Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Machine Learning Deep Learning Applications in supply Chain Management

Ofeoritse Solomon Tuoyo[1], Md Sazidul Islam[2], Md Anayet Ullah[3], Zulkiflee Abdul-Samad[4], Sarder Abdulla Al Shiam[5], Mohammed Alaa H. Altemimi[6], Hafiza Mamona Nazir[7]

[1]Data Scientist/ Project Manager, Masters of Science in Administration, Central Michigan University, USA, tuoyo1os@cmich.edu
[2]MSC in Business Analytics, Trine University, USA, sazid.gub@gmail.com
[3]Student, Masters of Science in Business Analytics (MSBAN), Trine University, USA, anayet148@gmail.com
[4]Department of Quantity Surveying, Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia, zulkiflee1969@um.edu.my
[5]MSC in Business Analytics, Department of Management, St. Francis College, sshiam@sfc.edu
[6]Department of Information and Communication Engineering, Al-Khwarizmi College of Engineering, University of Baghdad, Baghdad, Iraq, mohammed.alaa@kecbu.uobaghdad.edu.iq
[7]Assistant Professor, Department of Statistics, University of Sargodha, Pakistan, mamona.nazir@uos.edu.pk

This paper examines the current level of implementing machine learning and deep learning to meet the challenges and needs of supply chain management. Machine learning and deep learning have been instrumental in revolutionizing decision-making and enhancing the performance of supply chain management operations. While global systems of supply chain continue to become complex, machine learning and deep learning afford appreciable paradigms to deal with issues like demand forecast, inventory control and logistics management. This work analyzes 43 selected peer-reviewed papers and case studies on machine learning and deep learning in supply chain management, having in mind fundamental algorithms that include neural networks, CNNs and reinforcement learning. It discusses how big data sources and predictive analytics models are used to combine real-time decision-making into supply chain management systems. It is evident from the results that both machine learning and deep learning play a central role in the development of issues linked with consumption forecast, route planning, evaluation of risk and prediction of maintenance demands. These technologies enable enhancements in the way that data is preprocessed and predictions. Self-organization has the potential to manage risks within a supply chain. The possible obstacles are data security, the absence of restrictions in the application of algorithms, and the qualification of specialists. The study proves the gross advantages of implementing machine learning and deep learning technologies. These technologies help in driving cost reduction, increasing flexibility, and improving productivity, making them strategic solutions to the growth of the supply chain management businesses.

Keywords: Machine Learning, Deep Learning, Supply Chain Management, Neural Networks, Supply Chain Resilience, Big Data in SCM, Predictive Analytics.

1. Introduction

Supply chain management has now become a very complicated area to master in today's very dynamic business environment that requires optimal means to accomplish its goals and address such key issues as stocks, deliveries, customers, and suppliers. (Khedr, 2024) explained, the emerging technologies affecting the traditional supply chain models are machine learning and deep learning, which are designed for predictive and analytical functions in order to solve complex SCM issues. Implementations and assimilations of Machine learning and deep learning into supply chain management have allowed organizations to boost the precision of forecasting, attain the right inventory stock, lower working expenses and make faster decisions (Tirkolaee et al., 2021). A few studies have addressed the application of machine learning and deep learning in integrating big data from SC sources, offering decisions and improving the tolerance of disruptions (Aamer et al., 2020). Machine learning algorithms are applied for predicting the variation patterns of demand, and the DL approaches are CNNs and RNNs that are helpful in dealing with the several layers of structured data that could be used in finding the optimal route or risk assessment or quality control (Yu et al., 2024). Thanks to recent years' global supply chain disruptions, including the COVID-19 pandemic, the demand for more effective and protective, data-driven supply chain management solutions has emerged (Rolf et al., 2023). The interest in the acquisition of machine learning and deep learning is now focused on risk management, supply chain reliability and protection of competitive advantages for businesses. The application of machine learning and deep learning in SCM is comparatively new and has grown in the last several years as organizations recognized the opportunities in applying data analytics to their operations. Machine learning broadly refers to a range of methods that enable a system to improve the ways in which it identifies patterns in data, responds to new data, and processes tasks without being specifically programmed to do so (Ali et al., 2023). In supply chain management machine learning has mainly been implemented in demand forecasting, inventory management, supplier selection, and transportation management. Deep learning with machine learning that utilizes artificial neural networks with more than one layer is best suited for large-scale and unstructured data types that pervade supply chain operations in the form of images and texts. There are still some issues that have to be met today, for example, data quality, integration with existing systems and privacy (Ali et al., 2023). The increased technological development, continuous innovative solutions appear in real-life settings, so there is a research gap in presenting new insights that explain or identify further potential opportunities in applying both machine learning and deep learning in supply chain management. It is important to undertake a review of the literature within the scholarly work within this field in order to establish the prevailing trend, emerging research gaps, and future research directions. The existing body of knowledge relevant to machine learning and deep learning applications in supply chain management to identify concepts and themes that define the field of supply chain management enhanced by machine learning and deep learning.

Research Motivation

This is the motivation for research into the use of Machine Learning and Deep Learning in Supply Chain Management to improve efficiency and effectiveness in an increasingly complex environment (Wang et al., 2018). These technologies assist the companies in precise demand forecasting, efficient inventory control, analysis of the data for decision making, and other effectiveness features that reduce overall costs. Machine learning and deep learning enhance responsiveness because they work with real-time data, and there is always an opportunity to adapt by customer shifts or supplier unavailability(Islam et al., 2021). They help to improve visibility and constructiveness, which contributes to environmental objectives as companies seek to minimize cost within supply chain. In a rapidly growing market where organizations are forced to embrace technologies that deliver value to their supply chain and clients. Machine learning and deep learning bring automation to supply chains starting with warehouses and even extending to delivery methods that are efficient and minimize human influence due to probability of errors(Kotsiopoulos et al., 2021). It is desire to build better and more, agile supply chain networks that forces organizations to harness the power of machine learning and deep learning in terms of risk assessment, resiliency checks, staying relevant and competitive to achieve sustainability and operational excellence targets (Zhu et al., 2021).

Objectives of the Research

The objectives of this research on Machine Learning and Deep Learning applications in Supply Chain Management are as follows:

- Examine how these technologies help reduce costs and use resources more effectively in supply chains.
- Investigate how machine learning and deep learning models forecast demand, manage inventory and support decisions based on data.
- Assess how these technologies allow quick responses to changes in demand, supply, and market conditions.
- Analyze how these technologies help reduce waste, optimize logistics, and lower environmental impact.
- Explore how machine learning and deep learning automate processes like warehousing, sorting, and delivery, making them faster and more accurate.
- Examine how predictive analytics identify risks, predict disruptions, and strengthen supply chain resilience.
- Identify common issues, such as data quality problems, and explore solutions for successful implementation.

