

RESEARCH ARTICLE

Artificial Intelligence Enabled Supply Chain Management: Unlocking New Opportunities and Challenges

Artificial Intelligence and Application

yyyy, Vol. XX(XX) 1–5

DOI: [10.47852/bonviewAIA42021814](https://doi.org/10.47852/bonviewAIA42021814)



Shankha Shubhra Goswami^{1,*}, Surajit Mondal¹, Shouvik Sarkar² and Krishna Kumar Gupta¹,
Sushil Kumar Sahoo³, Rohit Halder¹

1 Department of Mechanical Engineering, Abacus Institute of Engineering and Management, India.

2 Department of Mechanical Engineering, Durgapur Institute of Advanced Technology and Management, India

3 Department of Mechanical Engineering, Indira Gandhi Institute of Technology, India.

*Corresponding author: Shankha Shubhra Goswami, Department of Mechanical Engineering, Abacus Institute of Engineering and Management, India, ssg.mech.official@gmail.com. ORCID: <https://orcid.org/0000-0002-0033-3089>

Abstract: This paper delves deeper into the potential of Artificial Intelligence (AI)-enabled Supply Chain Management (SCM) as a groundbreaking technology capable of revolutionizing supply chain operations and ushering in a new era of possibilities. In today's dynamic business landscape, where agility and efficiency are paramount, AI plays a pivotal role in redefining how supply chains operate. The journey commences with an in-depth exploration of AI's fundamental concepts and its manifold applications within SCM, shedding light on its adaptability across various aspects of the supply chain, from demand forecasting to inventory optimization. Moreover, this paper illuminates the myriad benefits that AI brings to SCM practitioners. These advantages encompass heightened operational efficiency through real-time data analysis, cost reduction through predictive maintenance and optimized routing and a superior customer experience resulting from improved demand prediction and personalized service offerings. However, acknowledging the transformative power of AI in SCM, we must also acknowledge the hurdles in its implementation. This paper underscores the significant challenges that organizations may face while integrating AI into their SCM processes, ranging from data quality issues and concerns regarding privacy and security to the need for domain-specific human expertise. To address these hurdles effectively, the paper proposes a comprehensive framework. This framework encompasses a holistic strategy that aligns AI initiatives with organizational goals, governance and ethics considerations to ensure responsible AI deployment, and a clear roadmap that guides the implementation journey from inception to full integration. In conclusion, this paper offers valuable insights into the opportunities and challenges that AI-powered SCM presents in the ever-evolving business landscape. By providing practical recommendations, it equips organizations with the knowledge and tools needed to successfully harness the potential of AI in their supply chain operations, ultimately paving the way for enhanced competitiveness and sustainability in the future.

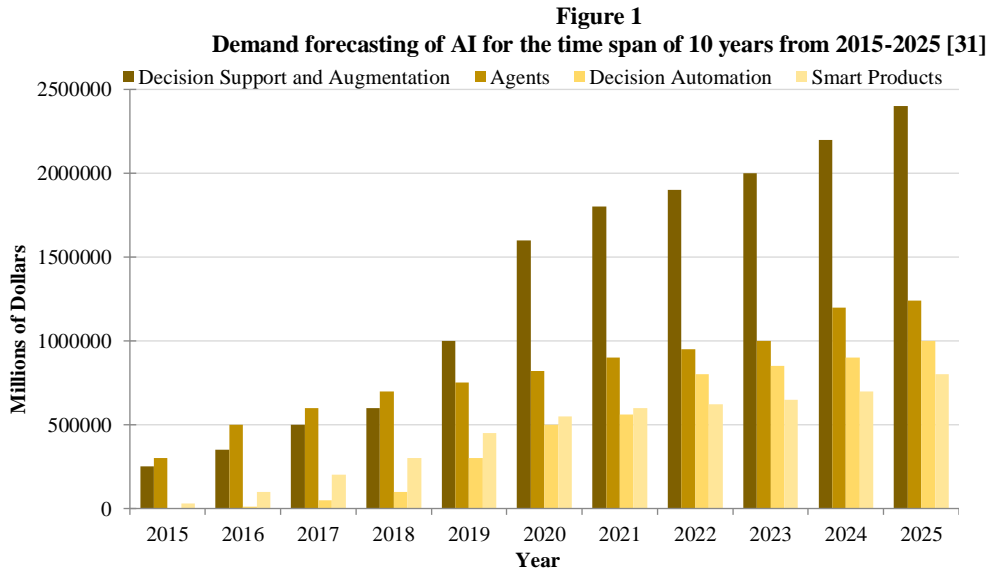
Keywords: artificial intelligence, supply chain management, machine learning, opportunities, challenges

1. Introduction

AI-powered SCM is a rapidly emerging field that uses the most recent developments in AI and Machine Learning (ML) to improve and simplify supply chain processes. AI-powered supply chain management solutions may assist firms in better forecasting inventory demands, reducing waste, accelerating delivery times, and increasing overall efficiency. This technology enables businesses to manage their supply chains with previously impossible levels of precision and agility [32]. As more firms embrace AI-powered SCM systems, the technology's effect is likely to spread across a wide variety of trades and industries, from

industrial and logistics to retail and e-commerce. AI-powered SCM automates and optimizes supply chain processes by integrating multiple technologies such as predictive analytics, ML algorithms, natural language processing, and robots.

These technologies can help organizations gained tremendous attention, enabling them to progress fluently without delays. By analyzing historical sales data, customer behaviour, AI algorithms can generate high stock outs [33]. AI-powered SCM also has the potential to increase supply chain transparency and traceability, which is becoming increasingly important for organizations in industries such as food and pharmaceuticals. By using block chain technology, for example, organizations can create a secure, decentralized ledger that tracks the movement of goods from inventory up to the final delivery. Figure 1 shows the increase in company values throughout a time span of 10 years from 2015 to 2025.



