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AI Applications in Supply Chain Management: A Survey

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Article

AI Applications in Supply Chain Management: A Survey

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Abstract: The advent of Industry 4.0 and the integration of Artificial Intelligence (AI) is transforming Supply Chain Management (SCM), improving efficiency, resilience, and strategic decision-making capabilities. This research provides a comprehensive overview of AI applications in key SCM processes, including customer relationship management, inventory management, transportation networks, procurement, demand forecasting and risk management. AI technologies such as Machine Learning, Natural Language Processing and Generative AI offer transformative solutions to streamline logistics, reduce operational risk and improve demand forecasting. In addition, the study identifies barriers to AI adoption, such as implementation challenges, organizational readiness and ethical concerns, and highlights the critical role of AI in promoting supply chain visibility and resilience in the midst of global crises. Future trends emphasize human-centric AI, increasing digital maturity, and addressing ethical and security concerns. This review concludes by confirming the critical role of AI in shaping sustainable, flexible and resilient supply chains, while providing a roadmap for future research and application in SCM.

Keywords: Artificial Intelligence (AI); strategic decision-making; Supply Chain Management (SCM); industry 4.0; digital transformation

1. Introduction

In the midst of the fourth Industrial Revolution, where transformative technologies such as Artificial Intelligence (AI), advanced robotics and Internet of Things (IoT) are reshaping production and business overall, the lines between humans and machines are becoming less distinct. And what is more, Industry 5.0 brings humans and technology even closer [1,2]. In general, AI involves the use of computers to perform tasks that are typically run by humans, such as learning, understanding, recognizing, reasoning, and adapting [3]. The economic contribution of AI technologies will reach around 13\$ trillion by 2030 [4], while the supply chain management market is expected to surpass 62.2\$ billion by the same year [5].

Supply chains hold a lot of concern and focus from many enterprises, governments, consumers, and gain broader media coverage [6]. In today's major competitive environment, a cloud supply chain based on Industry 4.0 technologies and digital platforms transforms in the "supply chain-as-a-service" paradigm [7]. The benefits of employing AI in Supply Chain Management (SCM) are resilience improvement [8–10] and risk management [11–13], end-to-end visibility and transparency [2,14,15], information and process resilience [16], real-time tracking of goods in every part of the supply chain [17], sustainability [18], food safety and public health [19].

Past academic work concerning AI in SCM emphasized the need to lessen the current hype [20], brought to the surface the lack of know-how in organizations [21] and the lack of understanding from ordinary decision-makers [22], proposed an AI taxonomy relevant to SCM [4], described the most frequent AI techniques and SCM subfields [23,24], utilized a bibliometric review to trace the evolution of AI research in SCM [2], critically reviewed the drivers, practices, benefits, barriers and consequences of AI adoption [25–27], proposed an AI integration framework [28], and reviewed the effect of AI in

operational efficiency, strategic innovation and sustainability [29]. Moreover, the following studies offered a practical framework of AI applications in SCM [30], reviewed the role of AI in supply chain analytics [31,32], examined the organizational and behavioral factors that promote AI adoption in supply chain [33], introduced a research framework for AI in supply chain resilience [34], and explored the relationship between AI applications and supply chain concentration [35]. Finally, these studies investigated the potential of AI in supply chain visibility [36], evaluated the benefits and challenges of AI in agricultural supply chain [37], examined the relationship between AI and supply chain finance [38,39], and proposed specific officer roles in overseeing AI utilization in SCM [40].

The scope of this research covers a thorough analysis of AI applications in SCM, with a focus on the key processes of the chain. Chapter two and three cover relevant information on supply chain and AI, respectively. Also, chapter three describes specific AI applications in SCM, and more specifically in the areas of customer relationship management, inventory management, transportation networks, procurement, demand forecasting, resilience, and risk management. Finally, chapter four highlights future trends, challenges, and threats of AI presence in SCM and finally, in chapter five, conclusions are presented.

