cost-saving strategies support organizations save money on equipment, supplies, and upkeep while ensuring a smooth supply chain. Leasing equipment, optimizing inventory management, purchasing in bulk, and conducting regular maintenance (Dutta et al. 2020) are just a few strategies that reduce costs and boost supply chain performance.

From Table 2.2, these ingenious technologies serve companies to boost productivity, cut expenses, and enhance overall performance by converting manual supply chain processes to automated ones. Assumably, there is a need for research into the social and environmental impacts of smart manufacturing. While the benefits of smart manufacturing are clear, there is a need to understand the potential negative effects on workers, communities, and the environment. Efficiency, productivity,

**Table 2.2** Smart technologies for supply chain transformation from manual operations to embracing automation

| Smart technologies | Description | Benefits of smart manufacturing |
|---|---|---|
| Internet of Things (IoT) (Belhi et al. 2022; Felstead 2019; Jha et al. 2022; Kamiebisu et al. 2022; Sylim et al. 2018) | Sensors and devices that collect data and communicate with each other over the internet | Real-time tracking of inventory, improved visibility into supply chain processes, reduced manual labor |
| Artificial Intelligence (AI) (Felstead 2019; Oh et al. 2019; Sun 2021; Terry et al. 2020) | Advanced algorithms that analyze data, predict outcomes and make decisions | Better demand forecasting, improved supply chain planning and optimization, enhanced decision-making |
| Robotic process automation (RPA) (Adel 2022b; Morris and Thomas 2020) | Software robots that automate repetitive tasks and processes | Increased efficiency and accuracy, reduced labor costs, improved data quality |
| Blockchain (Kashem et al. 2023; Khan et al. 2022) | A decentralized ledger that provides a secure and transparent way to track and verify transactions | Improved supply chain traceability, enhanced transparency and accountability, reduced risk of fraud |
| Cloud computing (Chung et al. 2018; Jha and Siano 2021; Pu et al. 2020) | A system of distant computers that processes, stores, and manages data | Improved scalability and flexibility, reduced IT costs, increased collaboration and accessibility |
| 3D printing (Diaz-Elsayed et al. 2020) | Additive manufacturing technology that creates physical objects from digital designs | Reduced lead times, increased customization and flexibility, improved supply chain resilience |
| Augmented reality (AR) (Sadeghi et al. 2022) | Technology that overlays digital information onto the physical world | Improved training and on boarding, enhanced visualization and communication, increased efficiency and accuracy |

sustainability, and social responsibility are key attributes of smart manufacturing that can be achieved by addressing these research gaps.

## 2.4 Methodology

The researchers conducted an open and reproducible systematic review using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) under the paradigm of narrative review. The earlier research idealized the guidelines (Kashem et al. 2022). Admittedly, the initial development of the research question pre-set the scope of the research: "*How does smart manufacturing impact supply* *chain efficiency, productivity, and sustainability?"* By using a systematic approach, searches for relevant studies that address the research question. In this case, the search would be conducted on Google Scholar and PubMed with specific search terms related to smart manufacturing, such as the technologies involved, the benefits, challenges, or implementation strategies. However, the keywords used related to smart manufacturing databases were as "smart manufacturing", "supply chain", " supply chain management", and so on. Also, the inclusion and exclusion criteria (in Table 2.3) have ensured that only relevant studies are included in the analysis.

When conducting a systematic review using the PRISMA framework, it is crucial to identify the prevailing ideologies that underpin the process. These ideologies typically include the need to develop a well-defined protocol, conduct a thorough search for relevant studies, carefully screen search results, extract relevant data, evaluate the included studies' quality, synthesize the analysis results, and interpret and report the findings clearly and concisely. The study organizes and summarizes these critical steps in the PRISMA analysis using a standardized format in Fig. 2.1, such as the one presented in Tables 2.4 and 2.5.

