

Integration of Artificial Intelligence into Supply Chain Operations to Achieve Sustainability

Dr. Anjum Nazir Qureshi

Rajiv Gandhi College of Engineering Research & Technology, Chandrapur, India

Abstract—Supply chain management includes several functions including acquiring raw materials, storing goods, production, and distribution. All the functions to operate a business, and its related aspects are carried out under the supply chain. These functions were earlier done through some conventional methods using machines and humans. Integrating AI into the supply chain has opened new prospects for improving the industrial process and making it more sustainable. Though the benefits of AI are limitless, it is equally important to navigate the complexities involved in its integration. This paper will discuss the role of AI in the supply chain, identify barriers to its implementation, and make it sustainable. This paper will support further research in using AI for supply chain operations.

Keywords— Supply Chain, AI, ML, Computer Vision, Sustainability.

I. INTRODUCTION

Artificial Intelligence has become one of the most widely used technologies. Many industries are harnessing the power of AI to make better products and services to satisfy their consumers and customers. It has become a hot topic for entrepreneurs, industrialists, and researchers worldwide. The applications where AI is being used are increasing with the expanding number of AI users. New applications are being developed every day. Researchers are busy making AI more comfortable and adaptable for everyone and expanding its usability. In the last few years, the research in AI has increased and it is being integrated with other recent technologies to have better results for the existing applications.

A report by CompTIA IT Industry Outlook released in 2024 overviews the potential of AI in modern digital operations. It says that 22% of industries are aggressively integrating AI into their wider number of products. 33% of firms use AI but not on a large scale while the rest 45% are still exploring the capabilities and opportunities of AI integration [1].

Though many business sectors are still exploring, most agree that AI will play a significant role in business growth and industries in the coming times. Most companies use AI for automation, enhancing consumer satisfaction, increasing output, and analyzing data. A survey by the Forbes advisors, shown in Fig 2 indicates the current trend among the business owners for using AI [2]. A study conducted by IBM in 2021 on the changes in the digital transformation landscape in the manufacturing industries revealed that after COVID-19, many industries adopted digital technologies. Decision-makers in the manufacturing industry began focusing their investments on IT and data systems, improving customer and consumer satisfaction, collaboration tools, and production efficiency. The few technologies manufacturers adopted to meet their goals are cybersecurity, data analytics, robotics, IoT, AI /ML, computer vision, and virtual reality. AI/ML and computer vision are preferred by 77% of the manufacturers to meet their goals.

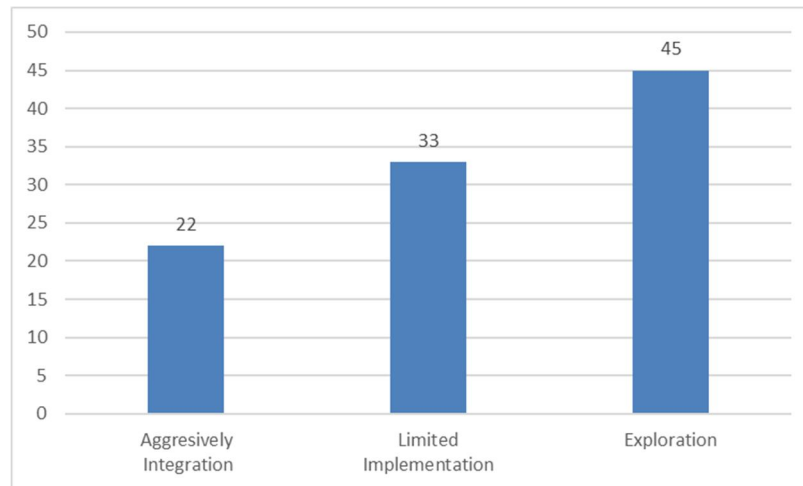


Fig 1. Current Adoption of AI [1]

Manufacturing industries are considered to be one of the major players in the world economy. Its contribution was 17% of the global GDP in the year 2021. The output generated globally in this sector was \$16.5 trillion. The manufacturing sector has undergone a significant change. Machine Learning (ML), Industry 4.0, and smart manufacturing techniques have changed the landscape. The few applications that enhance the manufacturing industry scenario are supply chain optimization, predictive maintenance, inspection and monitoring generative design, quality control, digital twin utilization, and energy consumption prediction [3].

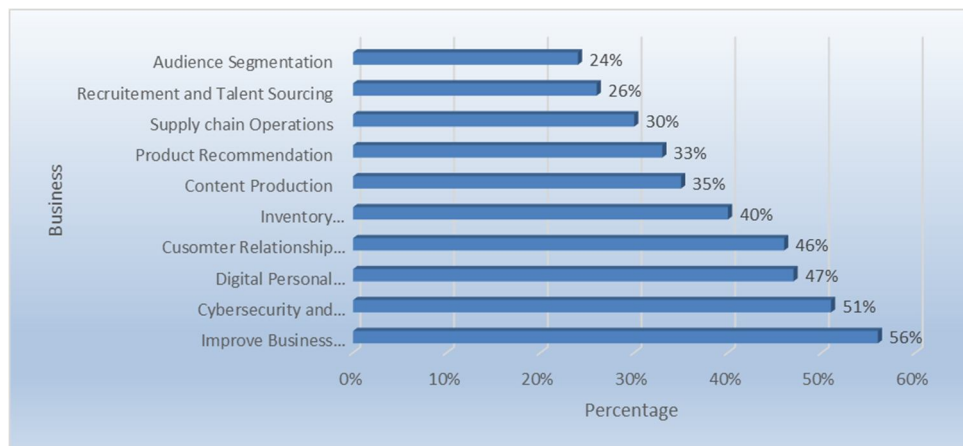


Fig 2. Trends among Business Owners for Using AI [2]

ML models are increasingly being used in supply chain optimization. Another subset of AI that has gained importance in the supply chain is computer vision or machine vision. AI in the supply chain is at the initial level of research. A few studies illustrate using ML and computer vision to enhance the functioning of supply chains. However, achieving sustainability in supply chains using AL-based models has not been widely covered. The objectives of this paper are i. Discuss how ML and computer vision will enhance supply chain operations, ii. Identify the barriers to using AI in the supply chain and iii. Study the role of AI in creating sustainable supply chains.