2. Methodology

Systematic Process:

An appropriate search strategy involving specific databases including IEEE Xplore, PubMed and Scopus and versions of keywords joined by Boolean operators is then formulated. The study identification is incorporate identification of relevant studies, screening or initial assessment of the studies and determining the eligibility of the studies and final inclusion of eligible studies. Information is further normalized to collect standard parameters, including study type, type of machine learning and deep learning model used and important conclusions, enabling comparability. A quality assessment is done to used filter higher quality of studies to reduce the risk that conclusions that are made originate from low quality evidence. Data synthesis is done based on themes providing qualitative understanding of machine learning and deep learning applications in supply chain management.

Material Collection:

The search involved the use of two different words that are synonymous with "deep learning, namely deep neural network and deep machine learning, and the word supply chain only. These keywords are used as the key terms that have to be included in the title, abstract or keywords of the articles. The search query used was: "TITLE-ABS-KEY ('Deep Neural Network' OR 'Deep Learning' OR 'Deep Machine Learning') 'Supply Chain'"). The search is conducted in another reputable peer-reviewed database called Scopus. The search returned 193 entries in publications. Out of the remaining 830 sources, 189 were in English after excluding conference proceedings. Filtering the selection to only peer-reviewed journal articles narrowed the overall results to 59, thereby excluding other categories of articles, such as reviews, conference papers, and books. To screen for relevance to the scope of the current review, abstracts of these 59 papers were reviewed. From this process, 16 papers were screened out because they did not form part of the supply chain or they did not include deep learning algorithms. The final population had 43 papers that are regarded as suitable for more detailed examination.

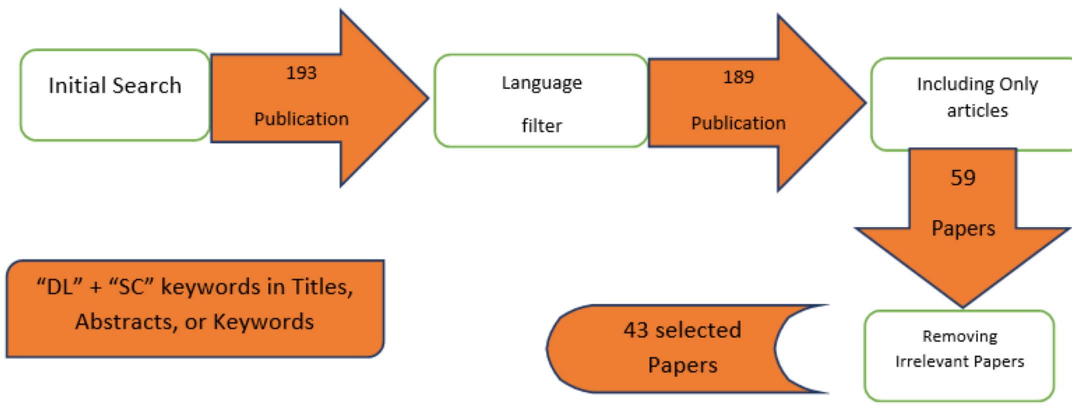


Figure No.01: Summary of Research Process

Table No.01: Main information of the Selected table

Description	Results
Number of documents	43
Number of sources	38
Time span	2018-2023

Author's keywords	154
Average citation per documents	16.23
Average citation per year per documents	5.087

Systematic Literature review results

This research work is methodologically grounded and applies descriptive analysis, structuration, and assessment of 43 identified scholastic peer-reviewed articles.(Hosseinnia Shavaki and Ebrahimi Ghahnavieh, 2023). The identified attributes include methodologies, applied algorithms and SCM areas, and the descriptive analysis briefly sums them up. Structural categories classify the studies by functionalities of supply chain management including demand forecasting, route optimization, and risk management, and methods such as neural networks and CNNs. This evaluation acknowledges fresh progress and key concerns in machine learning and deep learning executions and their applicability to solve supply chain issues and develop their effectiveness (Sharma et al., 2020).

Descriptive analysis

The first approach of the descriptive analysis is to provide an overview of the chosen papers included in the 43 peer-reviewed papers. The criteria covered in this aspect are the methodologies employed, the most utilized machine learning and deep learning algorithms and the primary supply chain management functions addressed (Taherdoost & Brard, 2019). The authors have included trends related to such technology applications as neural networks, CNNs, reinforcement learning, and the integration of predictive analytics with big data. The analysis is arranged according to the main scopes of the studies, including demand forecasting, route optimization, and risk assessment, among others; thereby presenting an understanding of how machine learning and deep learning are applied in mitigating the identified supply chain management issues (Chatzithanasis et al., 2021).

Descriptive analysis based on publication year

Fig. 1 presents the annual trend of scientific papers for the years 2018 to 2023. The total papers presented have increased in the papers of recent years; from the year 2018, the papers have been increasing (Hosseinnia Shavaki & Ebrahimi Ghahnavieh, 2023). This trend persisted up to 2023 this year being the most published year, indicating an emerging interest and achievements in the use of deep learning in supply chain management. This upward trend represents the future direction of the application of these technologies within this field and the future years may continue to experience this upward pattern (Ni et al., 2020).

Descriptive analysis based on authors' country

Figures in the table below show the global distribution of scientific papers on Deep Learning in Supply Chain Management written by researchers of various nations in the period from 2018 to 2023 (Tirkolaee et al., 2021). The United States has contributed most with 102 papers during the period under consideration, largely due to its focus on technology and research in supply chain management. China is second with 82 papers, evidencing the country's increasing attention to applying deep learning to supply chain operations. Germany, the United Kingdom and India contribute substantially, which may be attributed to the research group in these countries. Other countries, of publication Australia reveals an upward trend across all countries with higher numbers in 2022 and 2023, further strengthening the role of deep learning for solving increased supply chain management problems. The Australia contributes small yet regular papers; this shows that the topic is an international concern. The trend of publications by country reveals an upward trend across study, countries with higher numbers in 2022 and 2023, further strengthening the role of deep learning for solving increased supply chain management problems. Altogether, 482 papers have been published during the time of study representing the world-leading ducted across the globe in aiming to incorporate deep learning to improve supply chain managements operations and decisions(Riahi et al., 2021). This trend scenario points to further development and cooperation in this area for world leading companies.