Figure 2.1 depicts the systematic review procedures, while Table 2.5 summarizes the findings. Studies identified through the initial search are categorized according to their relevance to the research question during the screening process. The literature review involves two stages, each of which is crucial in ensuring that only the most relevant and high-quality studies are included in the analysis. Researchers screen the titles and abstracts of potentially relevant studies and thoroughly examine the full text to determine confidently whether each study meets the rigorous inclusion criteria. In the extended format, studies are screened based on their title, abstract, and full text to ensure the analysis results are robust and meaningful. We excluded irrelevant studies and selected those that meet inclusion criteria, such as being published in a peer-reviewed journal and focusing on smart manufacturing databases. Once the relevant studies have been identified, information on the study design, methodology, results, and conclusions are reviewed. The careful and transparent reporting of the key findings and their implications in light of the relevant studies is critical to any meaningful discussion. It allows for a better understanding of the results and promotes transparency and credibility in the research process. In the end, performing

**Table 2.3** Inclusive and exclusion criteria

| Inclusive criteria | Exclusive criteria |
|---|---|
| • The study must be published in English<br>• The study must be a peer-reviewed journal article or conference proceeding<br>• The study must be related to smart manufacturing and supply chain<br>• Papers that discuss quantitative or qualitative research<br>• Papers that present empirical findings, case studies, or theoretical perspectives | • Studies that are not related to smart manufacturing or supply chain management<br>• Research that does not explicitly discuss the impact of smart manufacturing on the supply chain<br>• Research that is outdated, unpublished, or not peer-reviewed<br>• Studies that are not available in English or not accessible through academic databases |

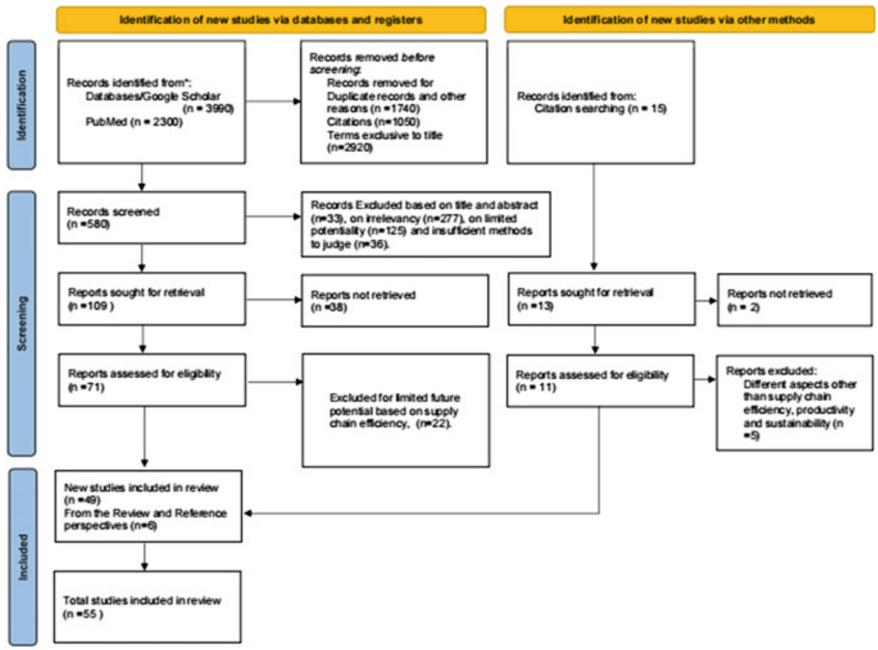


**Fig. 2.1** PRISMA flowchart

**Table 2.4** Systematic literature search and bases of inclusion and exclusion

| Keywords/search string | Search engine | No. of papers |
|---|---|---|
| "smart manufacturing" | Google Scholar | 3990 |
| "smart manufacturing" and "supply chain" | Google Scholar | 46 |
| "smart manufacturing" | PubMed | 2300 |
| "smart manufacturing" and "supply chain" | PubMed | 50 |

a PRISMA study on smart production over the supply chain gave a thorough summary of the entire research and revealed knowledge gaps that might call for more research.