II. ML TECHNIQUES IN SUPPLY CHAIN OPTIMIZATION

Supply chain optimization aims to maximize the operating efficiency of the various operations in the supply chain. It intends to provide its products at lower costs to the customers but earn high-profit margins. The organizations balance the costs incurred in manufacturing, transportation, and inventory management. These goals should be met to fulfill the customer's expectations and create better supply standards [4]. Supply chain vulnerabilities generally can be observed in five dimensions: (i) planning and supplier networks, (ii). Transportation and logistics. (iii) resilient finances (iv) complexity of the product and (v) maturity of the

organizations. Disruptions in the supply chain should not continue for more than one month. These disruptions when not tackled on time, in the coming decade, may cost nearly 45% of the yearly profits [5]. Some distinct challenges that can be solved using ML in the supply chains are substandard management of the supply chain relationships, inefficient planning for the resources, poor quality of maintenance for safety standards, increased expenses for transportation, and inability to meet the needs of the customers and lack of planning in managing costs for the given task [6]. Some of the ML use cases in the supply chain are [7]:

A. Inventory Planning

Inventory planning can profoundly impact a company's cash flows and profits. ML algorithms can predict the changes in demand for goods based on the data gathered from market status, variation of trends, and analyzing the history of promotion and sales. This will help fill the stores in advance based on the demands to avoid the customers' disappointment, fill up the stores based on analysis, and avoid overproduction. This will help to prevent excessive manufacturing of the goods. ML in the supply chain facilitates effective data analysis to provide accurate forecasts even though a wider range of data is unavailable, and the datasets are insufficient. ML can solve the problems faced in the supply chain by using techniques like data augmentation, incremental learning, and reinforcement learning.

Data augmentation is a method that generates data for the ML models. It enhances the performance of the ML models and reduces the dependency on training data [8]. Data augmentation can be used to train models to detect defects in the manufactured products. Simulation of different types of shapes and sizes of the defects improves the ability of the ML models to detect aberrations. Data augmentation in supply chain operations assists in predicting demand, optimization of inventory levels, and improving overall efficiency [9].

Incremental learning is a method where ML-based models learn and enhance their knowledge consecutively without disremembering the formerly collected data. It learns from the new available data and incrementally updates the models. The models developed using incremental learning facilitate efficient use of resources as they require less storage space for data. Moreover, these models can enable real-time adaption, enhancing the ML models due to their ability to break tasks into smaller parts and effectively learn new tasks [10]. Reinforcement learning is a powerful AI-based technique that allows machines to acquire information and make decisions in dynamic environments. Businesses usually rely on rule-based systems to manage orders. This may not be suitable for the marketing environments. Reinforcement learning maximizes the reward signal with time, enabling the agents to learn the best actions for optimizing the inventory levels and ensuring that all the orders are fulfilled. The automated order management system needs various data to make data-driven decisions. It helps to know when and how much to order to meet the demands of their customers, minimize investments involved, and ensure the availability of the products at minimum costs [11].

B. Warehouse Management

Warehouse management is often related to deciding on some factors that can influence the performance of supply chains. These factors include receiving, picking orders, storing, and shipping. ML is emerging as a favorable technology for solving issues related to warehouse design. ML can solve problems such as assigning locations for storing and picking orders, allowing intelligent warehousing, and managing the order-picking sequence or schedule [12,13]. ML algorithms are gaining more importance in the supply chain with the growth in the volume and complexity of the data. These algorithms are pivotal in streamlining the order fulfillment process and ensuring customers receive accurate timely deliveries. AI and ML can analyze real-time data on warehouse layouts and customer demands. This helps to reduce travel time within the warehouse and reduces the time of delivery or shipping [14]. Moreover, a large amount of time and energy is needed to gather information regarding the products and customers to plan for warehouse operations. The primary goal of warehouse operations is to deliver more products to the customers on time and at the lowest possible cost. This is required to ensure proper services for the customers. [15]. The time needed to fulfill the orders can be further reduced by integrating ML algorithms with voice-controlled picking systems to guide the workers during the picking process. ML helps to identify, create, and predict warehouse operations. Sensors are used to collect real-time data to monitor the status of the warehouse machinery. Data analysis using ML helps in predicting the time for maintenance. It is helpful to avoid unexpected breakdowns and reduce downtimes. This ensures the smooth running of operations, extends the lifespan of equipment, and enables savings by reducing the costs required for maintenance [16]. Automation in warehouses using robots is another interesting feature of AI and ML. These models work with low-cost hardware and are extensively used for repetitive tasks like transporting products. Automation in the warehouses reduces labor costs and ensures faster operations. Additionally, it improves safety in the warehouse with minimal human intervention. This allows the industries to concentrate on planning for

more productive and impactful business activities [17]. Furthermore, ML can play a pivotal role in automating return processing. The algorithms are used to categorize returned goods as resalable and repairable. It will simplify the reverse logistics and reduce losses. Moreover, the ML algorithms can be used to make decisions on restocking and disposing of goods [18].



Fig 3. ML in Warehouse Operations [18]

C. Logistic Route Optimization

ML supports real-time route optimization by analyzing earlier routing. It improves the speed of processing orders and reduces the cost involved. This technique is helpful for e-commerce platforms where they have to reach several customers in less time. Deciding the best routes using the ML algorithms allows reach customers on time and satisfy them to have improved customer satisfaction and better profits. However, traffic is a major factor that influences shipping time. ML algorithms can predict traffic by studying the peak hours in the logistic centers. Traffic analysis of logistics centers is used to make decisions on the time slot that can be used to deliver goods to the customers quickly to win their trust and make them happier. Autonomous vehicles and drones are the latest solutions available to overcome the struggles companies face in delivering goods to places where road transportation facilities are either scarce or not available. Lack of transportation facilities increases wastage and loss of goods. Drones and autonomous vehicles can save investments and time. Integrating AI and ML improves delivery logistics for companies producing goods with a lesser shelf life [19].