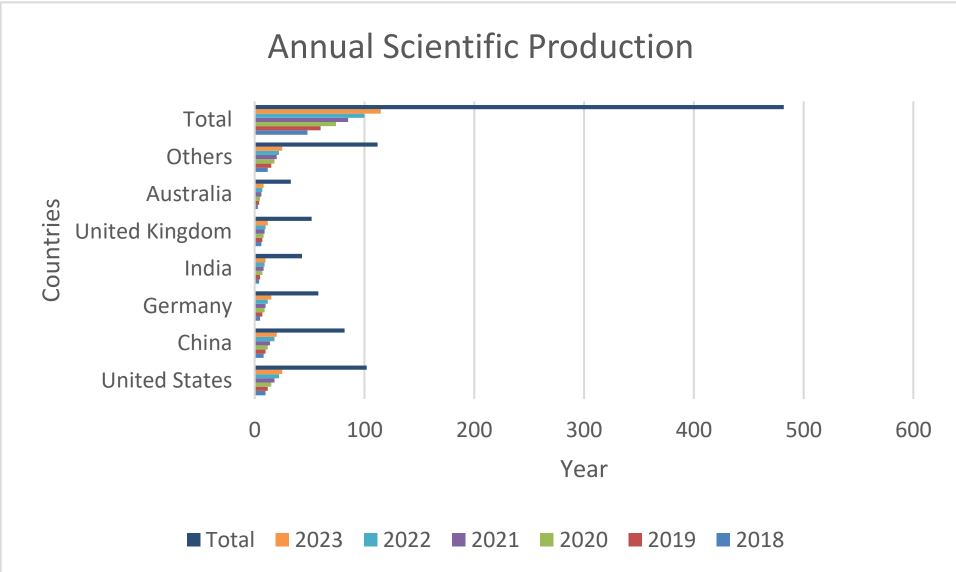
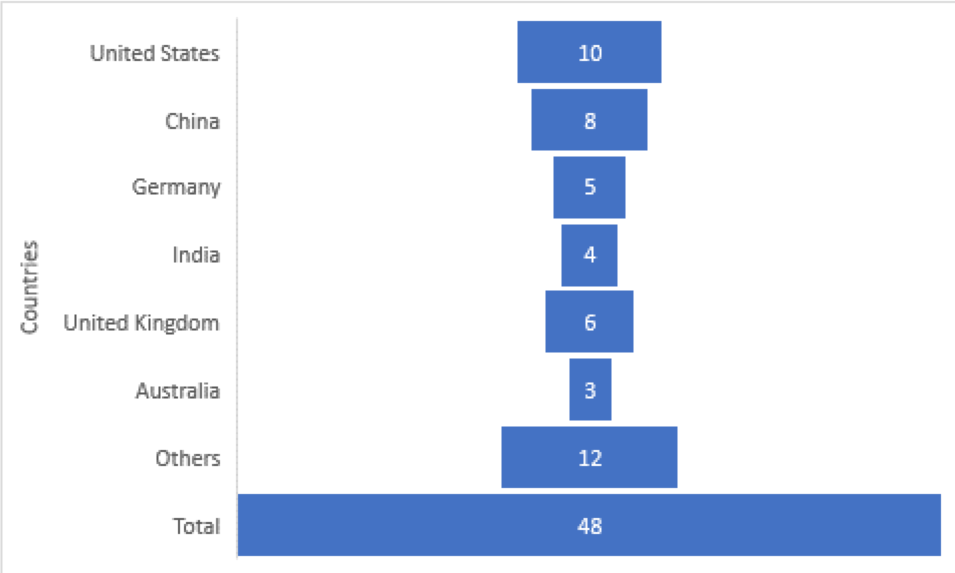


Fig No.02: the number of papers authored by each country from 2018 to 2023

Descriptive Analysis Based on Keywords

The evaluation of keywords from the 43 selected papers shows that the most often used keywords are deep learning, supply chain management, neural networks, predictive analytics, and big data(Akbari & Do, 2021). These keywords indicate the areas of interest for the research, highlighting that the research embraces modern deep learning approaches to use in solving the problem areas in SCM, such as demand forecasting, route arrangements, and risk management. For example, as the current community interests shift from the general algorithms, such as CNNs and reinforcement learning, towards more specific functions, such as inventory management under SCM, the occurrence of these terms increased (Hosseinnia Shavaki & Ebrahimi Ghahnavieh, 2023).



The table presents the distribution of publications by country and the year-by-year analysis from 2018 to 2023 of deep learning SC applications. In the number of publications for each year, the USA has been leading the world, followed by China and Germany. There are noticeable and consistent increases in the research output from countries such as India, the United Kingdom, and Australia(Akbari & Do, 2021). Keywords used from these research papers suggest that publications from 2018 and 2019 reveal basic aspects of the deep learning technology, including "Neural Networks," "Predictive Analytics," etc., while recent contributions from 2020-2023 began to explore the advanced applications of the DL technology: "Reinforcement Learning," "Big Data," "Real-time Optimization," etc. Therefore, the continuous increment in publication numbers of all countries indicates the enhancement of DL as the global solution for sophisticated SCM issues(Riahi et al., 2021).

Descriptive Analysis Based on Journals

Table No.02: Distribution of Publications by Journal (2018–2023)

Journal Name	Number of Papers
International Journal of Production Research (IJPR)	10
Computers & Industrial Engineering	8
Journal of Business Logistics	7
Expert Systems with Applications	6
Transportation Research Part E	5
Others (combined smaller contributions)	7
Total	43

This is true in that the distribution of papers among the various journals defines the interdisciplinarity of deep learning research supply chain management. IJPR and Computers and Industrial Engineering are most prominent in the area, reporting on conceptual developments and applications of DL models in several SCM conditions (Ni et al., 2020). Miscellaneous contributions from other journals represent numerous narrowed-down investigations into the particular issues, for instance, demand forecasting, inventory control, and probability of supply chain failures (Younis et al., 2022). These examples underpin the increasing awareness of the degree to which DL is becoming a more integrated feature of the supply chain process across its various elements.