## 2.5 Common Strategies for Supply Chain Efficiency, Productivity, and Sustainability

Smart manufacturing integrated advanced technologies such as AI, IoT, and cloud computing into manufacturing processes to improve operations, enhance productivity, and reduce their environmental impact by automating tasks and streamlining processes (Adel 2022a). By using robotics and AI, manufacturers automate tasks such

**Table 2.5** Summary report on PRISMA flowchart

| | |
|---|---|
| Introduction | This PRISMA flowchart provides a comprehensive guide to the steps involved in conducting a systematic review and ensures transparency and reproducibility. Numerous studies have been done in supply chain management and smart production over the years. This report analyzed the year-wise research trends in the abovementioned fields using the PRISMA flowchart |
| Search string and criteria | To conduct this study, we searched several electronic databases, including PubMed and Google Scholar. The search terms used were "supply chain," "smart manufacturing," and "smart manufacturing and supply chain." We limited our search to articles published between 2014 and 2023. After screening the titles and abstracts, we selected articles that met our inclusion criteria |
| Summary trend | After screening the articles, we identified 55 studies that met our inclusion criteria. We then analyzed the year-wise research trends using the PRISMA flowchart. The results are presented below<br>**2014–2016: 04**<br>The focus of these studies shifted towards using advanced technologies such as RFID, IoT, and big data analytics from 5 studies<br>**2017–2020: 19**<br>These studies during this period focused on various aspects of supply chain, including sustainability, resilience, agility, and customer satisfaction, inclusive to machine learning and artificial intelligence<br>**2021–2023: 32**<br>Although the number of studies during this period was relatively low, these studies focused on emerging technologies such as blockchain, digital twins, and Industry 4.0 |
| Overview | The year-wise research trend analysis using the PRISMA flowchart unwrapped that the number of studies on smart manufacturing and supply chain has been increasing steadily. The focus of these studies has also been shifting from traditional metrics to advanced technologies and emerging trends. In recent years, there has been an increase in the use of ML, AI, IoT, and big data analytics, showing a rising interest in using these technologies to improve performance |

as assembly, quality control, and material handling, reducing the need for manual labor and increasing production output (Kalsoom et al. 2020). Furthermore, smart manufacturing technologies enable manufacturers to optimize their supply chains, reducing lead times and improving responsiveness to customer demand (Oh and Jeong 2019). Finally, intending to enhance the sustainability of manufacturing operations, optimized production processes reduce waste and energy consumption, leading to a smaller environmental footprint (Vieira 2016). Additionally, these manufacturing technologies allow for the use of clean energy sources, the reduction of greenhouse gas pollution, the use of more environmentally friendly materials, and the optimization of transit paths (Correia et al. 2021). As such, smart manufacturing will play an increasingly critical role in the future of manufacturing, enabling manufacturers to meet the demands of the modern marketplace and reduce their environmental impact.

### 2.5.1 Smart Manufacturing and Supply Chain Efficiency

Smart manufacturing has revolutionized supply chain operations by improving efficiency through real-time monitoring and analysis of supply chain data (Lin et al. 2016). According to a recent study, smart manufacturing enhances supply chain efficiency, saves costs and improves customer satisfaction (Khan et al. 2022). IoT sensors and other smart technologies enable manufacturers to monitor the status of their production processes, identify bottlenecks, and make real-time decisions to optimize their operations (Sun et al. 2022). This leads to reduced lead times, increased throughput, and enhanced agility (Dutta et al. 2020). In addition, smart technologies such as IoT sensors and RFID tags are used to track products (Wu et al. 2023). So, this real-time visibility helps companies optimize their supply chain operations, reducing lead times and improving delivery performance which might be embodied in Table 2.6.