D. Production Planning

ML-powered supply chains support supply chains by providing better-optimized production planning. ML algorithms gather data and analyze it to decide on production planning, based on the performance of the machines and demand in the market for a given commodity. One of the key features of using ML in production is its ability to make data-driven decisions. It uses the data to predict the demands, which can be used to allocate resources for production and simplify its process.

This will help to prevent conditions like overstock and out-of-stock [20]. ML enhances production by easing the tasks of developing new designs and reducing the time needed. The algorithms help to design new products by considering parameters like weight, strength, investment, and the available materials. Moreover, these algorithms help select the best designs after evaluating all the parameters and allow modification if needed. It enables designers to look at the issues differently and develop out-of-the-box thinking for having novel and unique product designs. ML algorithms facilitate the detection of manufacturing errors before sending the products to the market. Furthermore, it allows us to identify the reasons for deviations by analyzing the historical data and suggesting improvements to enhance production [21].

E. Chatbots

Chatbots help in making the supply chains more sustainable. These intelligent chatbots help industries by providing better and more efficient communication to online customers. Large operational volume has emerged as a major concern for the supply chain operations. Chatbots enhance customer satisfaction by providing quicker responses allowing easier acquiring of logistics, automating placing orders for raw materials, navigating the probable locations and options for the raw materials, and arranging for the logistics and the sale after completing the production process. These chatbots provide effective solutions to the supply chain by allowing the deployment of resources and their recovery in the supply chain [22]. Chatbots are expected to emerge as excellent intelligent assistants leveraging ML algorithms to understand complicated logistic queries. This helps deliver appropriate information to the stakeholders, enables better decision-making, and handles supply chain management. However, these chatbots are expected to transform conventional communication strategies. They are available anytime across various channels and use text, voice, and video to provide a seamless communication experience to the logistic professionals. Chatbots can use analytics to predict issues in the supply chain and provide customized solutions and suggestions to optimize the supply chain and logistic operations [23].

F. Better Consumer Experience and decision making

The ability of ML to identify patterns and insights from data augments business operations enhancing decision-making and efficiency of operations. Businesses can therefore utilize ML algorithms to boost profits by ensuring better consumer experiences and reduced costs [24]. ML algorithms can enhance supply chain visibility. It helps the organizations to follow orders from supply to delivery. Moreover, gathering real-time data and its continuous analysis ensures that the right stock is available to the consumers. The timely delivery and availability ensure a better consumer experience and supports business growth. ML supports the customer service team and consumers by allowing reduced human interventions. Support chats on websites or AI-enabled assistants help consumers find quick answers to their queries and help elevate consumer satisfaction [25]. The data-driven decisions on various aspects like predicting demands, arranging stocks for consumers, tracking the orders, etc., enable the executives to make better decisions. It helps to evaluate the best and worst scenarios. Furthermore, the ML algorithms can suggest appropriate solutions to make better decisions. Business leaders and executives can utilize this analysis to develop solutions that balance the pricing of goods, consumer demands, satisfaction, and profits.

G. Security

The conventional programming models often fail to adapt to the complexity of the supply chains. ML algorithms are feasible to work with voluminous data sets and complicated patterns. Moreover, the security requirements for the AI and ML models are different. ML models can bring clarity, adaptability, control, and forensic vision into the supply chains. They can be synced with the business processes and governance to minimize risks for data privacy and cyber security [26]. ML models recognize abnormalities that indicate potential threats and help organizations recondition weaknesses rapidly and reduce the risks of data misuse. Moreover, these models can assess the cybersecurity behavior and awareness of third-party suppliers to mitigate security risks in the supply chain. These models automate responses to the incident risks and proactively recommend effective remedies [27].

III. COMPUTER VISION FOR SUPPLY CHAIN OPTIMIZATION

Computer vision (CV) can efficiently enhance and redefine supply chains. It can enable the reconstruction of supply chain operations to ensure efficient and safe systems.

The supply chain optimization implemented using computer vision technology involves nine basic steps: arrival monitoring, wait timer, forklift operations, heatmaps and traffic, quality control, label scanning, safety compliances, gauge reading, and delivery [28]. Computer vision applications in the supply chain minimize human intervention and decrease the need for human labor. Some of the benefits and use cases of computer vision in the supply chain are:

A. Quality Control

A CV-based system can be implemented using a camera in the production line to capture images. These captured images are compared with the predefined dataset to identify flaws and imperfections in color, texture, packaging, geometric composition, etc. One of the advantages of using a CV in quality control is the higher grade of

accuracy. These systems give more precise results compared to the types of equipment used by humans. Another benefit lies in its ability to perform repetitive tasks without affecting the accuracy. CV-based systems are fully automated, run faster, and work longer to increase production eliminating the need for break or rest. Additionally, the chances of errors are less. Manual control may sometimes lead to mistakes and can incur industry losses [29]. CVs facilitate quality control and defect detection by identifying the anomalies in the objects using algorithms like convolution neural networks (CNN) to classify them as functional or malfunctioning. The products that meet the complete standards are kept while the others are removed. Some benefits that companies can have by using CV for quality control are a reduction in manual labor, seamless classification for anomalies by using algorithms, cost savings, and resource savings by minimizing the entry of defective products in the market. This helps maintain the product quality and reputation of the industries. It provides long-term profitability. CV can adapt to diverse environments and the needs of industries. However, industries should focus on being updated on technologies to leverage the benefits of CV in quality control [30]. Some of the use cases of CV in quality control are assessing medical images for counting bacteria or detecting the presence of viruses, identifying counterfeit products during packaging, finding cars in restricted areas, controlling pests in agriculture, the presence of human beings or those moving around the production areas to monitor their work and avoid any unidentified persons, managing the goods on the shelves of the supermarket, etc. [28].

B. Inventory management

Real-time observations retrieved from the videos can help improve the efficiency of industrial operations. It will be a game-changer for improving inventory management and avoiding stockouts. Computer vision systems are implemented using algorithms to precisely identify stocks and know their count. These algorithms can easily classify the products. There are very few chances of miscounting that may occur due to human error. Moreover, CV systems maintain better accuracy in inventory tracking for longer periods. Human beings can't focus for long, leading to errors. Automation will provide consistent performance irrespective of the scale of operations and longer periods. For example, inventory levels in an industry are important to ensure profits and avoid customer dissatisfaction and loss of sales.