2. Supply Chain

A supply chain can be understood as a network that creates value through interconnected elements. It involves various business sectors working closely together including production, services, funds, and information. The main objective is to ensure that products are available to consumers [41]. It is vital for contemporary businesses to build integrated supply chains with infrastructure and networking features [42]. The SCM research landscape has evolved significantly over time. Initially, the focus was on freight transportation. However, subsequent studies have brought to light other critical areas such as risk [43], performance [44] and integration [45]. In addition, there is an increasing focus on the flow of information within the network of organizational relationships [46], both internally and externally, alongside the management of supply networks. Given these research challenges, the main objective of SCM is to enhance four key flows: goods, information, cash flows and overall processes [47]. A major obstacle to managing the supply chain as an integrated system is the lack of appropriate information technology. Despite the emergence of the industry 4.0 technologies, the significant costs associated with their installation and operation at each stage of the chain have not yet been fully explored [48]. Moreover, there are specific barriers and drivers that allow for a sustainable SCM [49]. Namely, there are social, economic, and environmental concerns on one hand, and technological, competitive, and operational benefits on the other hand.

Key components that are typically included in a SCM framework (Figure 1) are Customer Relationship Management (CRM), inventory management, transportation networks, procurement, demand forecasting, resilience, and risk management. These principal activities play a critical role in both the internal and external aspects of a business, which can be understood as a complex system involving inputs, internal processes, and outputs. There are quite a few challenges and opportunities from implementing AI technologies in the above processes, that both pave the way for a cautious but fruitful transition [20].

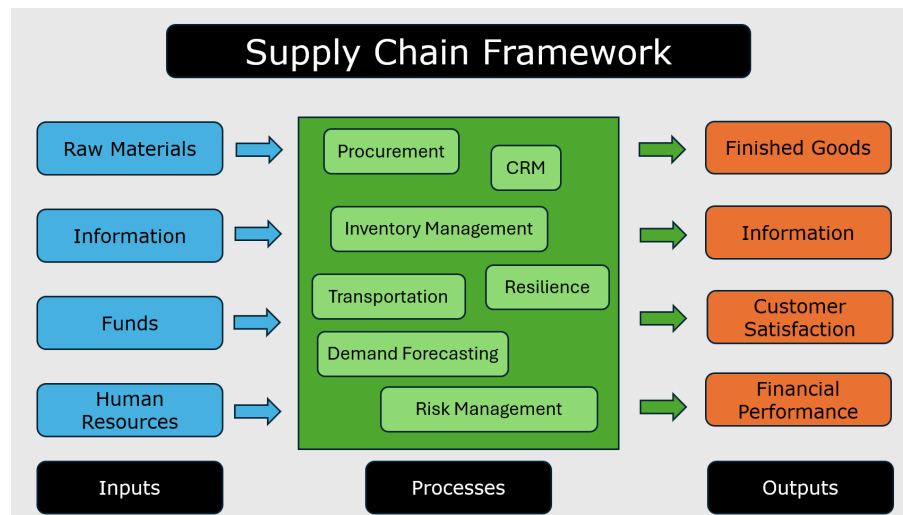


Figure 1. Supply Chain Management Framework: Inputs, Processes, and Outputs.

3. Artificial Intelligence

AI is defined as intelligence that machines can display and emulate all human cognitive functions, such as problem-solving and decision-making to the benefit of organizational optimization and automation. The presence of AI is evident in the fields of agricultural management, education, healthcare, fashion, e-commerce, gaming, and military [1]. The roots of AI go back to the 1950s, and its key techniques include Machine Learning (ML), Deep Learning (DL), Neural Networks (NN), Natural Language Processing (NLP), Computer Vision (CV), Knowledge Representation and Reasoning (KR&R), Recommender Systems (RS), and Optimization (OP) [3,50]. A branch of AI is Generative AI (GEN AI), which can produce a variety of different forms of content, namely, text, graphics, audio, video or other data forms and leverages machine learning models [51]. A prime example of Generative AI is ChatGPT, which offers an adequate number of benefits, but also various threats and challenges to SCM [52,53]. IoT has the leading role of generating data for AI to analyze. Integrating IoT and AI within the SCM context provides notable advancements in supply chain transparency, agility, and overall functionality [54]. Artificial Intelligence of Things, which refers to utilizing IoT to execute smart tasks with the aid of AI integration, is one of these upcoming developments that can convert a complex supply chain into a unified process [55]. Figure 2 depicts various AI manifestations as they have been AI-generated by the Microsoft Designer program.