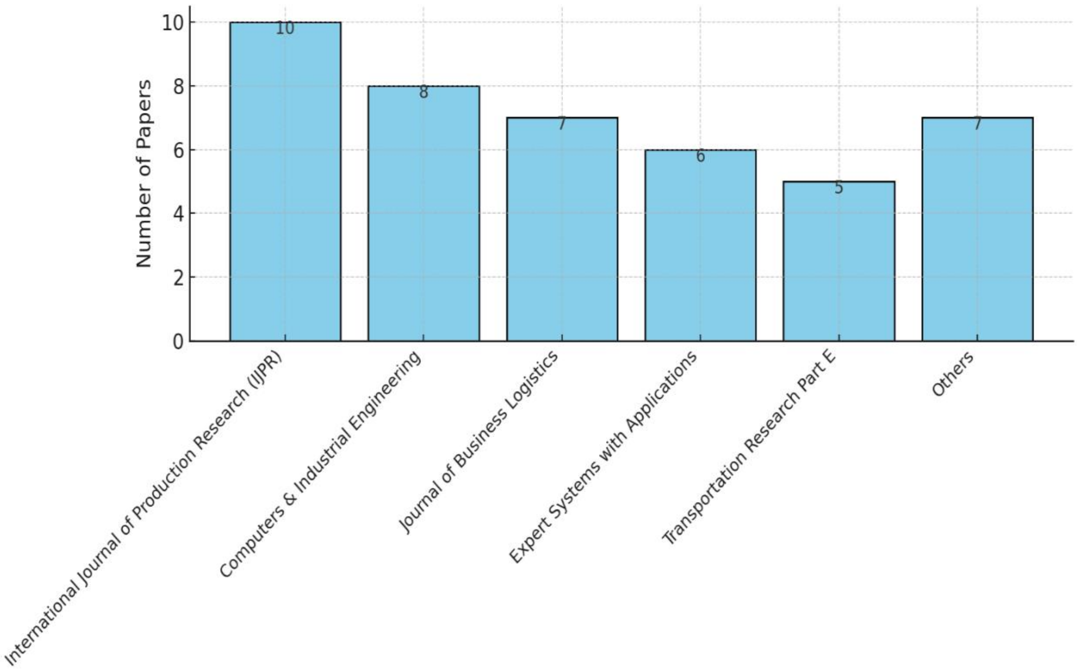


Figure No.03: Distribution of Publication by Journal (2018-2023)

Deep neural network (DNN) and its applications in the SCM

DNNs have numerous revolutionary roles in SCM to improve the decision-making process that covers demand forecasting, inventory control and management, supply chain planning and scheduling, and predictive maintenance. DNNs understand the historical and real-time data precisely and forecast demand, the optimal transportation routes, equipment failure, etc., and save costs and increase the efficiency of a particular system (Huang et al., 2020). DNNs support dynamic optimal price adjustment, the identification of fraud cases, and integrating intelligent chatbots to enhance customer satisfaction (Zhang et al., 2021). These shortcomings that include data quality, computational requirements, and model interpretability, DNNs facilitate more operation, less risk, and better decisions that are critical in supply chain, hence making DNN a crucial tool in supply chain today, as remarked.

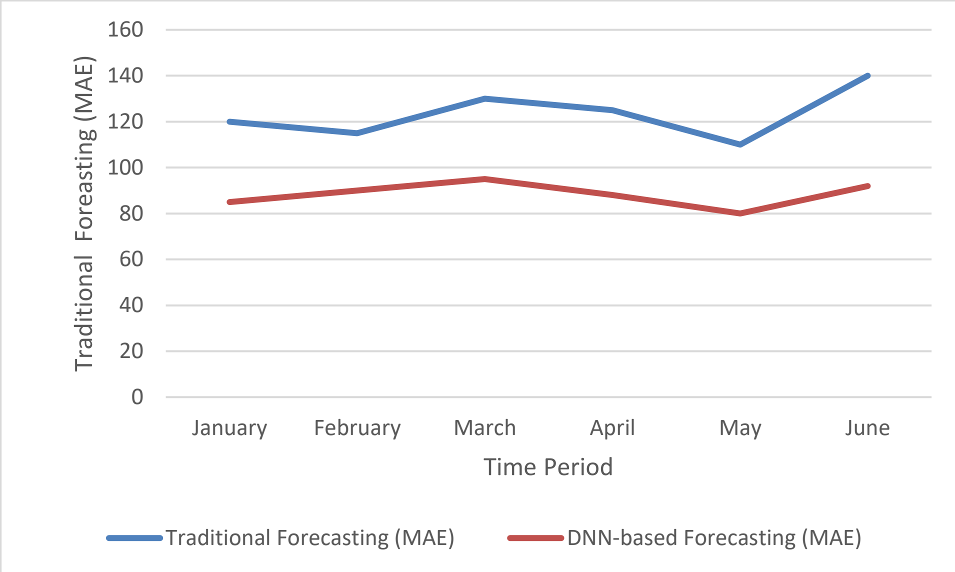


Figure No.04: Demand Forecasting Accuracy Table

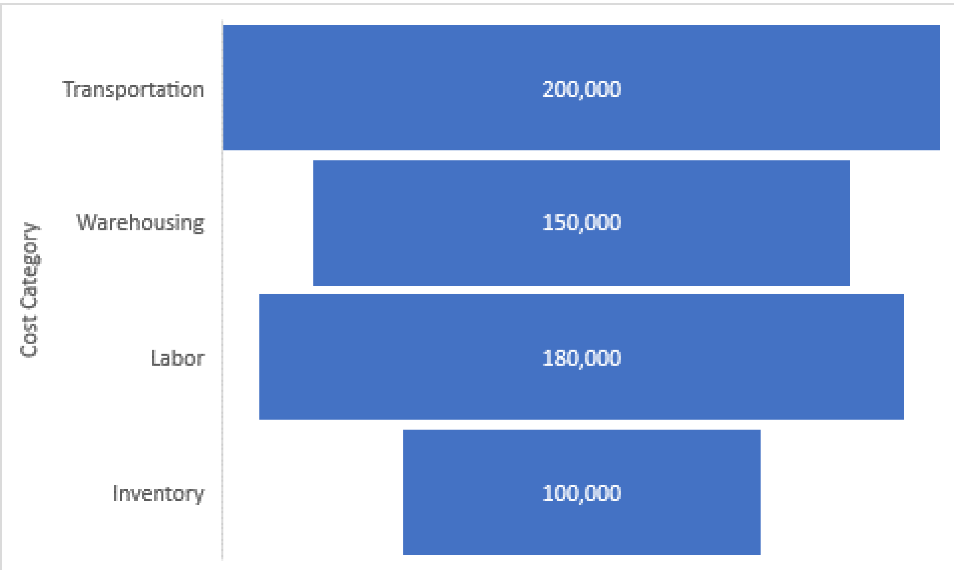


Figure No.05: Supply Chain Cost Reduction Table

Table No.03: Predictive Maintenance: Equipment Downtime Table

Time Period	Pre-DNN Downtime (Hours)	Post-DNN Downtime (Hours)
January	40	20
February	35	18
March	45	22

April	38	15
May	50	25
June	42	20

Applications of Convolutional neural network (CNN) and its variants in the SCM

There is a broad list of applications of Convolutional Neural Networks and their derivatives in Supply Chain Management which enhances supply chain operations and enhances decision-making(Addo-Tenkorang & Helo, 2016). CNNs are most useful in processes such as visual inspection for the presence of defects on products in manufacturing lines and surveillance of the conditions within a warehouse using images from cameras or drones. It serves in managing stock by tracking and sorting products automatically, as well as in routing and navigation in logistics by analyzing real-time visual input. CNNs help in demand forecasting by analyzing some images of shelves and help in the preventive maintenance by analyzing images and detecting whether equipment is going to fail in a short time. Derivatives such as YOLO (You Only Look Once) and ResNet even improve the functionality of CNNs in real-time object recognition and deep feature extraction, which makes CNNs invaluable in risk mitigation, customer satisfaction, and supply chain optimization (Bassiouni et al., 2023).