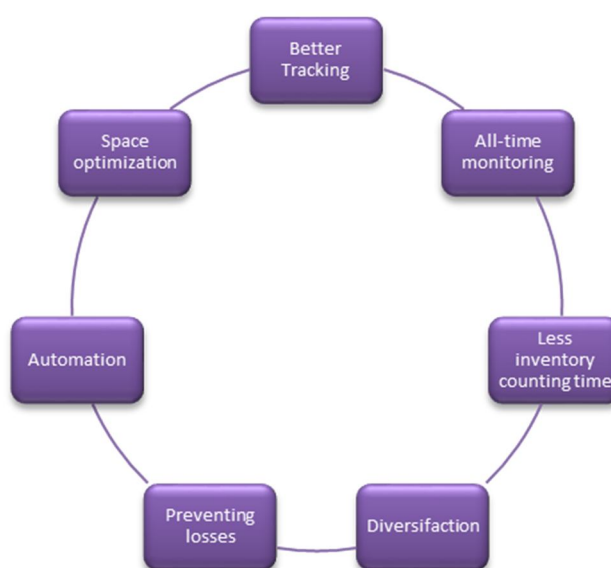


Fig 4. Benefits of Using CV in Inventory Counting

The cameras and algorithms in CV enable continuous scanning and its analysis in real time. It accurately detects the quantity and location of the products. The need for manual detection and hence errors caused due to it is reduced. Continuous updates on the inventory data enable timely restocking to avoid stockouts and maintain the finest inventory levels. Similarly, when the stock falls below a predetermined count, the CV systems initiate notifications for restocking. It identifies the misplaced and the mislabeled items. The staff can focus on inventory issues due to timely alerts and notifications. It ensures that the products are readily available and the customers are always contended. It enables a more simplified and efficient inventory management procedure. The robots used for sorting, picking, and placing activities can be enabled with computer vision to enable better movement

in the storage areas and minimize the chances of misplacing products. CVs can improve their accuracy by using ML. Feedback loops allow systems to learn from previous faults to minimize the chances of repeating mistakes. CV in inventory management uses images and videos to reduce waste by continuously scanning the products and sending an alert for the goods near expiry. It also helps create a 3D detailed map to decide on layouts for storing items to better utilize the horizontal and vertical space [31].

C. Automating Warehouse

CV systems enable the automation of warehouses through their ability to understand and act accordingly on the visual data. CVs enable automated data capture in warehouses to encourage applicable solutions. The ability to detect and classify objects using CV algorithms plays a crucial role in maintaining accurate records of the movement of products and reforming storage layouts. These algorithms analyze the visual data to recognize the defects and damages allowing only good quality to reach the customers. CVs in robotic systems enable safe navigation to avoid obstacles, to find ideal paths, and to match the movements of robots with other humans and animals. Moreover, environmental monitoring for conditions like lighting, rain, humidity, and excess temperature enables the arrangement of optimum storage methods to avoid losses. CVs augment warehouse security by continuously checking for security breaches, theft, and unauthorized access. Furthermore, it detects hazardous working conditions to ensure that the workers always are safe at their workplace and that safety protocols are followed [32]. Some companies using AI and computer vision to automate warehouse operations are Powerhouse AI, Amazon, Ocado, and DHL. Though AI and CV use cases in warehouses are in the initial stages, many business organizations have confirmed their potential for massive transformation. LogisticsIQ, in one of its reports, predicts that the warehouse automation market will reach USD 44 billion by 2028, at a compound annual growth rate of 15% between 2023 and 2028 [33].

D. Routing Vehicles and Controlling Traffic

Computer vision plays a key role in route optimization. It analyzes the traffic patterns and the delivery route to ensure timely delivery and reduce transportation costs. CVs when integrated with GPS can actively adapt to changes in real-time routes [34]. AI and computer vision can analyze the historical data of the routes, and the existing routes, evaluate the geographical and environmental concerns, and find the shortest route. These algorithms help reduce carbon footprints by identifying efficient vehicle routes [35]. When combined with the cameras and sensors, vision-based object detection algorithms can help the vehicles follow proper routes without collisions and automatically discover obstacles. Moreover, when used for robots with localization and simultaneous mapping capabilities, helps plot routes, discover new routes, and avoid obstructions by automatically understanding and reacting to the change in surroundings [36]. Computer vision can benefit organizations by helping with fleet monitoring and increasing speed and accuracy. It analyzes drivers' behavior and monitors the condition of vehicles to ensure conformity with the safety standards and regulations and optimize the planning of routes. It automatically detects damaged goods during transportation, allowing instantaneous restorative actions [37]. Advances in AI and ML will improve traffic analysis capabilities, to provide more sophisticated information. Integrating cameras and algorithms will aid in monitoring larger areas to obtain detailed traffic information. Moreover, using edge computing resources for video processing can reduce the bandwidth requirements, for traffic surveillance systems [38].

E. Security and Preventing Losses

Video monitoring was done in factories and companies using cameras that could only record activities around but could not analyze what it recorded. Computer vision opened up new possibilities for recognizing people, objects, and their activities. This real-time identification understands the context of a video, by using multiple models that work parallelly at the detection and application layer. This gives better results, by helping to extract valuable data from the videos and the captured images. For example, it will identify persons wearing certain safety equipment and distinguish them from others. The cameras have transformed from passive recording devices to active analyzers. For instance, in the production line computer vision algorithms can monitor each component throughout the production process, and identify safety hazards and barriers. Moreover, CV algorithms can assist in monitoring goods from arrival to dispatch. It can detect ineffectualness in the picking, loading, and packaging to reduce costs, decrease delivery times, and improve customer satisfaction [39]. CVs can be used for crowd detection and behavior analysis to foster security at the logistic facilities by counting people, predicting people's density, and analyzing their behaviors. With the growing importance of privacy issues, these vision systems allow on-device analysis eliminating the need to send data to the cloud. It ensures the offline operation of these systems continuously [40]. Consumer privacy is a

growing concern among the companies that use CVs. Every industry has to deal with a large number of people, monitor their actions, and at the same time take precautions to maintain the privacy of the data shared by the people and their identity. The industries that use video analytics to study consumer behavior can protect their privacy by blurring faces. This will not reveal the person's identity but the industries can track their movements and periods when the footfall is more etc. Similarly, workers' faces can be blurred, but data on their productivity and the processes followed can be collected and analyzed. Transportation industries can use CVs to detect medical emergencies issue alerts to the concerned authorities and monitor the safety of the riders. The analytics can be easily done by blurring the faces of all the passengers without affecting their safety [41].