1.1. AI-powered SCM forecast inventory

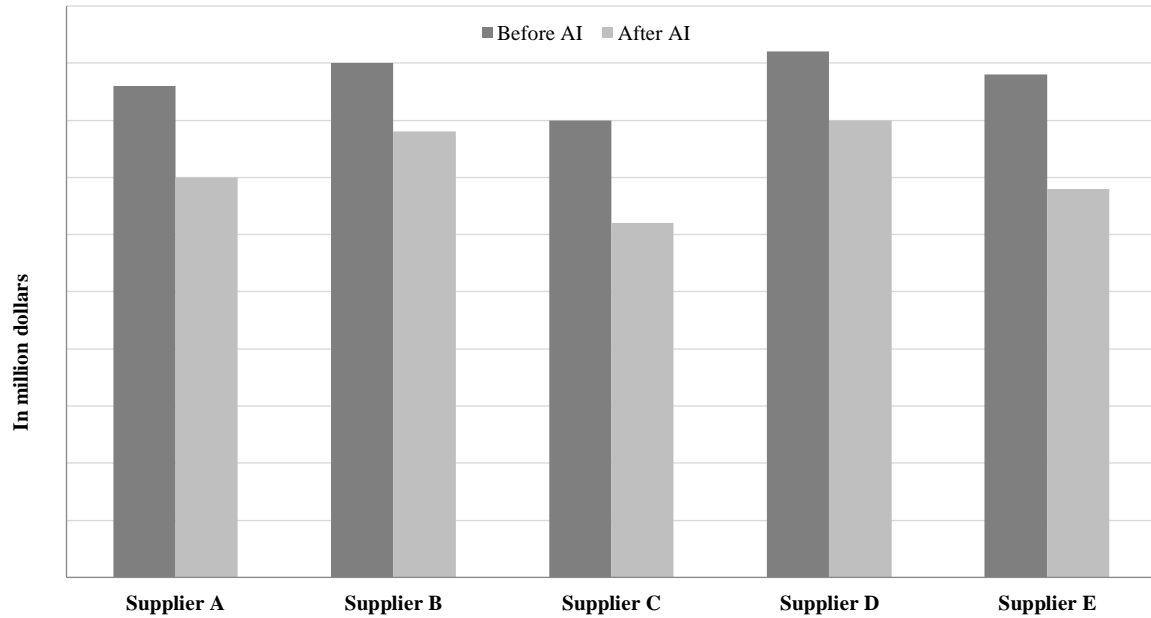
There are several AI techniques that can be used for inventory forecasting that identify patterns and trends that can be used to make predictions about future inventory levels. This technique is particularly useful for short-term inventory forecasting, where there is a lot of historical data available. ML can be used to build predictive models that take into account a wide range of factors that influence inventory levels, including sales data, production schedules, weather patterns, and market trends [16]. These models can be used to generate more accurate and precise inventory forecasts than time-series forecasting. Deep learning is a more advanced form of ML that helps to identify complex patterns and relationships. This technique is particularly useful for forecasting inventory levels in complex supply chains, where there are many interrelated factors that influence inventory levels. A case study has been conducted on five suppliers shown in Table 1. These five suppliers used to supply nut and bolts to a small scale valve manufacturing company located in Howrah, West Bengal, India. The name of the company and the suppliers are completely kept anonymous due to privacy reasons. The data and information presented in Table 1 are collected from the company’s past history [12]. This article tried to figure out the changes and improvement made after the implementation of AI compared to the previous scenario without AI. Figure 2 clearly represents the reduction in inventory carrying costs before and after AI implementation.

Table 1
Five selected suppliers and their ratings
(Source: Collected from the past history of a valve manufacturing company)

Supplier	Quality Rating	On-Time Delivery (%)	Cost Performance (%)	Communication
Supplier A	92	98	95	Excellent
Supplier B	88	96	92	Good
Supplier C	94	94	97	Excellent
Supplier D	86	92	89	Fair

ier D				
Suppl	90	97	91	Good
ier E				

Figure 2
Reduction in inventory carrying costs before and after AI implementation
(Source: Company's recorded database)



AI-powered SCM has transformed the logistics and transportation system by providing new capabilities and efficiencies in areas such as route optimization, capacity planning, predictive maintenance, real-time tracking, and autonomous vehicles [10]. It can help companies augment their logistics and transportation operations services. Route optimization is a key area where AI-powered logistics software can make a significant impact. By analyzing real-time traffic data and weather information, it can enhance delivery routes to reduce delivery times and costs. This can help companies improve their delivery performance and customer satisfaction while also reducing fuel costs and vehicle wear and tear. Capacity planning is another area where AI-powered SCM can be valuable [21]. By predicting future demand for transportation and logistics services, companies can plan for and allocate resources accordingly, avoiding costly underutilization or overutilization of assets.

Predictive maintenance is also an important capability of AI-powered logistics and transportation. By monitoring the condition of transportation equipment and improving asset reliability [11]. Real-time tracking is another area where AI-powered logistics and transportation make the difference. It can proactively manage their logistics operations and provide more accurate and timely deliveries to their customers. Finally, autonomous vehicles such as drones and self-driving trucks are an emerging capability of AI-powered logistics and transportation. These vehicles can advance proficiency and diminish costs by eliminating the need for human drivers, dropping fuel consumption, and refining delivery times [31]. Overall, AI-powered SCM has the potential to renovate logistics and transportation by providing new capabilities and efficiencies that were previously impossible. By leveraging the power of AI, companies can gain a competitive advantage in the logistics and transportation market while also improving their customer service and reducing costs.

1.2. Significance on AI-powered SCM

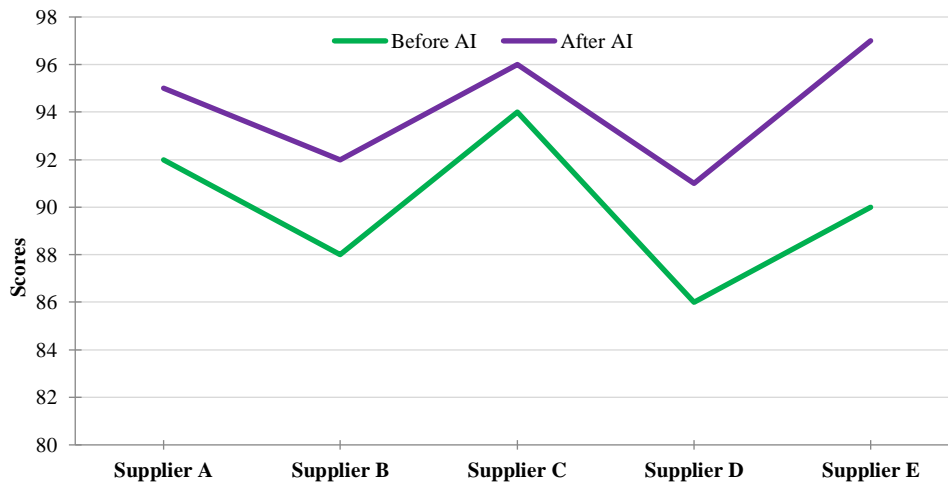
AI-powered SCM is a rapidly growing field that uses AI technology to optimize and streamline the supply chain process [22]. Here are some potential benefits of AI-powered SCM.