Deep reinforcement learning (DRL) and its applications in the SCM

Deep Reinforcement Learning integrates RL with DL to allow systems to acquire robust control policies by self-training through a number of iterations within an environment. This combination is very useful in supply chain management since the supply chain continually requires dynamic decision-making, flexibility, sensitivity to conditions on the field, and optimization(Rolf et al., 2023). Thanks to DRL’s ability to learn, generalize, and act in various and diverse scenarios, DRL optimize and even introduce changes in routine repeated activities of SCM that entail stochasticity, delay, noise, and other factors that do not favor mechanistic solutions. Deep reinforcement learning has dynamic uses in inventory management, operations with transport, demand put, and many more. Part of the main areas where DRL is used is where inventory and stock are managed optimally. It is pertinent that the organization retain the appropriate stocks to minimize both costs related to stock-out and those of stock excess (Snyder, 2019). DRL is capable of perfecting inventory control policies by determining the ideal times and quantities for reordering depending on the ever-changing demand, lead times, and unanticipated disruptions in supply chains. Different environmental factors are learned through the continual interaction of the DRL agents with the inventory system(Mongeon & Paul-Hus, 2016). The upshot is that you have pleasing inventory figures, lower expenses, and the ability to respond well to shifts in the market. Another significant use is demand planning, which forms a significant aspect of supply and purchase planning. Most of the traditional approaches to demand forecasting ineffective due to the non-linear nature of existing data(Sutton, 2018). DRL has an ability to learn demand from prior sales and forecast future demand, bearing in mind current and future market trends, and refine its predictions as data increases. This makes the rate dynamic, which is productive in decreasing rate mispredictions, synchronizing supply and demand, and therefore cutting surplus, hence making the supply chain more efficient(Sutton & Barto, 1999). DRL has the strong role of enhancing transportation costs, accelerating delivery time across transportation networks, and controlling fleet resources in transportation and route optimization. DRL algorithms actually fine-tune the delivery routes by comprehending and building from factors such as traffic, weather conditions, and delivery time slots(Thorndike, 1898). DRL models learn from real-time data and environmental conditions to identify efficient routes that are cost-effective, time-saving, and improve on the overall fleet management solutions. Which in turn reduces the cost of transportation, hence enhancing quick and reliable delivery (Kegenbekov & Jackson, 2021). Yet another area where DRL helps out is the management and the layout of the warehouse part of a company. Better furniture services are an important way of improving on the service and cutting down on the costs of operation. Deep reinforcement learning enhance the arrangement of a warehouse because it is able to get used to the actions taken by the workforce in a given warehouse since actions taken include order picking and placement of the items (Minsky, 1961). DRL agents enhance the warehouse flow of operations and the patterns of storage with the long-term benefits of enhancing fulfillment rates, cutting down costs associated with labor, and increasing organizational efficiency. DRL is applied to the design, development, and optimization of the supply chain networks (Minsky, 1961). Supply chain network design requires maximizing overall supply chain performance by selecting multiple aspects like suppliers, warehouses, distribution centers, etc. Deep reinforcement learning assist in finding the right setup of these components for transportation, production capacity, and storage by learning the best decisions. These movements correspond to changes in demand and supply conditions and contribute to the creation of networks that are in many ways cheaper and more appropriate to shifting circumstances. Deep reinforcement learning determine the right resources required for a product as well as enhance the right distribution, of labor and machinery to enhance production throughput and reduce time wastage(Adi et al., 2020). Deep reinforcement learning decides in real-time based on demand and production bottlenecks and optimize the use of resources, avoid delays, and increase production throughput. There is another important area, which is risk management and resilience construction in the supply chains. DRL identify and analyze how to minimize the impacts of disruption risks such as a supplier or a transportation breakdown or a demand fluctuation. The capability to constantly expose its users to the risk scenario and learn from how various strategies manage the risk allows DRL to build supply chain resilience and improve its performance in managing disruptions as well as changing business context. Dynamic pricing optimization is another industrial application of DRL in SCM(Mongeon & Paul-Hus, 2016). Pricing is a sensitive area, especially in competitive markets, when customers' demand and suppliers' supply cannot be easily predicted. Deep reinforcement learning allows companies to make changes in their price setting and react to instances of the market changing and competitors and consumers behaving in a certain way. From these variables, DRL systems learn how best to set their prices in a way that would allow for maximum revenue retention while keeping the prices reasonable so as to not scare off their customers. In supplier selection and relationship management, DRL assist the organization in decision-making by having a look at some factors such as the price offered by the supplier, the time the supplier will take to deliver the products, reliability, and the quality of the suppliers (Mongeon & Paul-Hus, 2016). Deep reinforcement learning models are used for managing supplier relationships by altering the contractual aspects as well as negotiation and critical measurement criteria, helping to build lasting value for the organization. The extent to which supplier relations learned and advanced over some time is likely to enhance supply chain effectiveness and lower procurement expenses. The application of self-driving cars and drones is advancing in the field of SCM with improved logistics and decreasing delivery costs(Adi et al., 2020). DRL provide benefits in navigation where self-driving cars and drones should learn the most effective routes and the most efficient amount of time to deliver their cargo or perform necessary operations. The above technologies driven by DRL are likely to transform last-mile delivery services and lessen operational costs within the supply chain ecosystem. It concluded that deep reinforcement learning is capable of offering numerous beneficial solutions in various contexts of supply chain management, including, but not limited to inventory control, dynamic pricing, transportation, and managing risks (Chong et al., 2022). The ability to learn from landscapes and adjust to changing conditions, there is nothing more effective for automatizing decision-making processes and the effectiveness of the supply chain than DRL systems. There is great potential for DRL to make supply chains wiser, more adaptive, and less costly in the future to help build more robust and efficient supply chain operations in the future (Yunxiang & Zhao, 2024).

