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Enhancing supply chain resilience with artificial intelligence a bibliometric analysis and systematic literature review

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Abstract

Among many innovative technical solutions, Artificial Intelligence (AI) is considered a promising approach for fostering resilient supply chains. This study aims to investigate how AI enhances Supply Chain Resilience (SCRES) by identifying AI applications in supply chain contexts, evaluating their impacts on SCRES, and uncovering gaps and emerging trends for future research. We adopted the PRISMA procedure to collect appropriate papers and then employed VOS Viewer to uncover key insights within scholarly literature. After that, selected papers underwent systematic content analysis to synthesize key concepts and applications as well as valuable aspects of AI application in fostering SCRES. The AI-SCRES relationship is an emerging field, with a notable increase in publications, particularly driven by unprecedented events like the COVID-19 pandemic. Findings showed 11 AI techniques frequently mentioned in the literature for SCRES enhancement. Bayesian networks emerged as the most discussed and mature, followed by artificial neural networks and genetic algorithms. These technologies are predominantly used for risk prediction, automated reasoning, optimization, and decision support. While AI offers substantial benefits such as enhanced decision support and demand forecasting, it also brings challenges like the need for highly skilled personnel, investment costs, and data-related risks.

Keywords: Artificial Intelligence, Bibliometric analysis, Supply chain resilience, Systematic literature review.

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1. Introduction

In the dynamic and interconnected global economy, the intricate web of supply chain networks faces continual challenges, and recent unprecedented events like the COVID-19 pandemic, the Russia-Ukraine war, and the US-China trade war have laid bare the inherent fragility of these networks. The resulting severe economic ramifications and widespread logistical challenges underscore the imperative for robust resilience strategies that can adapt to unforeseen shocks and disruptions [1]. SCRES are essential today to mitigate disruptions from global crises and maintain continuous business operations. Therefore, SCRES has attracted considerable interest in academic and practical communities. Researchers have explored the relationship between supply chain capabilities and resilience outcomes and have developed frameworks and assessment tools to measure and evaluate supply chain resilience.

Artificial Intelligence (AI) emerges as a transformative tool poised to revolutionize and bolster supply chain resilience [2, 3]. As supply chains become increasingly complex and interdependent, AI offers unparalleled opportunities to enhance adaptability, responsiveness, and risk management [4, 5]. Recent studies on supply chain management have focused on how AI can make supply chains more robust [6, 7] by improving monitoring, managing risks, sourcing, and distribution [8]. Researchers demonstrated that AI can predict and prevent supply chain problems by using past data [9] and can also help identify and manage risks to keep the supply chain strong [10]. Despite a burgeoning body of literature exploring the applications of AI in this domain, a comprehensive synthesis is conspicuously absent to understand how AI technologies contribute to enhancing SCRES, which is crucial for businesses seeking to fortify their supply chains against unforeseen disruptions. There is a lack of structured analysis regarding using specific quantitative methods and algorithms within the SCR domain.

Furthermore, the literature often treats technological solutions and human factors in isolation, overlooking the critical intersection between AI and human decision-making in SCRES. This gap signifies an urgent requirement for research that integrates these aspects, offering a holistic view of how AI can complement and enhance human-led supply chain strategies. Therefore, our research aims to address these critical gaps by providing an integrated, comprehensive analysis of AI's role in augmenting SCRES, focusing on practical implementation, methodological rigor, and the synergy between technology and human expertise. Our research questions (RQ) are as follows:

RQ1: How has research at the intersection of SCRES and AI changed over time?

RQ2: Which AI techniques have been applied to SCRES research and real-world applications?

RQ3: Which crucial duties in enhancing SCRES are mostly handled by AI techniques?

RQ4: What are the challenges in using AI to increase supply chain resilience?

RQ5: What are the research gaps and outlook for future research in the field of AI application to foster SCRES?

2. Materials and Methods

2.1. Systematic Literature Review Approach

This study used a combined methodology of bibliometric network analysis and systematic literature review (SLR). SLR enables researchers to clarify the current state of research and pinpoint gaps and areas needing further investigation [11]. The bibliometric approach is an indispensable tool for conducting a comprehensive research overview, employing quantitative and visual methods to uncover key insights within scholarly literature [12]. The SLR protocol documents all steps to ensure transparency and reproducibility, with the PRISMA flow diagram aiding in visualizing the selection process.

2.2. Data Collection

Table 1.
Summary of keywords.