Nowadays, it is more than evident that AI leads the way in revolutionizing every aspect of SCM and is employed to make educated predictions on demand and transportation routes, suggest innovative solutions, and optimize operations costs [56]. Moreover, the need to make ends meet in a highly competitive environment sets AI as the main force to succeed. Even when faced with a global pandemic crisis, such as COVID-19, AI is a crucial factor that helps management achieve its goals [57]. Furthermore, although there is a hesitation in managers to utilize AI [57], neurosymbolic AI is explicitly suitable to give explanations for every decision based on AI models [58].

Managers' perceptions and intentions in utilizing AI in decision-making are still in a contemplating phase, even though the COVID-19 crisis strengthen business operations through AI [57]. AI-driven SCM optimization delivers a range of benefits that markedly enhance inventory management, improve demand projection, optimize logistics, increase efficiency, productivity, and upgrade decision-making policies [59]. The adoption of AI in supply chain decision-making is also triggered by the Environmental, Social, Governance framework. Respectively, these triggers are product waste reduction and greenhouse gas emissions reduction, product security and quality, and agile and lean practices [60].

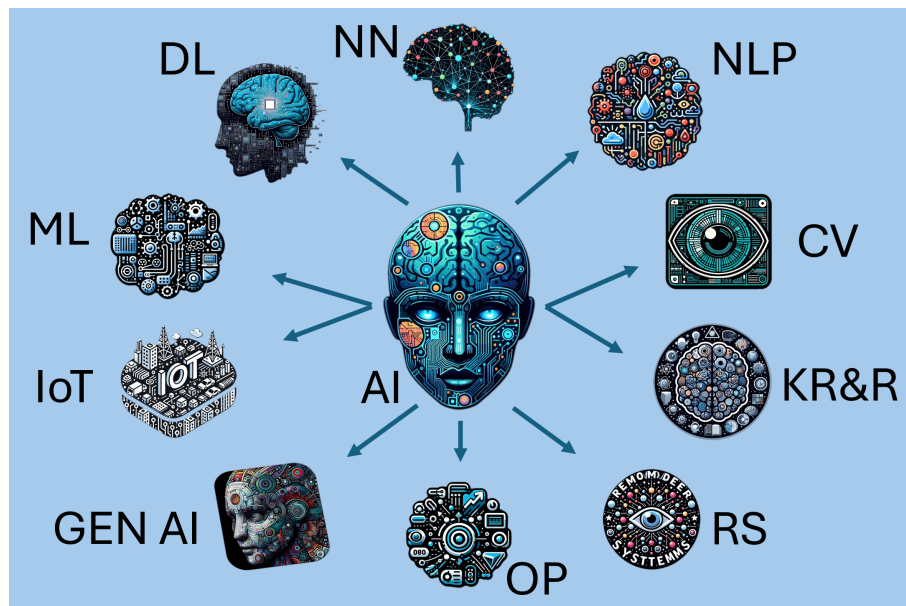


Figure 2. AI manifestations - AI-generated icons.

3.1. Customer Relationship Management

Customer Relationship Management comes to further address and nurture customer needs, boosting the role of classic SCM. An agent-based model that tracks customer experiences in a social network can build upon word-of-mouth reputation to accelerate revenues generation [22]. Chatbots and virtual assistants powered by AI can address customer concerns, manage order fulfillment, support tickets, improve response time and ensure live shipment tracking [14,59].