- AI-powered technologies may automate operations, evaluate statistics, and optimize supply chain processes, leading to increased competency and lower costs [13]. This might result in higher profitability and a competitive edge in the market.

- AI-powered supply chain management may improve decision-making and predictive analytics for businesses [35]. This aids forecasting, organization, and portfolio management, all of which can lead to increased customer satisfaction.
- AI-powered supply chain management improves transparency for consumers. This aids in identifying possible dangers, reducing delays, and preventing noncompliance with rules [23].
- AI-powered supply chain management may improve sustainability by reducing waste and carbon impact. This might boost company reputation and attract environmentally sensitive clients.
- AI-powered SCM improves supply chain resilience by anticipating and responding to diversions like natural catastrophes and supply chain problems [30]. This can assist to mitigate the effects of these occurrences on the company and its consumers.

AI-powered SCM may help make better judgments, boost transparency, improve sustainability, and strengthen supply chains. Figure 3 clearly shows the improvement in supplier performance scores before to and following AI installation.

Figure 3
Improvement in supplier performance scores before and after AI implementation
(Source: Company's recorded database)



2. Literature Review

A study by Yeo et al. [37] offers a thorough analysis of AI applications in SCM, covering SCM, quality assurance, and logistics optimization. The writers also cover the difficulties adopting AI, including the necessity for skilled workers and the standardization of data. In-depth analyses of AI applications in SCM, such as demand predicting, portfolio organization, and quality control, are provided in a study by Pillai et al. [24]. The authors also cover the possible advantages of AI in SCM, including increased productivity, lower costs, and better judgement. Kumar et al. [16] offered a thorough analysis of AI's uses in SCM, including inventory control, logistics planning, and supplier management. The authors also talk about difficulties adopting AI, like poor data quality and privacy issues. The application of AI in SCM offers plentiful welfares, including the need for data standardization, documents discretion concerns, and the requirement for trained employees.

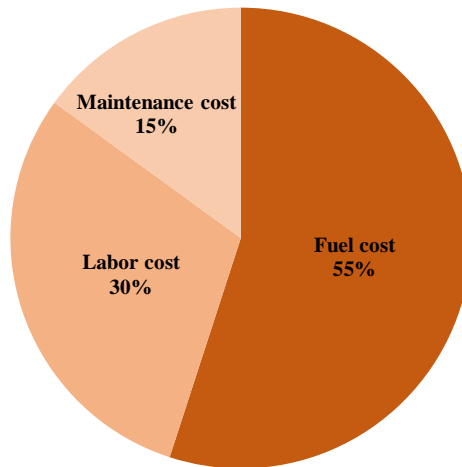
2.1. Applications of ML in SCM

ML has become an increasingly popular tool for SCM due to its ability to analyze vast quantities of records and recognize arrays and trends. Below are some relevant studies on ML in the field of SCM. Zawish et al. [38] provided an overview of the current state of ML in SCM, including applications such as demand forecasting, inventory management, and logistics optimization. The authors also discuss the challenges associated with implementing ML in SCM, such as data quality and availability. In addition, Belhadi et al. [6] also discussed about the potential benefits of ML in SCM, such as improved efficiency and cost savings. They conclude by outlining several research directions for future studies in this area. ML has been increasingly applied in SCM to improve decision-making, reduce costs, and enhance efficiency. In recent years, researchers have conducted various studies on the integration of ML techniques in SCM. This literature review summarizes some of the most relevant research works that explore the benefits, challenges, and applications of ML. One of the primary benefits of ML in SCM is its ability to process large amounts of data quickly and accurately.

For instance, in their study on warehouse optimization, Akter et al. [1] used ML algorithms to analyze data from sensors and cameras, enabling them to predict congestion and improve the layout of the warehouse. Similarly, in a study on supply chain risk management, Liu et al. [20] employed an ML-based approach to analyze data from social media platforms and news sources, enabling them to identify potential risks and take preventive measures. Another area where ML has been applied in SCM is demand forecasting. Researchers have found that ML algorithms can provide more accurate demand forecasts compared to traditional statistical models. For example, Mahmoud & Slama [21] used a deep learning algorithm to forecast demand for automotive spare parts, achieving better accuracy than traditional statistical models. Likewise, Leitner-Hanetseder & Lehner [18] used ML algorithms to predict the demand for perishable goods, which helped improve inventory management and reduce wastage. ML has also been applied in SCM for quality control and defect detection. For instance, Dennehy et al. [9] used a convolutional neural network (CNN) to analyze images of products and identify defects, achieving high accuracy in defect detection. Similarly, in a study on detecting counterfeit products, Bibi et al. [7] used an ML-based approach to analyze images and distinguish between genuine and counterfeit products. Despite the benefits of ML in SCM, there are also some challenges to its implementation.

One of the most significant problems is the necessity for competent professionals to create and maintain ML models. SCM practitioners may lack the essential ML skills, and there is a paucity of data scientists that specialize in SCM [34]. Finally, machine learning offers huge promise for improving decision-making and efficiency in supply chain management. Its advantages in demand forecasting, quality control, and risk management have been established in several studies. However, its successful deployment involves resolving issues like as data quality and a trained labor scarcity. As a result, academics and practitioners must continue to investigate effective ways to incorporate machine learning into supply chain management. These studies indicate that ML has tremendous potential to enhance SCM performance by allowing for more accurate forecasting, better inventory management, and more effective logistics operations. However, successful ML application in SCM necessitates careful evaluation of data quality and availability, as well as organizational and technological aspects [13]. According to recent research, AI-enabled SCM may save up to 55% of fuel, 30% of labor, and 15% of maintenance costs in supply chain operations, as seen in Figure 4, resulting in an overall cost reduction in logistical operations.