4. Research gaps and future directions

Supply chain management is one of the areas where machine learning and deep learning have been reported to greatly transform, but there is still a research gap and challenges in the literature(Ni et al., 2020; Younis et al., 2022). The first limitation is the absence of differentiated by-industry solutions, while most of the works offer general systems that do not consider the specifics of the healthcare sector, automobiles, and others. Third, there is a lack of models created for the context of real-time decision-making; most of the works investigate retrospective data, not the current and evolving ones Another limitation is the integration of machine learning and deep learning with the new promising technologies, including blockchain, IoT, and edge computing is minimal which hinders the possibility to present the integrated supply chain solutions for end-to-end visibility. Actually, there is not enough information about the application of sustainability in the literature and the part that the use of machine learning and deep learning play in decreasing CO2 emissions, using limited resources, and so on. Ethical and social concerns, including privacy, use of robots in employment, and other issues, are often omitted in models, making stakeholders unwilling to accept the technology and regulators unable to approve the use of the technology (Younis et al., 2022). The implementation side, by nature, supply chain data is disjointed and sometimes partially available, which greatly impacts the performance of machine learning and deep learning models and issues regarding data privacy inhibit conglomerate vision (Tirkolaee et al., 2021). Due to the huge resource and sophisticated hardware requirements for training deep learning models, their implementation is still a challenge, especially to SMEs. This further challenges the applicability of these technologies to large and global-scale supply chain systems. This is compounded by the dearth of professionals who are conversant with both SCM and recent developments in machine learning and deep learning techniques and low organizational change-readiness. Overcoming these gaps and challenges opens the possibility for the research to aim at real-time systems, models oriented to sustainability, cross-disciplinary integration, and frameworks for bidirectional cooperation between humans and AI (Tirkolaee et al., 2021).

Proposed Framework for Future Research

The current and future development of machine learning and deep learning applications in supply chain management is neither exhaustive nor optimal; a research framework for future research is needed. There is a need to create models that will be dependent on the sector, and the given market sectors include health, fashion, and automobile industries in consideration of their supply chain (Lin et al., 2022). The real-time decision-making systems have to be a focus as well, such as models that are capable of handling dynamic data in pursuit of tasks such as demand forecasting, inventory, or management of disruptions. Incorporation with progressive technologies such as blockchain for safe data exchange, IoT for real-time tracking, and edge computing for decreased latency forms a strong potential supply chain ecosystem. In addition, sustainability-focused machine learning and deep learning models that could drive the reduction of carbon emissions, minimize waste, and incorporate sustainable supply chains should be designed in line with the global SDGs, such as Climate Action and Responsible Consumption and Production. The technical and operational aspects, responsible data management, avoiding the folding of AI algorithms, and integrating humans into the AI systems should be considered in the future investigation in order to obtain the great acceptance of AI in the supply chain by society and regulation (Dohale et al., 2022). There is a need to develop the shared and adaptable machine learning and deep learning models for other industries and regions of the world. Affordable and effective approaches, especially for small businesses, are important and integrating the cloud-based platforms will help expand the use of such technologies. There is required cross-sector engagement between academia, industries, and governments to creating awareness and training of the existing and future supply chain management professionals and machine learning and deep learning professionals. Having a framework that includes stages of conceptualization and pilot testing, as well as deployment and scaling, this work maps out how the future of research could look like and help drive innovation, sustainability, and global efficiency in supply chain functions (Taherdoost & Brard, 2019).

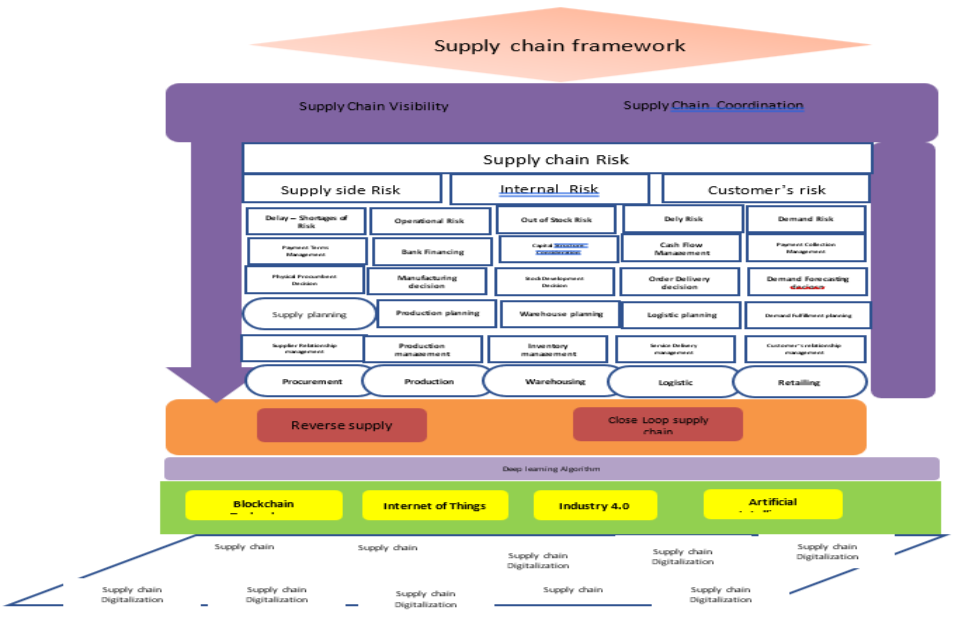


Fig:06: Proposed research framework for the applications of DL in the SCM

Managerial implications

The deployment of key enablers such as machine learning and deep learning in supply chain management opens up exciting possibilities that have practical ramifications for how managers have to design their supply strategies and make operational choices and decisions in the first place (Tirkolaee et al., 2021).

Enhanced Decision-Making:

Machine learning and deep learning models offer prescriptive analysis and real-time detailed information to the managers to make decision-making in areas including demand forecasting, inventory management, and logistics (Rane et al., 2024). It is possible to minimize uncertainty and increase operational effectiveness in this way.

Improved Supply Chain Visibility:

The authors conclude that the implementation of IoT and blockchain with the integration of machine learning and deep learning give managers full end-to-end control, resulting in better tracking and tracing of products, better management of risks and higher transparency to all relevant stakeholders (Kalusivalingam et al., 2020).

Sustainability and Corporate Social Responsibility:

The reportedly advanced models of machine learning and deep learning help managers to integrate sustainable supply chain practices into companies' plans and performance, including the choice of the shortest and most energy-efficient supply routes, minimizing of wastage in manufacture, and implementation of a circular economy (Rane et al., 2024). Such practices not only create a positive image towards international sustainable development objectives but also improve brand image and environmental legal requirements.

Cost Efficiency and Scalability:

Through the use of automated mechanisms, methods, and patterns, managers achieve cost optimization and scale up the business through the use of machine learning and deep learning technologies (Raparthi et al., 2021). The cloud implementation of machine learning and deep learning solves the problem of the accessibility of advanced technologies for SMEs in particular.