IV. PROMOTING SUSTAINABLE SUPPLY CHAINS

A sustainable supply chain successfully integrates factors: environmental, labor, ethics, and human rights. It is not limited to any product or industry but extends to people and the planet to ensure best practices for supply chains and sustainable logistics. With the global awareness of sustainability, business organizations are committed to sustainable practices in the supply chain to attain their business objectives. They are more empowered to encourage the stakeholders in the supply chain to leverage sustainable practices promote better labor practices, and assist the suppliers in surviving the era of expeditious economic and geopolitical growth. AI, ML, Robotics, computer vision, and other emerging technologies are enablers in ensuring sustainable supply chains. The sustainable supply chain is presently considered a holistic term. Its key components are green, transparent, and circular supply chains.

Sustainable supply chains rely on the following components:

- Collaboration and sharing information among industries of the same sector and ensure supply chain transparency to avoid damaging competitiveness and earn benefits of enhanced customer satisfaction.
- Overcoming the complexity of supply chains by leveraging the available technologies to manage end-to-end tasks and support environment-friendly practices for manufacturing and logistics.
- Setting standards, benchmarks, and guidelines consensually accepted by all the stakeholders in the supply chain allows easier tracking and managing compliance. Positive correlation among the industries and stakeholders will foster profits and growth.
- Sharing the news of attaining sustainability goals to earn a powerful reputation among the customers and lead by example to achieve measurable benefits.



Fig 5: Sustainable Supply Chain Management [43]

Green supply chain management (GSCM) integrates environmental factors and benchmarks into the supply chain. It involves knowing the impact of industrial operations on the environment [42]. ML algorithms can manage voluminous data and can be used to discover or extract a lot of information. GSCM includes product

recovery, restoration, and disposal. It can be used as an important tool for the viable utilization of resources in the circular economy [43]. AI helps design and control GSCM systems with constructive feedback on organizational processes like business, marketing, finance, and sales. AI, ML and other related algorithms improve the sustainability of the supply chains by collaborative working with the organizations. Some of the benefits of using ML in the GSCM are [44]:

- These algorithms make their supplies green by allowing organizations to share their supply chains. The organizations share transport techniques using AI/ML to enable real-time updates on shipping situations, stock availability, costs, and transportation. These algorithms expedite shipping and reduce pollution and transportation expenses.
- Driverless or independent vehicles that use AI/ML are more efficient than man-made cars. These driverless vehicles use advanced GPS tools to find the routes. This reduces delivery time and also emissions.
- AI algorithms identify shipping necessities. Shipping efficiency is improved by monitoring the shipping environments to find shorter routes. Moreover, as these computational methods are very fast, they help balance the packages and fuel efficiency.
- AI can be trained to foster decision-making in GSCM. AI-based systems can reduce risks by analyzing the supply chain and suggesting improvements to assure long-term relationships with other organizations and customers.
- ML algorithms continuously monitor the items to detect damaged and expired goods. It reduces waste and demand for reverse logistics. Manufacturers can use sensors and ML to track the exact number of goods to be manufactured. The tailored production techniques reduce toxic emissions and translate processes to be fuel efficient.

Supply chain transparency refers to information management techniques and how companies use communication technologies for supply chain management. Though emerging technologies like blockchain and digital platforms are increasingly used in supply chains to ensure sustainability, a better understanding of transparency is required to understand what technologies should be used, what data should be shared, and who should be involved in the sharing [45]. Supply chain transparency can be composed into six dimensions of information to improve sustainability. The six dimensions of information include traceability, transaction, impact, policy and commitment, activity, and effectiveness [46].

ML algorithms are crucial in ensuring transparency in supply chains for businesses in the modern era. These algorithms help the organization attain traceability and accountability. ML can empower businesses using real-time monitoring, predictive analytics, and abnormalities disclosure strategies to ensure optimized resource distribution, establish safe operations, and predict disruptions in the supply chains. Moreover, the traceability solutions by ML, help to enact digital threads for recording the whole procedure from source to delivery. It improves transparency and assists in conformity with regulative needs and principled standards, promoting trust among the stakeholders and consumers. ML enables innovation and resilience across the supply networks by automizing the procedures needed for quality control, establishing better communication with the customers, and identifying favorable circumstances for development [47].

The ML algorithms' anomalies and pattern detection capabilities can be leveraged to take preventive measures to minimize the impact of probable disruptions. Moreover, these algorithms ensure better traceability, by using automation and data analysis across the supply chain to comply with better quality and safety to match the regulation standards and policies of the company [48].

Natural language processing (NLP) and CV can be key enablers in decreasing carbon emissions during production by optimization of processes. It enables tracking the whole production by identifying the source of raw materials, different production techniques and processes, and monitoring the distribution of the final product. The track and trace technology can enhance visibility and traceability by enabling real-time asset tracking and risk management. It helps foster collaboration and efficiency in the supply chain ecosystem, to enhance customer satisfaction [49]. ML algorithms strengthen traceability systems by controlling quality issues by identifying damaged products and their locations.

This minimizes the chances of customer complaints and the return or recollection process. Moreover, the data analysis capabilities enable organizations to design regulatory standards and ethical practices by studying experiences of fraud and customer dissatisfaction. Despite the numerous benefits of ML in supply chain data quality, interoperability, data security, and privacy concerns are some issues that should be addressed to protect information and secure the use of the supply chain [50].