Figure 4
Distribution of cost savings resulting from logistics optimization
(Source: Company's recorded database)



2.2. Impact of natural language processing in SCM

Natural Language Processing (NLP) is an area of AI that has been increasingly applied in SCM to improve communication, automate processes, and enhance decision-making. This literature review summarizes some of the most relevant research works that explore the benefits, challenges, and applications of NLP in SCM. One of the primary benefits of NLP in SCM is its ability to automate communication and improve collaboration among stakeholders. For instance, in their study on supply chain risk management, Modgil et al. [22] employed an NLP-based approach to analyze data from social media platforms and news sources, enabling them to identify potential risks and communicate with relevant stakeholders. Similarly, in a study on supplier selection, Zhou et al. [39] used NLP algorithms to analyze supplier contracts and automate the evaluation process. Another area where NLP has been applied in SCM is demand forecasting. For example, Salhab et al. [29] used an NLP-based approach to

analyze customer reviews and social media posts, enabling them to predict demand for fashion products more accurately. Likewise, Sahoh et al. [26] used NLP algorithms to analyze customer feedback and improve demand forecasting for consumer goods.

NLP has also been applied in SCM for information extraction and classification. For instance, in their study on product information extraction, Attaran [3] used an NLP-based approach to extract product attributes from unstructured data sources such as product descriptions and reviews. Similarly, in a study on supply chain disruption classification, Kumar et al. [17] employed an NLP-based approach to classify disruption events and enable rapid response. Despite the benefits of NLP in SCM, there are also some challenges to its implementation. One of the main challenges is the complexity of the language used in SCM. SCM uses a broad range of technical terminology, jargon, and acronyms, making it difficult to create correct NLP models. Another difficulty is the demand for high-quality data. NLP algorithms require a vast quantity of data to train efficiently, and data quality is important to model correctness. Finally, NLP offers huge promise for improving communication, decision-making, and efficiency in supply chain management. Its advantages in demand forecasting, information extraction, and risk management have been established in several studies. However, successful implementation necessitates resolving issues such as language difficulty and data quality. As a result, researchers and practitioners must continue to look for new approaches to successfully incorporate NLP with SCM.

2.3. Novelty and research gap on AI based SCM

Artificial intelligence is rapidly being used in supply chain management to increase efficiency, accuracy, and agility. However, there are still research gaps regarding the full potential of AI in supply chain management. Here are some probable research gaps and unique methods to AI-based Supply Chain Management.

- While AI offers significant promise for enhancing supply chain operations, its integration with other technologies such as blockchain, IOT, and big data analytics is not widely explored. There is a need to examine how AI may be used with these technologies to improve supply chain efficiency and transparency.
- Ethical and sustainability problems should be considered when deploying AI-based supply chain management, notwithstanding its potential for cost savings. Researchers can investigate ways to balance the benefits of AI with ethical and sustainability concerns, such as the influence on labor, the environment, and social responsibility.
- Human-machine collaboration: As AI becomes more prevalent in supply chain management, it's important to explore efficient ways to combine humans and machines for maximum performance. Researchers can investigate ways to create human-machine interfaces that allow for productive cooperation, decision-making, and communication.
- Optimizing supply chains requires coordination among stakeholders across organizations. Research can look at how AI might help inter-organizational collaboration by enabling real-time communication and decision-making, as well as offering insights into supply chain performance.
- As supply chain systems become more complex and dynamic, it's important to explore how AI-based SCM may improve resilience and flexibility. Research may look at how to create AI algorithms that can deal with uncertainty and unexpected occurrences, as well as how to construct SCM systems that can adapt to changing market conditions and client demands.

In conclusion, while AI-based SCM has demonstrated considerable promise, research needs remain in areas such as AI integration with other technologies, ethical and sustainability issues, human-machine cooperation, inter-organizational collaboration, and robustness and adaptability. Addressing these limitations can result in new methods to AI-based SCM that increase supply chain efficiency, transparency, and sustainability.

3. Positive and Negative Outcomes of AI-Powered SCM

There are several potential benefits of AI-powered SCM. Here are a few of them.

- Improved efficiency by allowing supply chain managers to quickly assess knowledge [5]. This can result in increased efficiency and faster reaction times.
- AI algorithms improve SCM accuracy by eliminating human error in demand forecasting, inventory management, and product shipment.
- AI-powered supply chain management may save costs by automating development and reducing mistakes.
- AI can give real-time visibility into the supply chain, allowing managers to watch inventories, monitor shipments, and identify potential interruptions before they cause big concerns.

AI-powered SCM is better known for its accuracy, cost savings, and better decision-making. While there are many potential positive outcomes of AI-powered SCM, there are also some potential negative outcomes to consider. Here are few examples.

- AI-powered supply chain management may automate monotonous operations, potentially leading to job displacement [24]. Workers who formerly performed those duties may need to be retrained or seek other employment.
- AI-powered supply chain management systems may be exposed to security breaches and cyber-attacks. If an attacker obtains access to the system, they may disrupt or compromise the whole supply chain.
- If the data is erroneous or partial, the subsequent judgments may be faulty [27]. Overreliance on technology without sufficient checks and balances can result in poor decision-making and a lack of flexibility in the face of unforeseen circumstances.
- AI-powered SCM may create ethical problems including data privacy, spying, and algorithmic prejudice [38].

To summarize, while AI-powered SCM has numerous potential benefits, firms must also examine the possible drawbacks and take efforts to prevent them. However, AI increases accuracy, efficiency, cost-effectiveness, and sustainability while allowing for more proactive and data-driven decision-making. Table 2 shows a comparison table of the important KPIs and gains obtained using AI versus traditional supply chain management approaches.

Table 2
Comparisons between AI-Enabled SCM and traditional SCM
(Source: Author's own elaboration)

Metric	AI-Enabled SCM	Traditional SCM	Improvement with AI
Demand Forecast Accuracy	Improved	Less accurate	Higher forecast accuracy
Inventory Optimization	Efficient	Manual, suboptimal	Lower carrying costs, less waste
Logistics Optimization	Optimized routes	Manual planning	Reduced transportation costs
Supplier Performance	Data-driven analysis	Manual assessment	Enhanced supplier relationships
Risk Mitigation	Predictive analytics	Reactive approach	Proactive risk prevention
Customer Service Efficiency	Chabot's 24/7 support	Limited support	Improved response times
Quality Control	Computer Vision	Manual inspection	Reduced defects, improved quality
Sustainability Metrics Monitoring	Environmental analysis	Limited monitoring	Reduced environmental impact

4. Contribution of AI for Optimizing Supply Chain Processes

AI has greatly enhanced supply chain operations. It has altered the way businesses manage their supply chains, boosting efficiency, cutting costs, and enhancing overall performance [14]. Here are three key ways AI may assist with supply chain efficiency.