3.2. Inventory Management

One of the biggest challenges in SCM is inventory management and its relevant cost, as demand patterns change to facilitate diverse needs [61]. AI-powered systems can optimize inventory, when taking into consideration factors such as demand, storage costs, lead time and even supply chain constraints [14]. Integrating AI in inventory management offers numerous advantages, namely reduced stock-outs, minimized overstocking, strategic clearance sales and improved profit margins [17]. AI techniques provide new, innovative ways to inventory control and planning challenges by capturing inventory patterns naked to the human eye [22]. Machine Learning techniques, like reinforcement learning and anomaly detection, are capitalizing on data insights to fine-tune inventory levels. The analysis of historical stock quantities, abrupt changes in trends, and handling of large volumes of data produces informative reports on estimated inventory status [62,63]. Robotic systems assisted by AI and drones can rationalize warehouse operations and automate functions, such as picking, packing [64] and inventory counting [65], leading to accuracy improvement and enhanced use of human resources [14]. In all available picking scenarios, there have been numerous proposed solutions based on simulation and mathematical models. An intelligent agent-based method could handle the added complexity driven by the growing adoption of new and premium services [22]. Large Language Models have played a crucial role in automating inventory management and order fulfillment by enabling advanced data analysis and decision-making capabilities, in areas such as historical logistics data (delivery logs, transportation trends, climatic conditions, and consumer demand predictions) [66].

3.3. Transportation Networks

The supply chain network is the backbone of SCM, as it brings together suppliers, manufacturers, distributors and customers [67]. AI can streamline delivery routes, vehicle loads, and logistics timelines to cut back fuel consumption and save work hours [14]. The use of network theory and graph algorithms allows for a better understanding of the key features of such a network by identifying bottlenecks and facilitating the flow of goods and information [62]. Identifying optimal areas for

logistics, storage facilities, and retail operations requires intricate planning since costs and performance depend on these decisions. AI is a valuable assistant in facility location planning by taking into consideration multiple factors, for example, customer demographics, land costs, transportation infrastructure and regulatory environment [68]. Dynamic route scheduling constitutes a major challenge for SCM, notably the last-mile delivery task. Although there are many heuristic techniques to handle everyday transportation issues, AI really shines in solving this vehicle routing problem, in the forms of genetic algorithms, ant colony optimization algorithms [22] and reinforcement learning [63]. On top of that, Generative AI can be employed to create backup plans to neutralize disturbances such as traffic jams and severe weather [69].

3.4. Procurement

Procurement and resource planning departments have to make everyday decisions concerning volume, capital, and risk related to obtaining items necessary for all operational purposes. Intelligent agent-based systems take up the role of a human decision-maker or provide aid to the purchasing manager with the sequence of strategic and operational procurement choices [22]. Intelligence process automation can refine routine operation, in cases of data entry, order management and invoice processing, while data collected from appliances and machinery is used to predict equipment failure and program predictive maintenance [59]. Generative AI analyzes a lot of parameters, like financial viability, product excellence, dependability, operational effectiveness, and green practices to put together an optimal portfolio of potent suppliers [69].

3.5. Demand Forecasting

The integration of AI into demand projection presents many benefits, such as improved production planning, strategic inventory allocation, risk mitigation and new product development [17]. Machine Learning techniques, like support vector machines, Neural Networks and decision trees are utilizing data-informed insights to produce more precise forecasts and give companies tools to develop dynamic inventory policies to satisfy ever-changing demand [62]. In another research [63], AI techniques used for demand forecasting are the auto-regressive integrated moving average, long short-term memory networks, gradient boosting machines, support vector machines and Deep Neural Networks.

Supply chain demand prediction and administration is a primary focus for SCM, where Artificial Neural Networks, data mining, and fuzzy models are employed to foresee consumer consumption [23]. Demand forecasting is solely based on historical data for existing products and services. In cases where there is a new product or an innovative service, the absence of any chronological records remains deterring for any estimated demand. Precisely for these instances, AI is a viable alternative for sales projection and planning [22]. AI-based analysis of social media, like sentiment analysis [70], can help in gaining deeper insights into customer behaviors and preferences, allowing predictive models to identify potential markets and profit margins [71].

The application of AI in demand forecasting for irregular demands [61] was investigated and the most effective approaches were identified. Neural Networks that were employed improved demand forecast accuracy, especially in cases of intermittent demands, lowering overall financial burdens, such as higher stock levels. Large Language Models have shown noteworthy progress in enhancing demand prediction accuracy by processing and analyzing large volumes of data, in both text and numeric form [66].