### 2.5.2 Smart Manufacturing and Supply Chain Productivity

Smart manufacturing also improves productivity by optimizing manufacturing processes and reducing waste. Smart technologies such as AI and big data analytics are used to analyze manufacturing data and identify areas where improvements can be made (Kalsoom et al. 2020). By using data to optimize manufacturing processes, companies increase throughput, reduce cycle times, and improve product quality (Sadeghi et al. 2022). For example, if a machine is experiencing a problem, smart manufacturing systems alert operators, enabling them to take corrective action immediately (Touckia et al. 2022). This reduces downtime and ensures that production runs smoothly (Dzhuguryan and Deja 2021). So, with the increasing global competition and customers' demand for faster delivery, better quality, and eco-friendliness, organizations need to continuously improve their supply chain performance (in Table 2.7).

### 2.5.3 Smart Manufacturing and Supply Chain Sustainability

Supply chain sustainability might work out for the ability of organizations to minimize their environmental impact while maintaining profitability.

As per Table 2.8, supply chains must be made more efficient, productive, and sustainable for companies to stay competitive and satisfy changing customer demands. Businesses might streamline their production processes, reduce waste, and boost product quality by utilizing clever technologies like IoT, AI, and big data analytics. Furthermore, smart manufacturing usually tracked their energy usage,

**Table 2.6** Strategies for supply chain efficiency concerning smart manufacturing

| Strategy | Details |
|---|---|
| Lean manufacturing (Jawahar et al. 2020) | Eliminating waste, cutting lead times, and enhancing the flow of materials and information throughout the supply chain are all made possible by lean production concepts |
| Technology integration (Frankó et al. 2020; Nath and Sarkar 2020) | Utilizing software for business resource planning (ERP), warehouse management systems, and transportation management systems helps to optimize inventory levels, streamline operations, and enhance collaboration throughout the supply chain |
| Demand forecasting (Chien et al. 2022; Kamiebisu et al. 2022) | Accurately forecasting demand endorses reducing inventory levels, minimizing stock-outs, and improving production scheduling |
| Supplier collaboration (Liu et al. 2022) | Collaborating with suppliers patronized to improve supplier performance, reduce lead times, and improve quality |
| Inventory management (Burmester et al. 2017; Dey et al. 2021; Kang et al. 2016) | Consolidating orders to lower the number of trips necessary to transport goods reduces numerous shipments and improves route effectiveness |
| Network design optimization (Cai 2014; Chung et al. 2018) | Evaluate the supply chain network design to ensure efficient routes between suppliers, manufacturers, distribution centers, and customers by considering the distance, transportation modes, and delivery frequency |
| Last-mile delivery optimization (Correia et al. 2021) | Focusing on optimizing the final leg of delivery to customers, alternative delivery methods such as crowdsourcing, lockers, or drones and exploring local distribution centers to reduce delivery times and transportation costs |
| Data analysis (Versino et al. 2023) | Use data analysis to identify trends and opportunities for route optimization through the factors such as order volume, delivery frequency, and transportation costs to identify areas for improvement |
| Packaging optimization (Sadeghi et al. 2022) | Evaluate packaging to ensure efficiency and maximize available space by reducing the number of shipments required and optimizing route efficiency |

(continued)

**Table 2.6** (continued)

| Strategy | Details |
|---|---|
| Routing software (Adel et al. 2022) | Utilize routing software to create optimal delivery routes based on factors such as traffic, weather, and driver availability by integrating real-time GPS data to make route adjustments as needed |
| Ensure transparency and accountability (Alkhader et al. 2021) | Establishing open communication channels and responsibility between all participants in the supply chain ensures that everyone is working toward the same objectives and that any issues are promptly identified and resolved |
| Continuously monitor and improvement (Terry et al. 2020) | Regularly review KPIs and metrics, and use this data to make informed decisions about process improvements, supplier relationships, and other areas of the supply chain that need attention |

reduced carbon emissions, and lowers their environmental footprint. Smart manufacturing will play an increasingly important role in driving innovation and growth as the manufacturing industry evolves.