4.1. Real case study example of demand forecasting

Walmart, one of the world's largest retailers, uses AI to optimize its supply chain operations. In 2019, Walmart implemented an AI forecasting system to improve its inventory management and reduce waste [8]. The AI system uses ML processes to examine past trades data, and weather patterns to forecast forthcoming demand. The system also takes into account seasonal trends and other external factors that may impact demand [36]. By using the AI system, Walmart was able to diminish its portfolio carrying costs by 7.5% and progress its overall inventory accuracy by 10%. The system also helped Walmart reduce its waste by 6%, as the company was better able to manage its inventory levels and avoid overstocking. In addition to improving inventory management, the AI system also helped Walmart optimize its logistics operations. By having more accurate demand forecasts, Walmart was able to better plan its transportation routes, reducing transportation costs and improving delivery times. Walmart's use of AI for demand forecasting has helped the company optimize its supply chain operations and improve its bottom line [22]. By having more accurate demand forecasts, Walmart has been able to reduce waste, improve inventory accuracy, and optimize its logistics operations. AI-powered demand forecasting provides businesses with a more accurate and timely ways of predicting future demand, helping them optimize their supply chain operations and improve their bottom line.

4.2. Real case study example of inventory management

Zara, the popular fashion retailer, uses AI to optimize its inventory management processes. Zara's AI system, called "Store Mode," analyzes sales to improve customer satisfaction [4]. The Store Mode system uses ML concept to analyze sales data from Zara's retail stores. The system then uses this data to optimize inventory levels at each store, ensuring that each store has the accurate products in stock at the right time. The organization also helps Zara reduce waste by ensuring that each store only stocks the products that are in demand [19]. By analyzing real-time sales data, the system can recognize the sales, allowing Zara to adjust its inventory levels accordingly. In addition to optimizing inventory levels, the Store Mode system also helps Zara improve its logistics operations. By having more accurate demand forecasts, Zara can improve its carriage routes and decrease carrying costs. Zara's use of AI for inventory management has helped the company reduce waste, improve customer satisfaction, and optimize its supply chain operations [1]. By using AI to analyze sales data and optimize inventory levels, Zara has been able to improve its bottom line and enhance its competitive advantage in the fashion industry.

4.3. Real case study example of logistics optimization

DHL, the global logistics provider, uses AI to optimize its logistics operations. DHL's AI system, called "NEXAI," analyzes data from multiple sources to optimize routing, transportation modes, and carrier selection. NEXAI uses ML algorithms to analyze data on customer orders, carrier performance, traffic patterns, and other relevant factors. The system then uses this data to optimize transportation routes and carrier selection to reduce transportation costs and improve service levels. In addition to optimizing logistics operations, NEXAI also helps DHL improve its environmental sustainability [37]. By optimizing transportation routes and modes, NEXAI helps DHL reduce its carbon footprint and meet its sustainability goals. DHL's use of AI for logistics optimization has helped the company reduce costs, improve efficiency, and enhance customer service levels. By using AI to analyze data and optimize logistics operations, DHL has been able to improve its bottom line and enhance its competitive advantage in the logistics industry.

4.4. Real case study example of quality control

PepsiCo, the global food and Beverage Company, uses AI to improve quality control in its production facilities. PepsiCo implemented an AI-powered system called "PepsiCo Food for Good" that uses ML algorithms to analyze data from various sources, including production equipment, quality control sensors, and environmental sensors. The system uses this data to identify patterns and anomalies that could indicate quality issues or equipment failures [2]. The algorithms can also predict equipment failures and maintenance needs, allowing PepsiCo to schedule maintenance proactively and minimize downtime. PepsiCo Food for Good also includes a computer vision system that inspects products for defects and quality issues. The technology may identify flaws such as discolouration, malformed items, and other concerns that may affect product quality [25]. The device can also identify pollutants such as foreign objects, guaranteeing that PepsiCo goods are safe to drink. PepsiCo has improved productivity, reduced expenses, and improved product quality by utilizing artificial intelligence for quality control. The technology has also helped PepsiCo retain its commitment to sustainability by lowering waste and resource consumption. PepsiCo's use of AI for quality control exemplifies how AI may enhance quality control in supply chain operations [15]. PepsiCo has been able to discover quality concerns proactively, limit downtime, and improve customer satisfaction by analyzing data and employing machine learning algorithms and computer vision systems.

4.5. Real case study example of risk management

Maersk is a global logistics company that uses AI-powered algorithms for risk management in its supply chain. Maersk uses an AI-powered system called "Risk Intelligence" that analyzes data from a variety of sources, including weather patterns, port congestion, vessel movements, and geopolitical events. The system uses this data to predict potential risks and provide recommendations for mitigating those risks. For example, if a potential storm is detected that could impact the transportation of goods, the system can recommend alternative routes or modes of transportation to ensure that the goods are delivered on time. Maersk also employs AI-powered data to improve its supply chain operations. The firm employs algorithms to evaluate data on cargo quantities, shipping routes, and modes of transportation in order to uncover potential for increased efficiency and cost savings. By streamlining its supply chain processes, Maersk can decrease the risk of interruptions and delays while also increasing customer satisfaction and lowering expenses. Maersk's use of AI for risk management exemplifies how AI may be used to improve supply chain processes. Maersk can proactively recognize potential hazards and take remedial action by analyzing data and using ML algorithms to guarantee that items are delivered on time and at the lowest feasible cost. By employing AI to manage its operations, Maersk can lower the risk of interruptions and delays while enhancing customer satisfaction and cost reduction.