Category I	Operator	Category II	Operator	Category III
"Machine learning" OR "artificial intelligence" OR "AI" OR "artificial neural network" OR "Bayesian network" OR "support vector machines" OR "logistic regression" OR "linear regression" OR "k-means" OR "decision tree" OR "random forest" OR "multi-agent systems" OR "agent-based systems" OR "genetic algorithm" OR "fuzzy logic"	AND	"supply chain" OR "supply network"	AND	"resilience" OR "disruption" OR "recovery" OR "robustness"

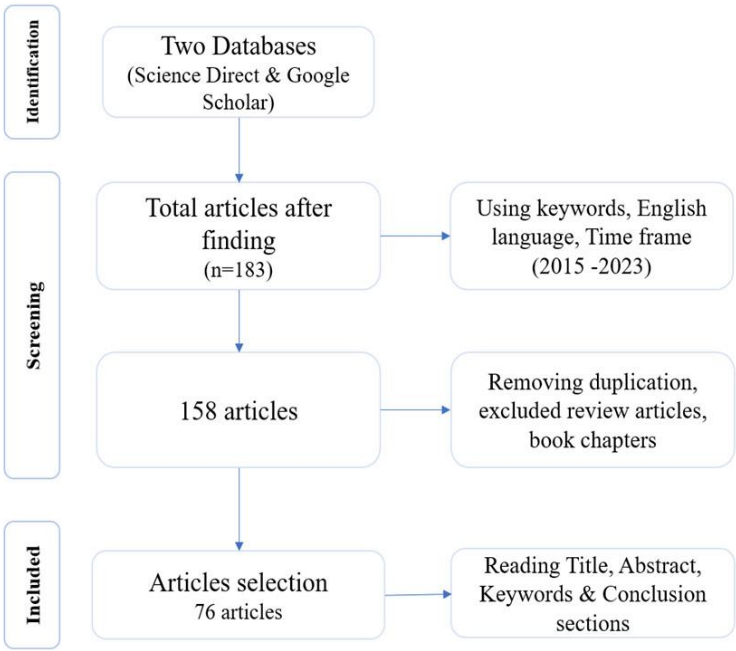

Figure 1.
PRISMA-based study selection and evaluation process.

We adopted and relied on studies by Spieske and Birkel [13] and Yang et al. [14] to construct a set of keywords (see Table 1). After using the keyword set to search on two database platforms, Google Scholar and Science Direct, it generated a preliminary sample of 183 English-language articles between 2015 and 2023. Subsequently, duplicates, reviews, and book chapters were filtered out, resulting in 158 articles. The next step involved using Python to iterate through all articles to extract the Title, Abstract, Keywords, and Conclusion sections. The authors then utilized GPT-4 Turbo (Natural Language Processing model), which provides an API to analyze the content and filter out articles not relevant to the analyzed topic. The outcome was the removal of 62 articles. Finally, to enhance the accuracy and relevance of our research, we manually read the sections, resulting in a final selection of 76 articles that met the criteria. Thanks to the utilization of the GPT-4 API, the identification and classification of articles leveraging AI to enhance efficiency in supply chain recovery have been accomplished.

2.3. Data Analysis

Collected data were analyzed using the following methods: Firstly, we carried out a descriptive analysis to explore the distribution of reviewed papers by published year, journals, and countries with bar charts and geographical maps. Secondly, we used bibliometric network analysis of keywords with VOSviewer to track publications, then conducted clustering, mapping, and geospatial analysis to provide a comprehensive view of the global research landscape. Thirdly, content analysis was deployed to conduct an in-depth investigation into the literature.

3. Results and Discussion

3.1. Descriptive Analysis

Figure 1 shows a significant increase in interest regarding the application of Artificial Intelligence (AI) techniques to enhance supply chain resilience. In 2015, only four articles were published on this topic. However, since then, research and discussions on utilizing AI to optimize the ability to cope with disruptions in the supply chain have become increasingly prominent.

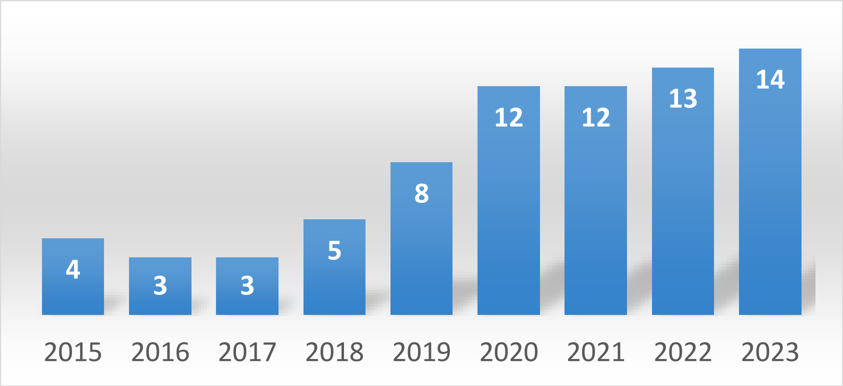

Figure 1.
Distribution of reviewed papers over time.

Figure 2 shows that the greatest concentration of research activity appears in North America and Asia, with the United States and China showing the darkest shades, indicating a substantial focus in these regions. South America and Africa display lighter shades, signifying fewer research occurrences in these areas. This geographical distribution may reflect the varying levels of investment in AI technologies and the diverse industrial demands and capabilities across the globe. The map underscores the leading role that certain countries play in pushing the boundaries of AI applications in enhancing the resilience and efficiency of supply chains.