Circularity in the supply chain integrates circular economy into supply chain management [51]. The Circular supply chain (CSC) allows the remanufacturing, reusing, recycling, and repair of materials [52]. Circular supply chain management (CSCM) augments the better utilization of resources throughout the product life cycle. It

examines the actions and the accessible technologies for the efficient implementation of the circular therapy models [53]. With the increasing importance of the circular economy, aspects like environmental impacts, reducing energy usage, and recovering natural resources are considered integral elements of the supply chain [54]. CSC follows the 7 R's (Redesign, Reuse, Repair, Recover, Recycle, Reduce, Refurbish) to take green steps and reduce the negative environmental impact of the industries and their related activities. Besides protecting the environment, CSC has some benefits: i. Recycling reduces the investment the manufacturers make in buying raw materials. ii. It helps the manufacturers to handle the interruptions in supply. iii. It helps improve sales and win the trust of the customers [55].

ML algorithms support the CSC by implementing circular methods for waste treatment and transportation, identifying incompetencies in the supply chain, improving product design, predicting the demand, and fulfilling it by following circularity of resources, remodeling existing patterns to encourage better utilization of resources, and predicting consumer's behavior [56].

The data-driven insights obtained through ML, foster the decision-making process of organizations and address the complexities in the supply chain to line up with the increasing requirements and interests for sustainable practices. Integrating IoT, Blockchain, and CV with ML can enhance CSC operations to achieve better transparency and automation. Moreover, ML for CSC helps to attain sustainability goals in a broader sense at the environmental, social, and economic levels [57].

V. BARRIERS AND SOLUTIONS TO IMPLEMENTATION OF AI IN SCM

Some potential barriers to AI in supply chain management are legitimate data, higher implementation costs, data security, challenges for adaptability, and scalability [58].

- Data is the basic constituent that enables decision-making in the supply chain. The present and past data are analyzed using AI/ML to foster supply chain operations and attain better results. However, according to experts in the supply chain domain, the accuracy level of the data provided by the AI platforms is around 85-90%. This raises concerns about the quality and accuracy of data and completely relying on the data obtained by AI to formulate decisions. One of the probable solutions is to collect and analyze data using AI but involve some level of human intervention to check its authenticity.
 - The large expenditure in implementing AI-driven algorithms or applications is another challenge professionals in this field face. Integration of AI might be easy at the initial stages, but finding the right tools, training the people to implement it, and finding appropriate opportunities for integration add to the costs. Moreover, the robust inclusion of AI will take some time despite the nature of businesses. Adopting new technology is impossible without initial investments. However, when the integration of AI into supply chains needs more research, it is better to foster awareness among business owners and professionals and accept the benefits of using AI. Though the training will incur additional costs to achieve better results in the long term, it is better to be an early adapter of AI and be determined to train the teams.
 - AI uses structured and unstructured data, related to the internal operations in the organization and uses some external data if needed. The leakage of private information or data security issues is a great concern for those moving towards AI. Though this aspect is still under debate, developers and service providers should include security measures in their tools. Introducing new technologies or unfamiliar concepts is not welcomed instantly by professionals, teams, or employees.
 - The people working especially in the supply chain domain are reluctant to adopt AI due to fear of failure, lack of trust, and understanding. An entire remodeling of procedures at once is not possible. It will create confusion and increase the chances of failure. Organizations must start by training employees and introducing them to the benefits of integrating AI into the supply chain. Once the teams are educated on the technology, their performance and outcomes can be analyzed to identify avenues for development, revision, and reimplementation.
 - Human beings can easily adapt to changes in output by changing their strategies. However, a machine cannot work beyond its maximum capacity. For instance, if an organization has to increase production, it will upgrade the existing machinery or involve new machines. A similar problem is observed while using AI. Though AI is intelligent, it can perform only the tasks it is trained for. It cannot adapt to changes in business operations until it is customized accordingly. Challenges in customization are one of the reasons that hinder the integration of AI in some cases.
- Moreover, obtaining a customized AI tool is challenging and pricey. Organizations using generic tools like ChatGPT may not face these issues but those following a unique format for work will face challenges while using AI.

VI. CONCLUSION

A few use cases of AI (ML and CV) for supply chain management are discussed in this paper. The study includes the components of a sustainable supply chain and how AI would contribute to making sustainable supply chains. It also identifies potential barriers to including AI in the supply chain and provides suggestions for overcoming them. Seamless integration or full-scale implementation of AI will need some time. Organizations must prioritize the training of teams and step-by-step implementation. Data is crucial for AI and most of its activities are data-driven. However, no organization would like to compromise its data. Security measures should be a priority among business owners and organizations to overcome the risks of implementing AI in the supply chain. Barriers to implementing AI underscore the need to develop strategies, that would provide chances of growth. The adaptability of AI will improve by making it more secure. Overcoming the barriers and crafting solutions for using AI, modifying the existing regulations and policies, and the right approach will revolutionize supply chains. Moreover, addressing the knowledge gaps will open new areas for research in this field, to reap the benefits of AI in supply chain operations.