3.6. Resilience and Risk

Supply chain resilience is improved with the help of AI in turmoil times. Moreover, firm performance is related to AI and supply chain resilience [72]. Especially, AI improves transparency by employing continuous monitoring, handling last-mile delivery and tailored-made demands and lessens the negative impacts of global crises, like COVID-19 [8,9]. A quality measure of resilience is also important, not just a quantity one. While it is crucial to understand the disruption and recovery actions a firm must take to roll back to normal proceedings, it is even more intuitive to boost the

quality of the network health, by investing in prevention policies [73]. There is empirical evidence that the level of visibility maintained and shared with all supply chain partners defines the impact of disruption events. Thus, AI fosters resilience in the supply chain [74].

Artificial Neural Networks are used to recognize and lessen risks in everyday operations in supply chains. These risk cases are disruptions in supply, variations in demands and shifts in market conditions [75]. Once again, analysis of historical data, patterns and trends can recognize and create risk management policies that alleviate disruptions’ affect and fortify resilience [62]. The integration of Deep Reinforcement Learning and predictive analysis further enhance decision-making processes in real time and anticipate disruptions [76]. The most used AI technique in supply chain resilience is Bayesian Networks, as a thorough approach to evaluate risk, analyze uncertainty, and decide amidst structural dynamics [77]. There is concrete evidence demonstrating that the data processing functionalities of AI impact supply chain performance by enhancing supply chain resilience overall [78]. The numerous successive crises and supply chain instabilities attest to the need for further utilization of AI to bolster resilience.

Additionally, resilience necessitates a forward-thinking approach to risk management, namely identification of potential threats, assessment of likelihood and impact, and implementation of prevention and/or mitigation policies [79]. Risks in SCM can be categorized to supply and demand risk, process and control risk, environmental and information risk [12], and is quantified as the multiplication of its likelihood and effects. Predictive risk management is based on AI methods and instruments, like ensemble learning and Neural Networks to anticipate risks and take actions to mitigate them [63]. Specific AI techniques, including fuzzy logic programming, Machine Learning, Big Data, and agent-based systems could be used to promote resilience in supply chain management [80]. A proactive approach to risk reduction in SCM can be achieved with Generative AI. The continual analysis of specific supplier performance indicators, data obtained from markets and IoT devices, and AI algorithms can identify potential emerging threats and facilitate documented decision-making [69]. Deep Convolutional Neural Networks (DCNNs) demonstrate remarkable efficiency stemming from calculating intricate and nonlinear correlations among variables. The utilization of DCNNs bolsters predictability and robustness in the global supply chain [81]. Large Language Models have demonstrated their worth as essential assets for improving risk assessment and mitigation by analyzing various data sources and delivering actionable intelligence [66].

Table 1 summarizes SCM key activities with their corresponding AI applications.

Table 1. SCM key activities and their corresponding AI apps.

SCM activities	AI apps
Customer Relationship Management	Agent-based Models, Chatbots, Virtual Assistants
Inventory Management	Machine Learning, Robots, Drones, Agent-based Models, Large Language Models
Transportation Networks	Network Theory, Graph Algorithms< genetic Algorithms, Ant Colony Optimization, Reinforcement Learning
Procurement	Agent-based Models, Process Automation, Generative AI
Demand Forecasting	Machine Learning, Support Vector Machines, Neural Networks, Decision Trees, Deep Neural Networks, Data Mining, Fuzzy Models, Sentiment Analysis, Large Language Models
Resilience	Artificial Neural Networks, Deep Reinforcement Learning, Bayesian Networks
Risk	Ensemble Learning, Neural Networks, Fuzzy Logic Programming, Machine Learning, Big Data, Agent-based Systems, Generative AI, Deep Convolutional Neural Networks, Large Language Models

4. Future Trends, Challenges, Threats

The future of AI is promising across all domains of human endeavor and innovation [1], garnering significant academic attention [31,82]. Significant disruptions, such as COVID-19, have commenced a discussion on reversing outsourcing in supply chains and further developing local and in-house manufacturing, utilizing the Manufacturing-as-a-Service model (MaaS) [4]. A shift towards human-centered AI in SCM is expected to manifest in the form of training and specializing human workforce, while boosting AI familiarity among the general population [56]. There is a clear trend in utilizing AI applications to tackle both traditional and fresh problems [24].