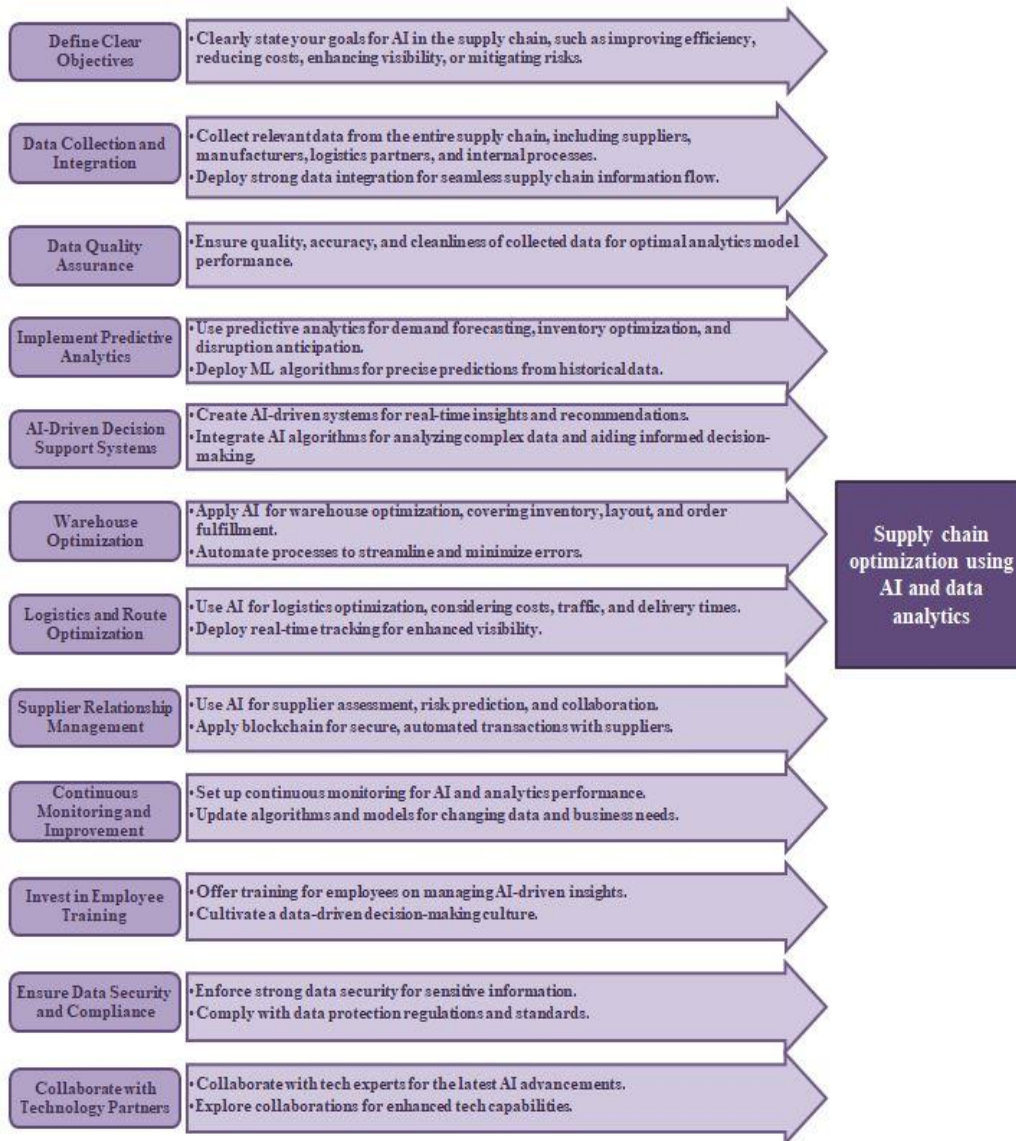
4.6. Real case study example of supplier selection

BMW, a leading automotive manufacturer, uses AI-powered algorithms to improve its supplier selection process. The company uses an AI-powered system called "Risk Radar" to analyze data on supplier performance and identify potential risks [36]. The system uses a range of data sources, including supplier contracts, financial data, and external data sources, such as news articles and social media posts, to analyze supplier performance. Based on this data, the system assigns a risk score to each supplier, indicating the likelihood of the supplier failing to meet BMW's requirements. BMW also uses AI-powered algorithms to optimize its supplier selection process. To find the top suppliers for each category, the organization utilizes an algorithm that considers a variety of characteristics such as supplier performance, quality, pricing, and dependability [28]. The application of artificial intelligence for supplier selection has helped BMW enhance the quality and dependability of its supply chain. BMW can use AI to analyze data and detect possible dangers, allowing it to manage supplier relationships proactively and decrease interruption risk. By employing AI to optimize the supplier selection process, BMW can ensure that it is working with the finest suppliers in each category, hence boosting product quality and dependability. The application of AI for supplier selection exemplifies how AI may increase the efficiency and efficacy of supply chain operations. BMW has reduced the risk of interruptions, improved the quality and dependability of its goods, and increased customer happiness by utilizing artificial intelligence to evaluate data and optimize supplier choices. AI has demonstrated significant potential for improving supply chain systems in a variety of ways.

5. Results Parameters Used for AI Implementation

In today's changing corporate landscape, the combination of AI and SCM heralds a transformational future. As firms increasingly rely on AI technologies to improve their supply chain operations, there is a pressing need to fully comprehend the complexities embodied in the outcomes of such efforts [12]. This study piece acts as a lighthouse, taking the reader through a thorough examination of outcome parameters and equations required for understanding the consequences of AI integration inside supply chain frameworks. Table 3 illustrates both the advantages and disadvantages of AI-powered SCM. The symbiotic link between AI and SCM involves several factors that must be carefully considered. From machine learning algorithms fine-tuning demand forecasts to autonomous systems optimizing logistics, every aspect influences the efficiency and robustness of contemporary supply chains. This essay takes an analytical journey, methodically dissecting these outcome factors to offer a quick glimpse into their impact on operational dynamics [19]. In this situation, there are a set of equations that convert the data-driven judgments made possible by AI into actionable insights. These equations are more than just mathematical constructions; they are the linguistic conduits through which the synergy between intelligent algorithms and supply chain complexities is expressed. This article intends to empower practitioners, researchers, and industry stakeholders with the information necessary for linking the transformational potential of AI. As we negotiate the complex network of parameters and equations, we urge the reader to explore the opportunities and encounters that emerge at the junction of artificial intelligence and supply chain management. By unraveling the numerical tapestry of these discoveries, this paper aims to provide a complete foundation for stakeholders looking to uncover untapped potential and navigate unexplored terrain in the early stages of AI-enabled SCM. Figure 5 shows a visual representation of the suggested paradigm.