Talent and Workforce Development:

The gap arising from supply chain management knowledge and technology must be closed, and managers should consider reskilling and upskilling their employees effectively. Through melding of training programs from various fields one guarantee that teams possessing machine learning and deep learning solutions are capable of supporting these programs (Wilson et al., 2024).

Ethical and Regulatory Considerations:

Managers need to consider issues of ethics like data privacy, biases in algorithms, and loss of employment due to the use of automation(Singh, 2023). There is going to be significant focus on the opportunities that ethical AI implementation policies present and the ways compliance with the data protection laws assist in sustaining stakeholder trust.

Adaptation to Change:

Managers cultivate innovation-friendly environments and encourage the spokespeople of their organizations to embrace change. Barriers to implementing disruptive technologies might be addressed by explaining the advantages of using the machine learning and deep learning integration and engaging workers in the process (Chatzithanasis et al., 2021).

Strategic Partnerships:

Industry solutions suppliers, academic facilities, as well as technology associations assist managers in understanding the progress of utilizing machine learning and deep learning practices in SCM. They equally enable co-creating solutions that are unique, given the unique needs of today's organizations and business operations(Agarwal & Jayant, 2019). Organizations stand to benefit both in operationalizing their supply chain management as well as accruing competitive advantage and sustainability in their deployment of the supply chain management frameworks.

5. Discussion

The use of machine learning and deep learning in supply chain management brings a paradigm shift in supply chain management addressing issues such as complexities, opacity and inaccurate demand planning. The findings raise many factors to point out for optimizing them to their fullest extent for an eventual SOS (Aamer et al., 2020). These field-specific functions are still not fully uncovered by existing general models because they do not take into consideration specific sectorial needs, for example, perishable products in the sector of healthcare or fast fluctuations of trends in the clothing industry. This leaves future research with the important task of developing such solutions tailored to these contexts while at the same time being scalable and transferable across different settings (Woschank et al., 2020). Two prime areas where machine learning and deep learning holds significant potential for supply chain management development is in real-time decision-making, especially in areas of predictive analysis and disruption responses. It lacks today's need and complexity because the current implementations depend on historical data and do not contain adaptive systems (Akbari & Do, 2021). When coupled with the integration of IoT, blockchain and edge computing to machine learning and deep learning they create a comprehensive SCM solution to emerging supply chain management problems. These integrations are vital in sustainability by promoting efficiency and best practices of resource use, minimizing wastage, and achieving zero carbon status. The ethical and social implications of machine learning and deep learning are intensively discussed because of the potential disruption of jobs and human-centric processes. The high computational complexity and cost associated with the deployment of Deep learning solutions are challenges that come with them, especially to the SME firms (Sahoo et al., 2023). Vendor-integrated platforms or low-bandwidth algorithms could help bring about sophisticated technology adoption across the links of the supply chain network. The results point to the need for nurturing an innovation culture, investing in employees, and collaborating with knowledgeable partners to create competitiveness. Sustainability and corporate social responsibility are identified as essential business goals, for which machine learning and deep learning provide means to integrate supply chain management activities with ESG agendas.

It is stated that the examined current issues in SCM express the potential of machine learning and deep learning to improve it but their further evolution depends on the solution of the existing gaps, the enhancement of ethical and sustainable practices, and making them accessible. With strategic and operational plans to drive a firm's functioning facilitates more sustainable supply chain management (Nagy et al., 2023). It is for this reason that future research and actual applications have to focus on these areas if lasting successes and effects are to be achieved.

6. Conclusion

These are among the fields that are set to increase SCM efficiency, visibility and flexibility: machine learning and deep learning. Such technologies enable change in terms of real-time decision-making, analytical forecasting, living sustainably, complete end-to-end supply chain visibility, etc. Critical shortcomings and barriers exist, such as a scarcity lack of generalizability across industries, real-time integration opportunity, and the great cavities of advanced AI application, and the apparent social issues of AI that are privacy and bias problems. The author illustrated earlier that there exist important gaps regarding the application of machine learning and deep learning in supply chain management and filling those gaps is essential to fully unlocking the potential of this emerging technology in supply chain management. The effective use of machine learning and deep learning alongside other emerging technologies like IoT, blockchain and edge computing offers the key direction for the supply chain point of view of creativity, flexibility, and sustainability. The effectiveness of the ethical AI frameworks as well as affordable and inexpensive technologies enable the increased use, particularly among SMEs. There are various key activities that managers, leaders, and organizations should undertake in order to ensure substantive use of these technologies: establish and promote a culture of innovation, increase talent acquisition, and seek new partnerships. There are utilization entails several challenges advancing from technological, operational, ethical, and managerial levels. When such gaps are closed and organizations align their SCM practices with sustainability and ethical considerations, they obtain sustainable competitive advantage, operational robustness and sustainable long-term value for stakeholders in a complex and constantly changing global market. There is a need to undertake future research on these critical areas to achieve the much-needed change brought by machine learning and deep learning in supply chains.

References

1. Aamer, A., Eka Yani, L., & Alan Priyatna, I. (2020). Data analytics in the supply chain management: Review of machine learning applications in demand forecasting. Operations and Supply Chain Management: An International Journal, 14(1), 1-13.
2. Addo-Tenkorang, R., & Helo, P. T. (2016). Big data applications in operations/supply-chain management: A literature review. Computers & Industrial Engineering, 101, 528-543.
3. Adi, T. N., Iskandar, Y. A., & Bae, H. (2020). Q-learning-based technique for reduction of number of empty-truck trips in inter-terminal transportation. ICIC Express Letters, Part B: Applications, 11(10), 987-994.
4. Agarwal, A., & Jayant, A. (2019). Machine Learning and Natural Language Processing in Supply Chain Management: A Comprehensive Review and Future Research Directions. International Journal of Business