Nowadays, AI faces many challenges, namely data privacy [66] and algorithmic bias [83], cybersecurity [66] and ethics [84], absence of transparency and documentation, lack of specialized professionals [31], and implementation challenges [1,63]. Also, there is a lack of evidence to measure its Return on Investment (ROI) in supply management enterprises, thus making it difficult to appraise its value [56]. Managers' attitudes toward adopting AI for decision-making remain in a deliberative stage, despite the COVID-19 crisis highlighting AI's potential to enhance business operations [57]. Additional challenges for AI in SCM are strong dependence on computer software, difficult implementation, and inapplicable in cross-function and cross-border supply chain decision frameworks [22]. On top of that, companies must advance and elevate their degree of digital maturity in their organizational culture context before trying to implement AI solutions in their SCM [85]. Over and above technical challenges, there are organizational hurdles to overcome, namely redefining processes, roles, and responsibilities [83].

The main threats of AI presence in human societies are disruption of current job landscape, use for nefarious purposes, weaponization, and increase in inequalities [1].

Industry 4.0 buzz is not consistent with companies' readiness to adopt its technologies, since they lack the expertise, specifically tied to their existent business domain [21]. Managers should be cautious and not hold lofty expectations [86] to the implications of AI concerning performance, since organizational features are critical as well [20]. Besides AI in SCM, Big Data, IoT, advanced Natural Language Processing, Blockchain [87], Robotics, Autonomous Vehicles and Drones are all crucial fields to explore scientifically for refining even more the management in the supply chain [50,88].

5. Conclusions

This paper highlights the transformative role of AI in revolutionizing SCM within the evolving contexts of Industry 4.0 and the emerging paradigms of Industry 5.0. By leveraging AI technologies, such as Machine Learning, Natural Language Processing, and Generative AI, SCM processes can unlock unprecedented levels of efficiency, resilience, and adaptability. Moreover, this study provides a thorough analysis of AI applications across key supply chain processes, including customer relationship management, inventory management, transportation networks, procurement, demand forecasting, resilience, and risk management. Notable advancements from existing literature are presented including enhanced demand prediction accuracy, optimization of logistics operations, improved supplier and customer relationships, and reduced operational risks, all contributing to a more agile and responsive supply chain ecosystem. Moreover, AI's critical role in fostering supply chain visibility and resilience has been underscored, particularly in mitigating challenges posed by global crises, disruptions, and uncertainties. However, despite these promising developments, several barriers impede the full-scale adoption of AI in SCM. These include technological implementation obstacles, disparities in organizational digital maturity, and concerns around ethics, transparency, and cybersecurity. Addressing these challenges is essential to unlocking AI's full potential for creating dynamic and sustainable supply chains. This comprehensive review outlines guidelines for future research to address these gaps by focusing on optimizing AI integration strategies, fostering digital readiness across industries, and addressing ethical and security-related concerns to ensure equitable and responsible AI deployment. To conclude, embracing a human-centric approach to AI paired with

innovations in AI-driven tools will be vital in shaping sustainable, resilient, and adaptable supply chains.

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Abbreviations

The following abbreviations are used in this manuscript:

Artificial Intelligence	AI
Internet of Things	IoT
Supply Chain Management	SCM
Customer Relationship Management	CRM
Machine Learning	ML
Deep Learning	DL
Neural Networks	NN
Natural Language Processing	NLP)
Computer Vision	CV
Knowledge Representation and Reasoning	KR&R
Recommender Systems	RS
Optimization	OP
Generative AI	GEN AI
Deep Convolutional Neural Networks	DCNNs
Manufacturing-as-a-Service	MaaS
Return on Investment	ROI

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