## 2.6 Criticism of Emerging Technologies Issues Related to Data Management, Privacy, and Security

Emerging technologies are increasingly used in manufacturing to optimize production processes and increase efficiency. However, as with any new technology, there are concerns about its impact on data management, privacy, and security as for emerging technologies in smart manufacturing (Alkhader et al. 2021; Ambrogio et al. 2022), which are:

- *Data security breaches*: Vulnerable to data security breaches supposed to compromise sensitive data and potentially lead to significant financial or reputational damage for organizations.
- *Lack of standards*: Due to no standardized protocols or best practices for managing data in smart manufacturing systems leading to inconsistencies and errors in data management.
- *Privacy concerns*: Handling vast amounts of data about employees, customers, and products might concern the privacy and security of this data.
- *Data ownership*: Disputes and legal challenges might arise due to the ambiguity surrounding data ownership generated by smart manufacturing systems.
- *Data quality issues*: Issues with data quality, such as inconsistencies, errors, or incomplete data to function effectively.

**Table 2.7** Strategies for supply chain efficiency in smart manufacturing

| Strategy | Details |
|---|---|
| Automation (Bellavista et al. 2021; Kang et al. 2016; Nguyen et al. 2021) | Automating repetitive tasks such as order processing, invoicing, and inventory management reduces staff time for more value-added activities, resulting in increased productivity |
| Cross-functional training (Jha et al. 2022) | Providing cross-functional training to employees improves collaboration across different departments and increases efficiency |
| Performance metrics (Lin et al. 2016) | Setting and monitoring performance metrics favors identifying inefficiencies and areas for improvement, resulting in increased productivity |
| Outsourcing (Morris and Thomas 2020) | Outsourcing non-core tasks like warehouse management, logistics, and transportation boosts output by enabling businesses to concentrate on their core skills |
| Increasing inventory levels of raw materials (Dey et al. 2021) | Safety stock, economic order quantity (EOQ), lead time reduction, just-in-time (JIT), vendor-managed inventory (VMI), strategic sourcing and capacity expansion are prevalent ways to consider in this aspect |
| A top-down approach to leadership (Dzhuguryan and Deja 2021) | For leaders to be effective in supply chain productivity, engaging in various activities such as efficient communication, establishing procedural standards, prioritizing tasks, enabling the workforce, and a robust training program is worth functioning |
| Paying close attention to the workforce and empowerment (Ambrogio et al. 2022) | Regular check-ins, active listening, recognition and rewards boost employees' motivation and engagement and encourage them to continue performing at a high level |
| Big data approach in manufacturing (Nguyen et al. 2021) | It entails gathering sizable quantities of data from many areas, including sensors, machines, production systems, and other pertinent sources to better industrial processes through predictive maintenance, real-time tracking, and other methods |

- *Integration challenges*: Integration with various technologies and systems might create data management, privacy, and security challenges.
- *Lack of transparency*: Due to complexity and opaque might be difficult for stakeholders to understand how data is being collected, managed, and used.
- *Regulatory compliance*: Need to comply with a range of different regulations related to data management, privacy, and security, which be challenging for organizations to navigate.