Insights & Transformation, 13(1).
5. Akbari, M., & Do, T. N. A. (2021). A systematic review of machine learning in logistics and supply chain management: current trends and future directions. Benchmarking: An International Journal, 28(10), 2977-3005.
6. Ali, M. R., Nipu, S. M. A., & Khan, S. A. (2023). A decision support system for classifying supplier selection criteria using machine learning and random forest approach. Decision Analytics Journal, 7, 100238.
7. Bassiouni, M. M., Chakrabortty, R. K., Hussain, O. K., & Rahman, H. F. (2023). Advanced deep learning approaches to predict supply chain risks under COVID-19 restrictions. Expert Systems with Applications, 211, 118604.
8. Chatzithanasis, G., Filiopoulou, E., Michalakelis, C., & Nikolaidou, M. (2021). A Brokering Model for the Cloud Market. International Conference on Cloud Computing,
9. Chong, J. W., Kim, W., & Hong, J. (2022). Optimization of apparel supply chain using deep reinforcement learning. IEEE Access, 10, 100367-100375.
10. Dohale, V., Gunasekaran, A., Akarte, M. M., & Verma, P. (2022). 52 Years of manufacturing strategy: an evolutionary review of literature (1969–2021). International Journal of Production Research, 60(2), 569-594.
11. Hosseinnia Shavaki, F., & Ebrahimi Ghahnavieh, A. (2023). Applications of deep learning into supply chain management: a systematic literature review and a framework for future research. Artificial Intelligence Review, 56(5), 4447-4489.
12. Islam, S., Amin, S. H., & Wardley, L. J. (2021). Machine learning and optimization models for supplier selection and order allocation planning. International Journal of Production Economics, 242, 108315.
13. Kalusivalingam, A. K., Sharma, A., Patel, N., & Singh, V. (2020). Enhancing Supply Chain Visibility through AI: Implementing Neural Networks and Reinforcement Learning Algorithms. International Journal of AI and ML, 1(2).
14. Kegenbekov, Z., & Jackson, I. (2021). Adaptive supply chain: Demand–supply synchronization using deep reinforcement learning. Algorithms, 14(8), 240.
15. Khedr, A. M. (2024). Enhancing supply chain management with deep learning and machine learning techniques: A review. Journal of Open Innovation: Technology, Market, and Complexity, 100379.
16. Kotsiopoulos, T., Sarigiannidis, P., Ioannidis, D., & Tzovaras, D. (2021). Machine learning and deep learning in smart manufacturing: The smart grid paradigm. Computer Science Review, 40, 100341.
17. Lin, H., Lin, J., & Wang, F. (2022). An innovative machine learning model for supply chain management. Journal of Innovation & Knowledge, 7(4), 100276.
18. Minsky, M. (1961). Steps toward artificial intelligence. Proceedings of the IRE, 49(1), 8-30.
19. Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics, 106, 213-228.
20. Nagy, M., Lăzăroiu, G., & Valaskova, K. (2023). Machine intelligence and autonomous robotic technologies in the corporate context of SMEs: Deep learning and virtual simulation algorithms, cyber-physical production networks, and Industry 4.0-based manufacturing systems. Applied Sciences, 13(3), 1681.
21. Ni, D., Xiao, Z., & Lim, M. K. (2020). A systematic review of the research trends of machine learning in supply chain management. International Journal of Machine Learning and Cybernetics, 11, 1463-1482.
22. Rane, N., Desai, P., Rane, J., & Paramesha, M. (2024). Artificial intelligence, machine learning, and deep learning for sustainable and resilient supply chain and logistics management. Trustworthy Artificial Intelligence in Industry and Society, 156-184.
23. Raparthi, M., Nimmagadda, V. S. P., Sahu, M. K., Gayam, S. R., Putha, S., Kondapaka, K. K., Kasaraneni, B. P., Thuniki, P., Kuna, S. S., & Pattyam, S. P. (2021). Blockchain-Based Supply Chain Management Using Machine Learning: Analyzing Decentralized Traceability and Transparency Solutions for Optimized Supply Chain Operations. Blockchain Technology and Distributed Systems, 1(2), 1-9.
24. Riahi, Y., Saikouk, T., Gunasekaran, A., & Badraoui, I. (2021). Artificial intelligence applications in supply chain: A descriptive bibliometric analysis and future research directions. Expert Systems with Applications, 173, 114702.
25. Rolf, B., Jackson, I., Müller, M., Lang, S., Reggelin, T., & Ivanov, D. (2023). A review on reinforcement learning algorithms and applications in supply chain management. International Journal of Production Research, 61(20), 7151-7179.

26. Sahoo, S., Kumar, S., Abedin, M. Z., Lim, W. M., & Jakhar, S. K. (2023). Deep learning applications in manufacturing operations: a review of trends and ways forward. Journal of Enterprise Information Management, 36(1), 221-251.
27. Sharma, R., Kamble, S. S., Gunasekaran, A., Kumar, V., & Kumar, A. (2020). A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. Computers & Operations Research, 119, 104926.
28. Singh, P. (2023). Digital transformation in supply chain management: Artificial Intelligence (AI) and Machine Learning (ML) as Catalysts for Value Creation. International Journal of Supply Chain Management, 12(6), 57-63.
29. Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of business research, 104, 333-339.
30. Sutton, R. S. (2018). Reinforcement learning: An introduction. A Bradford Book.
31. Sutton, R. S., & Barto, A. G. (1999). Reinforcement learning. Journal of Cognitive Neuroscience, 11(1), 126-134.
32. Taherdoost, H., & Brard, A. (2019). Analyzing the process of supplier selection criteria and methods. Procedia Manufacturing, 32, 1024-1034.
33. Thorndike, E. L. (1898). Animal intelligence: An experimental study of the associative processes in animals. The Psychological Review: Monograph Supplements, 2(4), i.
34. Tirkolaee, E. B., Sadeghi, S., Mooseloo, F. M., Vandchali, H. R., & Aeini, S. (2021). Application of machine learning in supply chain management: a comprehensive overview of the main areas. Mathematical problems in engineering, 2021(1), 1476043.
35. Wang, J., Ma, Y., Zhang, L., Gao, R. X., & Wu, D. (2018). Deep learning for smart manufacturing: Methods and applications. Journal of manufacturing systems, 48, 144-156.
36. Wilson, G., Johnson, O., & Brown, W. (2024). The Role of Machine Learning in Predictive Analytics for Supply Chain Management.
37. Woschank, M., Rauch, E., & Zsifkovits, H. (2020). A review of further directions for artificial intelligence, machine learning, and deep learning in smart logistics. Sustainability, 12(9), 3760.
38. Younis, H., Sundarakani, B., & Alsharairi, M. (2022). Applications of artificial intelligence and machine learning within supply chains: systematic review and future research directions. Journal of Modelling in Management, 17(3), 916-940.
39. Yu, X., Tang, L., Long, L., & Sina, M. (2024). Comparison of deep and conventional machine learning models for prediction of one supply chain management distribution cost. Scientific Reports, 14(1), 24195.
40. Yunxiang, G., & Zhao, W. (2024). Research on Supply Chain Optimization and Management Based on Deep Reinforcement Learning. Scalable Computing: Practice and Experience, 25(6), 4814–4824-4814–4824.
41. Zhu, L., Spachos, P., Pensini, E., & Plataniotis, K. N. (2021). Deep learning and machine vision for food processing: A survey. Current Research in Food Science, 4, 233-249.