REFERENCES

- [1] IT Industry Outlook 2024 (2024), CompTIA, https://comptiacdn.azureedge.net/webcontent/docs/default-source/research-reports/comptia-it-industry-outlook-2024_final.pdf?sfvrsn=8aeab92c_2
- [2] Katherine Haan, Rob Watts (2023) How Businesses Are Using Artificial Intelligence In 2024, <https://www.forbes.com/advisor/business/software/ai-in-business/>
- [3] 7 Applications of Machine Learning in Manufacturing and Real-Life Examples (2023) <https://pixelplex.io/blog/machine-learning-in-manufacturing/>
- [4] Tibco (2024), <https://www.tibco.com/glossary/what-is-supply-chain-optimization>.
- [5] McKinsey & Company (2022), What is Supply Chain, <https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-supply-chain>
- [6] Arindam Mukherjee (2023), Machine learning techniques in supply chain management, Supply Chain Management Review, https://www.scmr.com/article/machine_learning_techniques_in_supply_chain_management
- [7] Kostiantyn Bokhan (2024), Machine learning in supply chain: 8 use cases that will impress you, N-iX insights, <https://www.n-ix.com/machine-learning-supply-chain-use-cases/>
- [8] Kiran Maharana, Surajit Mondal, Bhushankumar Nemade, A review: Data pre-processing and data augmentation techniques, Global Transitions Proceedings, Volume 3, Issue 1, 2022, Pages 91-99, ISSN 2666-285X, <https://doi.org/10.1016/j.gltp.2022.04.020>.
- [9] Kiran Sachdeva (2024), What is Data Augmentation in Deep Learning? Techniques and Applications, Software Engineering Insights, <https://insights.daffodilsw.com/blog/what-is-data-augmentation-in-deep-learning>
- [10] Abid Ali Awan (2023), What is Incremental Learning? Datacamp, <https://www.datacamp.com/blog/what-is-incremental-learning>
- [11] Rolf, B., Jackson, I., Müller, M., Lang, S., Reggelen, T., & Ivanov, D. (2022). A review on reinforcement learning algorithms and applications in supply chain management. *International Journal of Production Research*, 61(20), 7151–7179. <https://doi.org/10.1080/00207543.2022.2140221>
- [12] de Paula Ferreira, W., Armellini, F., De Santa-Eulalia, L.A., 2020. Simulation in industry 4.0: A state-of-the-art review. *Computers & Industrial Engineering* 149, 106868.
- [13] de Paula Ferreira, W., Armellini, F., de Santa-Eulalia, L.A., Thomasset-Laperriere, V., 2022a. Extending the lean value stream mapping to the context of industry 4.0: An agent-based technology approach. *Journal of Manufacturing Systems* 63, 1–14.
- [14] Rodrigo Furlan de Assis, Alexandre Frias Faria, Vincent Thomasset-Laperriere, Luis Antonio Santa-Eulali, Mustapha Ouhimmou, William de Paula Ferreira, Machine Learning in Warehouse Management: A Survey, 5th International Conference on Industry 4.0 and Smart Manufacturing, Procedia Computer Science 232 (2024) 2790–2799
- [15] A. Ghaouta, M. Riad and C. Okar, "Machine Learning for Warehouse Management: A conceptual framework," 2021 Third International Conference on Transportation and Smart Technologies (TST), Tangier, Morocco, 2021, pp. 30-35, doi: 10.1109/TST52996.2021.00012.
- [16] Warehouse (2024), The Role of AI and Machine learning in Modern WMS, Generix, <https://www.generixgroup.com/en/blog/the-role-of-ai-and-machine-learning-in-modern-wms>

- [17] V. D. Hristov, D. V. Slavov, I. S. Damyanov and G. D. Mladenov, "Machine Learning for Automation of Warehouse Activities," 2022 8th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, 2022, pp. 1-4, doi: 10.1109/EEAE53789.2022.9831208.
- [18] Autostore (2023), Machine Learning: The Revolutionary Catalyst in Warehouse Automation and Supply Chain Management, <https://www.autostoresystem.com/insights/machine-learning-the-revolutionary-catalyst-in-warehouse-automation-and-supply-chain-management>
- [19] Artur Haponik (2024), Machine Learning in Logistics: 10 Use Cases of AI and ML, <https://addepto.com/blog/use-cases-ai-machine-learning-logistics-supply-chain/>
- [20] Serhil Leleko, Yevheniia Holborodko (2024), AI and Machine Learning in the Manufacturing Industry: Shaping the Next Industrial Revolution, <https://spd.tech/machine-learning/ai-and-ml-in-manufacturingindustry/%20stockouts%20or%20overstocking>.
- [21] Eugene Makieiev (2024), ML in Manufacturing Industry: 10 Use Cases in 2024, Integrio Systems, <https://integrio.net/blog/ml-in-manufacturing-industry>
- [22] Panigrahi, R.R.; Shrivastava, A.K.; Qureshi, K.M.; Mewada, B.G.; Alghamdi, S.Y.; Almakayeel, N.; Almuflih, A.S.; Qureshi, M.R.N. AI Chatbot Adoption in SMEs for Sustainable Manufacturing Supply Chain Performance: A Mediation Research in an Emerging Country. *Sustainability* 2023, 15, 13743. <https://doi.org/10.3390/su151813743>
- [23] ProProfs Editorial Team (2024), How Chatbots for Logistics Can Transform the Supply Chain Industry, <https://www.proprofschat.com/blog/chatbots-for-logistics/>
- [24] Ahmed M. Khedr, Sheeja Rani S, Enhancing supply chain management with deep learning and machine learning techniques: A review, *Journal of Open Innovation: Technology, Market, and Complexity*, Volume 10, Issue 4, 2024, 100379, ISSN 2199-8531, <https://doi.org/10.1016/j.joitmc.2024.100379>.
- [25] Peter Drakeley (2024), 5 Benefits of artificial intelligence in supply chain management, <https://www.eazystock.com/blog/artificial-intelligence-and-machine-learning-in-supply-chain-management/>
- [26] Diana Kelley (2024), Why MLBOMs Are Useful for Securing the AI/ML Supply Chain, Darkreading, <https://www.darkreading.com/vulnerabilities-threats/mlboms-are-useful-for-securing-ai-ml-supply-chain>
- [27] IPV Network (2023), A New Technological Revolution: Machine Learning Powered Supply Chain Intelligence, <https://ipvnetwork.com/a-new-technological-revolution-machine-learning-powered-supply-chain-intelligence/>
- [28] Sergiy Tikhonov (2021), Computer Vision for Quality Control, Softengi, <https://softengi.com/blog/computer-vision-for-quality-control/>
- [29] Georgia Wilson (2021), IBM: digital transformation in manufacturing 2021, Manufacturing DIGITAL, <https://manufacturingdigital.com/smart-manufacturing/ibm-digital-transformation-manufacturing-2021>
- [30] Autmix (2024), Computer Vision for Quality Control, <https://autmix.com/en/blog/computer-vision-quality-control>
- [31] Cogent Infotech (2024), Revolutionizing Retail Inventory Management with Computer Vision, <https://www.cogentinfo.com/resources/revolutionizing-retail-inventory-management-with-computer-vision>
- [32] ENCORD (2024), How to Leverage Computer Vision in Warehouse Automation, .
- [33] Karthik Vijayakumar (2024), Revolutionizing Warehousing with AI: How Computer Vision is Changing the Game, <https://kartvee.medium.com/revolutionizing-warehousing-with-ai-how-computer-vision-is-changing-the-game-107d33d07d58>
- [34] Neste.AI (2024), Optimizing Retail Supply Chains with Computer Vision, <https://nested.ai/2024/08/04/optimizing-retail-supply-chains-with-computer-vision/>
- [35] Puneet Mangla (2022), Computer Vision and Deep Learning for Logistics, Pyimagesearch, <https://pyimagesearch.com/2022/11/14/computer-vision-and-deep-learning-for-logistics/>
- [36] Katja Busch, Dr. Klaus Dohrmann (2024), AI-Driven Computer Vision, A DHL Perspective on The Impact of Computer Vision in Logistics, <https://www.dhl.com/in-en/microsites/csi/computer-vision/understanding-computer-vision>
- [37] Katja Busch, Dr. Klaus Dohrmann (2023), AI Computer Vision: Trending Technology in Logistics, <https://dhl-freight-connections.com/en/trends/ai-computer-vision-trending-technology-in-logistics/>
- [38] Augmented AI (2023), Enhancing Traffic Management with Computer Vision: Applications and Benefits, <https://www.augmentedstartups.com/blog/enhancing-traffic-management-with-computer-vision-applications-and-benefits>
- [39] PackageX (2023), Computer Vision and Logistics: From Image Acquisition to Decision Making, <https://packagex.io/blog/computer-vision-and-logistics>