Figure 5
Steps to optimize supply chain using AI
(Source: Author's own elaboration)



5.1. Forecast accuracy

Forecast accuracy is an essential metric in supply chain management, especially when considering the usage of artificial intelligence for demand forecasting. It determines how well expected demand corresponds to actual demand, helping businesses to manage inventory levels, manufacturing schedules, and overall supply chain efficiency. A lower prediction error rate indicates a more accurate forecasting method. For example, if the actual demand for a product is 100 units and the expected demand is 100 units, the error rate is zero, indicating a perfect forecast. In contrast, if real demand is 100 units but predicted demand is 120 units, the error rate is 20%, suggesting that the projection was exaggerated [11, 33]. The forecast error rate may be calculated using Equation 1.

$$\text{Forecast error rate} = \frac{\text{Actual demand} - \text{Forecasted demand}}{\text{Actual demand}} \times 100 \tag{1}$$

Actual demand refers to the quantity of a product or service that buyers want during a certain time period. Forecasted demand is the estimated quantity of the same product or service based on an AI-driven forecasting algorithm. The forecast error

rate is calculated as the absolute percentage difference between actual and predicted demand. It represents the magnitude of the projected mistake.

5.2. Operational efficiency

Operational efficiency is an important part of supply chain management, and Artificial Intelligence (AI) can help optimize numerous operational procedures. "Order Processing Time" is the parameter linked with operational efficiency in this context. Lower order processing times suggest that the supply chain is running more efficiently. This means that the firm will be able to fulfill consumer requests faster and respond to market demands sooner. Conversely, a longer order processing time may indicate bottlenecks or inefficiencies in the order fulfillment process. Operating efficiency is critical for achieving consumer expectations and keeping a competitive advantage in the market. The time it takes to process an order can be determined using Equation 2.

$$\text{Order processing time} = \frac{\text{Total time taken to process orders}}{\text{Number of orders processed}} \quad (2)$$

Total time taken to process orders: This includes the time it takes to place an order, fulfill it, and deliver it to the customer. It consists of multiple procedures, including order entry, picking, packaging, and shipping. Total number of orders processed: The total number of orders successfully processed during a particular timeframe. Order processing time is measured as the average time necessary to process a single order.

5.3. Supply chain visibility

A higher visibility index indicates that a significant portion of the supply chain is being tracked in real time. This requires a better understanding of the movement and status of commodities along the supply chain [22]. A lower visibility index may indicate gaps in real-time tracking, which might result in blind patches where cargo status is uncertain. Supply chain visibility is critical for making informed decisions and controlling risks. It lets businesses to identify and fix issues as they emerge, reducing the effect of interruptions. Improved visibility encourages greater collaboration with partners since all stakeholders are aware of the current state of the supply chain [16]. The visibility index can be determined using Equation 3.

$$\text{Visibility index} = \frac{\text{Number of real events} - \text{Time tracking events}}{\text{Total number of expected tracking events}} \times 100 \quad (3)$$

The actual number of real-time tracking events gathered within the supply chain. This comprises events such as product shipments, arrivals at distribution facilities, and other important logistical milestones. Total projected tracking events: The expected total number of tracking events based on supply chain activities. This acts as the baseline against which the actual tracking events are measured. Visibility index: A percentage figure indicating the level of visibility attained in the supply chain through real-time tracking.

5.4. Cost reduction

A larger cost savings % suggests a more successful AI adoption, with a significant reduction in overall operational expenses. A lower cost savings percentage may indicate that the cost-saving benefits of AI implementation are not as significant as previously thought. Cost savings are a significant driver for integrating AI in supply chain management. It enables enterprises to improve operational efficiency and competitiveness. The equation gives a clear metric for analyzing the financial impact of artificial intelligence on the supply chain, taking into accounts both the original investment and ongoing operational savings [38]. Equation 4 allows you to compute the percentage of cost savings.

$$\text{Cost savings percentage} = \frac{\text{Total cost reduction}}{\text{Total operational cost}} \times 100 \quad (4)$$

Total cost reduction: The total cost savings or reductions achieved as a result of implementing AI into supply chain management. This might include reductions in inventory costs, operating costs, transportation costs, and other relevant expenses. Total operational costs: The entire cost of carrying out supply chain tasks without the use of artificial intelligence; Cost savings percentage: A metric that represents the proportion of total expenses saved versus total operating costs.

5.5. Risk mitigation

The risk exposure reduction parameter is a key metric for determining AI's effectiveness in decreasing supply chain hazards. Firms may measure the decrease in risk exposure to evaluate the success of their risk mitigation techniques and make informed decisions to increase supply chain resilience [7,9]. Equation 5 calculates risk exposure reduction. The equation allows businesses to assess the impact of AI on risk exposure reduction, which aids in strategic decision-making and resource allocation. A positive reduction in risk exposure indicates that the company is successfully implementing AI to create a more resilient and risk-aware supply chain.

$$\text{Risk exposure reduction} = \frac{\text{Initial risk exposure} - \text{Final risk exposure}}{\text{Initial risk exposure}} \times 100 \quad (5)$$

Initial risk exposure: The amount of risk in the supply chain prior to the introduction of AI-powered risk mitigation methods. This can include risks associated with demand unpredictability, supply chain interruptions, geopolitical events, and other uncertainties. **Final risk exposure** is the level of risk in the supply chain following the application of AI-driven risk mitigation methods [39]. This includes reducing recognized risks and improving overall supply chain resilience. **Risk exposure reduction:** A percentage figure indicating the reduction in risk exposure obtained by AI-driven risk mitigation measures.

5.6. Return on Investment (ROI)

A strong ROI indicates that the financial advantages of AI installation surpass the total expenditures, implying a successful and profitable deployment. A negative ROI means that the financial benefits do not outweigh the costs, meaning that the implementation is not yielding the expected outcomes. ROI is an essential financial indicator that organizations use to measure the economic viability and effectiveness of their AI projects in supply chain management. It clearly shows if the investment in AI is contributing to the organizations overall profitability and efficiency. As the AI implementation advances, organizations should continue to assess and review their ROI. This requires evaluating continuing benefits and finding areas for further optimization [3]. Regular ROI evaluations allow businesses to adjust their strategies and make educated decisions on future AI expenses.