**Table 2.8** Smart manufacturing and supply chain sustainability

| Strategy | Particulars |
|---|---|
| Green logistics (Sun et al. 2022) | Utilizing environmentally friendly transportation modes such as rail and sea freight degrades emissions and lower costs |
| Sustainable packaging (Versino et al. 2023) | Using sustainable packaging materials such as biodegradable plastics and recycled paper reduces waste and improves sustainability |
| Energy efficiency (Frankó et al. 2020) | Energy-efficient practices include using renewable energy sources, optimizing lighting and heating, and reducing energy consumption during production revamp sustainability |
| Social responsibility (Liu et al. 2020) | Ensuring that suppliers meet ethical and social responsibility standards meliorates sustainability and reputation |
| Implement environmental management systems (Jha et al. 2022) | It helps businesses identify, manage, monitor, and improve their environmental performance complying with environmental regulations and avoiding the risks of environmental incidents |
| Promote sustainable transportation (Sun et al. 2022) | Encouraging employees to use public transportation or carpooling is supposed to reduce a business's carbon footprint and even offer incentives to employees who opt for sustainable modes of transportation |
| Use eco-friendly materials (Jha et al. 2022) | Choosing eco-friendly materials for products or packaging significantly minimizes the environmental impact of a business, whereas using recycled materials and reducing packaging impact to curtail waste and improve a company's overall sustainability |
| Environmental audit and improvement (Dutta et al. 2020) | An environmental audit helps businesses identify areas where they improve their environmental performance and identify opportunities to reduce waste, energy consumption, and emissions |
| Implement sustainable practices (Jha et al. 2022) | Sustainable practices such as reducing energy consumption, recycling, renewable energy sources assist businesses in shrinking their environmental impact while saving money in the long run |
| Engage with stakeholders (Jha and Siano 2021) | This includes customers, suppliers, and investors who help businesses build a culture of sustainability by raising awareness of environmental issues and encouraging stakeholders to take action for a more sustainable future in maintaining profitability |
| Implement energy conservation measures (Dutta et al. 2020) | This lessening technique includes switching to energy-efficient light bulbs, using renewable energy sources, and using energy-efficient equipment |

- *Risk management*: A wide range of data management, privacy, and security risks for effective management to prevent potentially serious consequences.

From the above considerations, several studies have highlighted these concerns and the need for better data management, privacy, and security measures in smart manufacturing. For instance, a study by Dutta et al. (2020) identified privacy and security as the most significant challenges in Industry 4.0, emphasizing the need for more robust data protection measures. Another study by Kashem et al. (2022) proposed a blockchain-based solution for secure data sharing in smart manufacturing, providing a decentralized and tamper-proof system to ensure data privacy and security (Wu and Zhang 2022). Similarly, a study by Chung et al. (2018) proposed a privacy-preserving federated learning framework for collaborative manufacturing, allowing multiple parties to share data while protecting individual privacy. Thus, future research should focus on developing and implementing these measures to ensure emerging technologies' safe and ethical use in smart manufacturing.

## 2.7 Post-COVID-19 Insights and Lessons

The COVID-19 pandemic has profoundly impacted the manufacturing industry, forcing companies to adapt their practices and processes to ensure the safety of their workers while maintaining productivity (Ambrogio et al. 2022). Initially, smart manufacturing, which relies heavily on automation, robotics, and data analysis, has emerged as a key solution for manufacturers looking to improve efficiency, reduce costs, and meet the demands of an increasingly competitive market (Kalsoom et al. 2020). As companies continue to adapt to the new reality of the post-COVID world, smart manufacturing will play an increasingly important role by accelerating the adoption of smart manufacturing practices and technologies (Diaz-Elsayed et al. 2020). More specifically, the pandemic has accelerated the adoption of smart manufacturing practices as companies look for ways to operate more efficiently with fewer employees on the shop floor (Ambrogio et al. 2022). With social distancing requirements and restrictions on travel and in-person meetings, companies have had to find new ways to communicate and collaborate remotely (Hacker et al. 2020). This has led to an increased focus on automation and digitalization, which are vital components of smart manufacturing (Terry et al. 2020). However, the use of artificial intelligence (AI) and machine learning (ML) in manufacturing has also become more prevalent during the pandemic (Nazir et al. 2021). These technologies are being used to monitor production lines, predict machine failures, and optimize processes, reducing the need for human intervention and improving overall efficiency (Sadeghi and Seo 2022). As a result, companies are able to produce more with fewer workers, reducing their labor costs and improving their bottom line. Hence these are the baseline for the up-gradation with the learning from COVID-19:

Owing to the above facts in Table 2.9, the COVID-19 pandemic has highlighted the importance of smart manufacturing as a means of improving efficiency, reducing