- [40]Gaudenz Boesch (2023), 25+ Applications of Computer Vision in Logistics (2024), Viso.AI, <https://viso.ai/applications/computer-vision-in-logistics/>
- [41]Elizabeth Alves (2022), How to Preserve Data Privacy With Computer Vision, AlwaysAI, <https://alwaysai.co/blog/preserve-data-privacy-with-computer-vision>
- [42]Thoo Ai China, Huam Hon Tat, Zuraidah Sulaiman (2015), Green Supply Chain Management, Environmental Collaboration and Sustainability Performance, 12th Global Conference on Sustainable Manufacturing, Procedia CIRP 26 (2015) 695 – 699
- [43]S.K. Mangla, S. Luthra, N. Mishra, A. Singh, N.P. Rana, M. Dora, Y. Dwivedi, Barriers to Effective Circular Supply Chain Management in A Developing Country Context, Production Planning & Control 29 (6) (2018) 551–569.
- [44]Vipin Kumar, Harikumar Pallathadka, Sanjay Kumar Sharma, Chetan M. Thakar, Manisha Singh, Laxmi Kirana Pallathadka (2022), Role of machine learning in green supply chain management and operations management, Materials Today: Proceedings, Volume 51, Part 8, Pages 2485-2489, ISSN 2214-7853.
- [45]Fritz MMC (2020) Sustainable supply chain management. In: Leal Filho W, Azul AM, Brandli L, Özuyar PG, Wall T (eds) Responsible consumption and production, 1st edn. Springer International Publishing, Cham, pp 1–14
- [46]T.A. Gardner, M. Benzie, J. Börner, E. Dawkins, S. Fick, R. Garrett, J. Godar, A.Grimard, S. Lake, R.K. Larsen, N. Mardas, C.L. McDermott, P. Meyfroidt, M. Osbeck, M. Persson, T. Sembres, C. Suavet, B. Strassburg, A. Trevisan, C. West, P. Wolvekamp (2019), Transparency and sustainability in global commodity supply chains, World Development, Volume 121,Pages 163-177,ISSN 0305-750X.
- [47]Moses Kiproticha, Jane Njeri (2024), Supply Chain Visibility and Transparency: Enabling Traceability and Accountability through Machine Learning Technologies, MZ Computing Journal, Vol 5 Issue1.
- [48]X. Li, X. Wang, X. Chen, Y. Lu, H. Fu, and Y. C. Wu, "Unlabeled data selection for active learning in image classification," Scientific Reports, vol. 14, no. 1, p. 424, 2024.
- [49]J. Lei, "Efficient Strategies on Supply Chain Network Optimization for Industrial Carbon Emission Reduction," arXiv preprint arXiv:2404.16863, 2024
- [50]M. M. Morovati, A. Nikanjam, F. Tambon, F. Khomh, Z. M. Jiang, Bug characterization in machine learning-based systems," Empirical Software Engineering, vol. 29, no. 1, p. 14, 2024.
- [51]Muhammad Farooque, Abraham Zhang, Matthias Thürer, Ting Qu, Donald Huisingh, Circular supply chain management: A definition and structured literature review, Journal of Cleaner Production, Volume 228,2019, Pages 882-900, ISSN 0959-6526
- [52]Andrea Genovese, Adolf A. Acquaye, Alejandro Figueroa, S.C. Lenny Koh, Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications, Omega, Volume 66, Part B,2017, Pages 344-357, ISSN 0305-0483.
- [53]Michael Lieder, Amir Rashid, Towards circular economy implementation: a comprehensive review in the context of manufacturing industry, Journal of Cleaner Production, Volume 115, 2016, Pages 36-51, ISSN 0959-6526.
- [54]M. Geissdoerfer, P. Savaget, N.M. Bocken, E.J. Hultink, The circular economy—a new sustainability paradigm, J. Clean. Prod., 143 (2017), pp. 757-768.
- [55]Mark Jackley (2023), What Is a Circular Supply Chain?, Oracle, <https://www.oracle.com/in/scm/circular-supply-chain/>
- [56]Hammaed Hala, Cheraffi Anass, Bengarbitt Youseff, Machine Learning for the Future Integration of the Circular Economy in Waste Transportation and Treatment Supply Chain,IFAC PapersOnLine 55-10 (2022) 49–54
- [57]Farshadfar Z, Mucha T, Tanskanen K. Leveraging Machine Learning for Advancing Circular Supply Chains: A Systematic Literature Review. Logistics. 2024; 8(4):108. <https://doi.org/10.3390/logistics8040108>
- [58]Marc Kloepfel (2024), Barriers to Implementation of AI in Supply Chain: Obstacles to Note and Possible Ways to Overcome It, Medium, <https://medium.com/@markkloepfel/barriers-to-implementation-of-ai-in-supply-chain-obstacles-to-note-and-possible-ways-to-overcome-35753c7d29d4>