To measure relative performance, organizations might compare their ROI to industry standards or rivals. A comparison to industry benchmarks provides context for analyzing if the organization's AI deployment is creating a competitive advantage. ROI is an important consideration in strategic decision-making. It helps businesses to prioritize AI efforts, effectively manage resources, and evaluate the scalability of successful implementations. A positive ROI increases confidence in the usefulness of AI and may justify more investments in advanced technologies or new use cases. The ROI may be calculated using Equation 6. The equation allows for long-term assessment of the financial effect of AI installation. Organizations may track how the benefits of AI evolve over time and adjust their strategy accordingly. Long-term ROI analysis allows for informed decisions on the continuation, modification, or expansion of AI activities in the supply chain [24]. ROI is an important statistic for assessing the financial viability of AI deployment in supply chain management. Organizations may make educated judgments about the efficiency of their AI initiatives and optimize their investments for long-term success by measuring financial returns in comparison to overall expenses.

$$\text{ROI} = \frac{\text{Net profit from AI implementation}}{\text{Total cost of AI implementation}} \times 100 \quad (6)$$

Net profit from AI implementation: The total financial gain resulting from the use of AI in supply chain management, including cost reductions, revenue growth, and other monetary advantages. **Total AI installation costs:** The total expenditure made to integrate AI technology into the supply chain. This includes the initial expenditures of technology acquisition, software development, employee training, and ongoing operational expenses. ROI is a percentage figure that depicts the return on investment and shows how profitable and efficient the AI application is.

5.7. Employee satisfaction

A higher employee satisfaction score shows that a greater proportion of the workforce is satisfied with the changes caused by AI implementation. A lower employee satisfaction score could indicate unhappiness, resistance, or concerns among employees about AI-enabled procedures. Employee happiness is critical to the effective implementation of AI technologies in the supply chain. Employees who are satisfied are more likely to adopt and effectively implement new technologies and processes. High employee satisfaction promotes a positive work atmosphere, higher productivity, and overall organizational success. Organizations should constantly review employee happiness and address any problems or challenges associated with the use of AI [8]. Regular feedback tools, surveys, and communication channels can help firms understand employee viewpoints and make necessary changes.

Employee satisfaction is positively correlated with production. Employees that are satisfied are more likely to adopt and effectively use AI solutions, which contributes to increased overall productivity. In contrast, dissatisfaction and resistance may result in suboptimal use of AI technologies, thereby reducing productivity. Employee happiness reflects business culture and how well employees feel supported when they adjust to technology developments [4]. A high level of employee satisfaction promotes innovation, collaboration, and ongoing progress. High employee satisfaction leads to higher retention rates, which reduces turnover and recruitment expenses. Positive working experiences connected to AI implementation can help the firm attract new personnel. Employee sentiment may be analyzed and tracked using AI technology [35]. Natural Language Processing (NLP) algorithms may assess employee happiness by examining comments, questionnaires, and communication channels. Predictive analytics may help predict potential challenges and address issues that impact employee satisfaction. Employee satisfaction is a key parameter for evaluating the human effect of AI deployment in supply chain management. A positive score indicates that the staff is supportive and involved in AI-driven transformation, which helps to foster a strong organizational culture and overall performance [36]. Regular communication, training programs, and a focus on staff well-being are essential for ensuring high levels of satisfaction amid technological transformations. Equation 7 may be used to determine an employee satisfaction score.

$$\text{Employee satisfaction score} = \frac{\text{Number of satisfied employees}}{\text{Total number of employees}} \times 100 \quad (7)$$

Number of pleased employees: The number of employees who are happy with the AI-enabled tools, procedures, and innovations implemented in the supply chain; Total employees: The whole workforce involved or impacted by the AI application in supply chain management; Employee Happiness Score: A percentage number indicating employee satisfaction with AI-driven supply chain advancements.

Table 3
Benefits and challenges of AI-powered SCM
(Source: Author's own elaboration)

Benefits	Description	Challenges	Solution
Improved Forecast Accuracy	AI algorithms enhance demand forecasting accuracy.	Data Quality and Availability	Data cleansing, integration, and improved data sources.
Reduced Inventory Costs	Optimization reduces carrying costs and stockouts.	Change Management	Employee training and a change management strategy.
Enhanced Customer Service	Chatbots and virtual assistants improve communication.	Initial Implementation Costs	ROI analysis and gradual implementation phases.
Efficient Route Planning	AI optimizes delivery routes, reducing transportation costs.	Cybersecurity Risks	Robust cybersecurity measures and regular audits.
Supplier Performance Improvement	Supplier scorecards enable better supplier management.	Ethical Considerations	Ethical AI frameworks and compliance guidelines.
Predictive Maintenance	Prevent equipment breakdowns, reducing downtime.	Integration with Legacy Systems	API integration or gradual system upgrades.
Risk Mitigation	Predictive analytics identify and address supply chain risks.	Scalability	Cloud-based solutions and scalable infrastructure.
Environmental Impact Reduction	AI aids in sustainability efforts, reducing carbon footprint.	Performance Monitoring	Continuous monitoring and AI model maintenance.

7. Conclusion

AI-powered supply chain management may improve inventory management, reduce lead times, and improve communication across departments and partners. Furthermore, AI may help businesses detect potential supply chain risks and bottlenecks and take proactive steps to mitigate them, resulting in enhanced resilience and agility in the face of unanticipated calamities like as natural disasters or global pandemics. However, applying AI in SCM requires careful preparation and attention. It is vital to ensure that the data used to train AI algorithms is accurate and relevant, and that the AI tools integrate easily into current workflows. Regardless of these restrictions, the benefits of AI-powered SCM are clear. As organizations continue to implement AI technology and examine its potential uses in supply chain management, we may expect to see even higher cost reductions, efficiency improvements, and better customer satisfaction. Finally, AI-powered SCM has the potential to help businesses stay competitive in a complex and evolving business environment.

Acknowledgement

We extend our heartfelt gratitude to all those who played a pivotal role in the completion of this research article. We also acknowledge the support and resources provided by Abacus Institute of Engineering and Management, Hooghly, which enabled

us to conduct this research. We are grateful to our colleagues and peers who offered valuable discussions and constructive criticism, enriching our perspectives and enhancing the rigor of our work.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Shankha Shubhra Goswami: Conceptualization, Investigation, Visualization, Supervision, Project administration. **Surajit Mondal:** Investigation, Resources, Writing - original draft, Writing - review & editing. **Shouvik Sarkar:** Methodology, Data curation, Visualization. **Krishna Kumar Gupta:** Methodology, Validation, Formal analysis. **Sushil Kumar Sahoo:** Validation, Data curation, Writing - original draft, Project administration. **Rohit Halder:** Formal analysis, Resources, Writing - review & editing.

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How to Cite

Goswami, S. S., Mondal, S., Sarkar, S., Gupta, K. K., Sahoo, S. K., & Halder, R. (2024). Artificial Intelligence Enabled Supply Chain Management: Unlocking New Opportunities and Challenges. *Artificial Intelligence and Applications*. <https://doi.org/10.47852/AIA42021814>