**Table 2.9** Key insights and implications of smart manufacturing

| Insights | Benefits |
|---|---|
| Remote work and collaboration (Alkhader et al. 2021) | Smart manufacturing allows for remote monitoring of production lines and machines (Kalsoom et al. 2020), enabling workers to collaborate virtually and reducing the need for in-person interactions (Hacker et al. 2020) |
| Automation and AI (Nazir et al. 2021) | Companies will continue investing in automation technologies to improve efficiency and reduce costs (Ambrogio et al. 2022), and AI and ML will be increasingly crucial in optimizing processes (Liu et al. 2020) |
| Cybersecurity (Felstead 2019) | As manufacturers become more reliant on digital technologies, they must invest in robust cyber-security measures to protect against cyber-attacks (Dutta et al. 2020) |

costs, and ensuring the safety of workers (Adel 2022b). As companies look to adapt to the new normal, the investment technology-prone-operation efficiency (Dutta et al. 2020), reduced human intervention (Sadeghi et al. 2022) and closer collaboration between manufacturers and technology providers (Oh and Jeong 2019) are going concerned. Thus, the industry must continue to invest in new technologies and collaborate closely with technology providers to drive innovation and stay ahead of the curve.

## 2.8 Post-Covid Implications

The manufacturing sector has been significantly affected by COVID-19, which has resulted in a severe supply chain shock for the forward and backward sides of the process. Smart technological integration is vital for industries to protect against possible shocks. Integrating smart technologies like the Internet of Things (IoT), artificial intelligence (AI), and automation has allowed this shift. Manufacturers may prioritize productivity, efficiency, and sustainability by implementing smart manufacturing to face upcoming challenges. Manufacturers are now more cautious due to the pandemic's exposure to supply chain vulnerabilities. They get visibility into their supply chains by utilizing IoT devices and real-time data analytics, which enables them to respond proactively to changes in demand and potential interruptions. Automation and AI-driven technologies significantly raise productivity by streamlining processes and eliminating waste. Industry 5.0, where robots collaborate with human workers, boosts productivity and efficiency. Smart manufacturing also provides a road to sustainability in addition to productivity improvements. Manufacturers can utilize AI to optimize energy use, decrease waste, and lower their carbon footprint in response to consumers' increased environmental consciousness and demand for eco-friendly products. Thus, IoT, AI, and automation technologies are becoming necessary tools for organizations to survive and grow in these epidemic times. Smart manufacturing is advantageous because it delivers sustainability, adaptability, and resilience.

## 2.9 Conclusion

Organizations operating in rapidly changing environments require an agile, flexible supply chain process. This process enables businesses to respond promptly to shifting dynamics in both supply and demand, decrease waiting periods, enhance customer service, boost efficiency, better manage risks, and gain a competitive advantage. Depending on this systematic review, this dynamism included the integration of Artificial Intelligence (AI) and Machine Learning (ML) that optimize demand forecasting while adopting Robotics and Automation Technologies that improve supply chain efficiency. Again, this smart manufacturing idealized blockchain technology to boost sustainability and ethical practices, embrace Sustainable Practices, and collaborate with Suppliers and Customers to create more agile and efficient supply chains. Additionally, using Big Data Analytics might optimize production processes and augment supply chain efficiency while integrating Augmented Reality (AR) and Virtual Reality (VR) technologies potentially expand supply chain agility and efficiency. So, an agile and flexible supply chain process involves establishing a cross-functional team, developing a strategy, identifying potential bottlenecks, and leveraging technology. Despite its benefits, smart manufacturing presents several challenges, including security concerns, technical expertise, integration issues, and high initial investment. These are now the problems for the upcoming research in this field. However, researchers could also explore how supply chain risk strategies advance supply chain agility and resilience in smart manufacturing. This includes examining the potential benefits of using predictive analytics and other risk management tools to identify and mitigate supply chain risks. Likewise, researchers will investigate the potential benefits of adopting circular economy principles in smart manufacturing to promote sustainability, reduce waste, promote resource efficiency, and increase resilience. Nonetheless, leading toward improved product quality and customer satisfaction, smart manufacturing surprised the manufacturers to reduce costs by identifying areas of waste and inefficiency, optimizing production processes, and reducing the need for manual labor at an extended level.

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