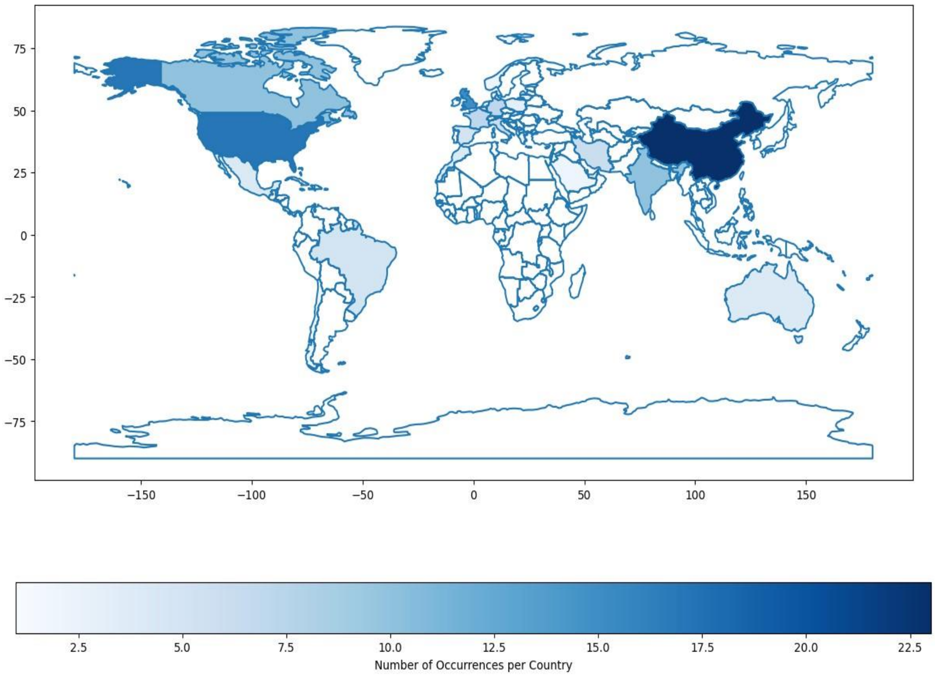

Figure 2.
Geographical distribution of reviewed articles.

3.2. Keyword Co-Occurrence Network Analysis

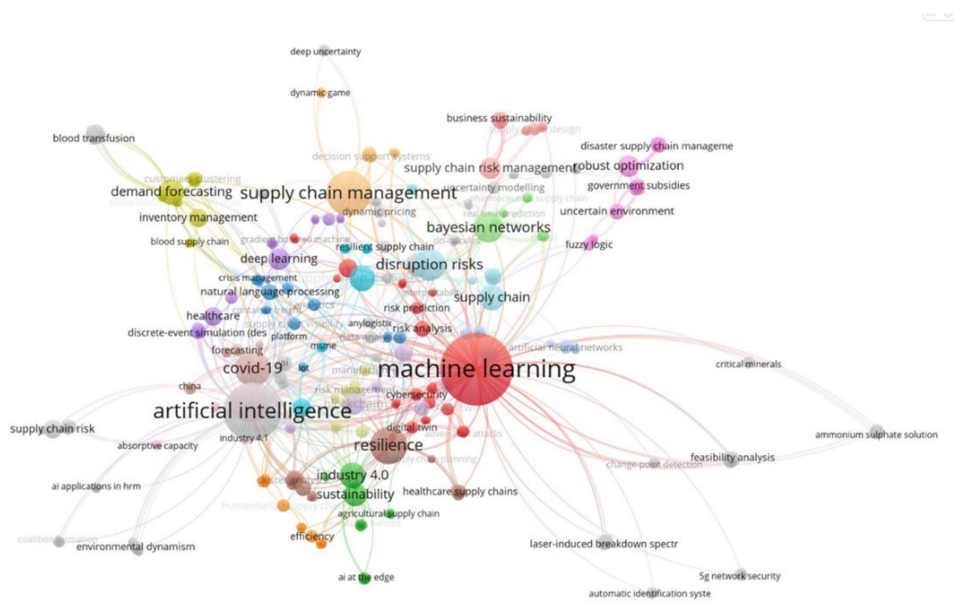

Figure 3.
Visualization of the bibliometric network of keywords.

Figure 3 shows the expansive and intricate field of machine learning as it intersects with artificial intelligence, underscoring its pivotal role in both foundational research and practical applications. Machine learning forms the nexus of the visualization, highlighting its prominence and indispensability in the artificial intelligence domain. The visualization prominently features "supply chain management", "risk analysis", "demand forecasting" and "inventory management", indicating substantial research interest in employing machine learning to enhance supply chain efficiencies and risk mitigation, especially during disruptive events like the COVID-19 pandemic. Specific machine learning techniques like "deep learning", "Bayesian networks", "fuzzy logic", "neural networks", and "discrete-event simulation" are noted for their significant use in complex risk assessment and decision-making processes. The visualization extends into various sectors, including "healthcare" and "agricultural supply chain", suggesting the versatile applicability of machine learning across different industries.

3.3. AI techniques in SCRES

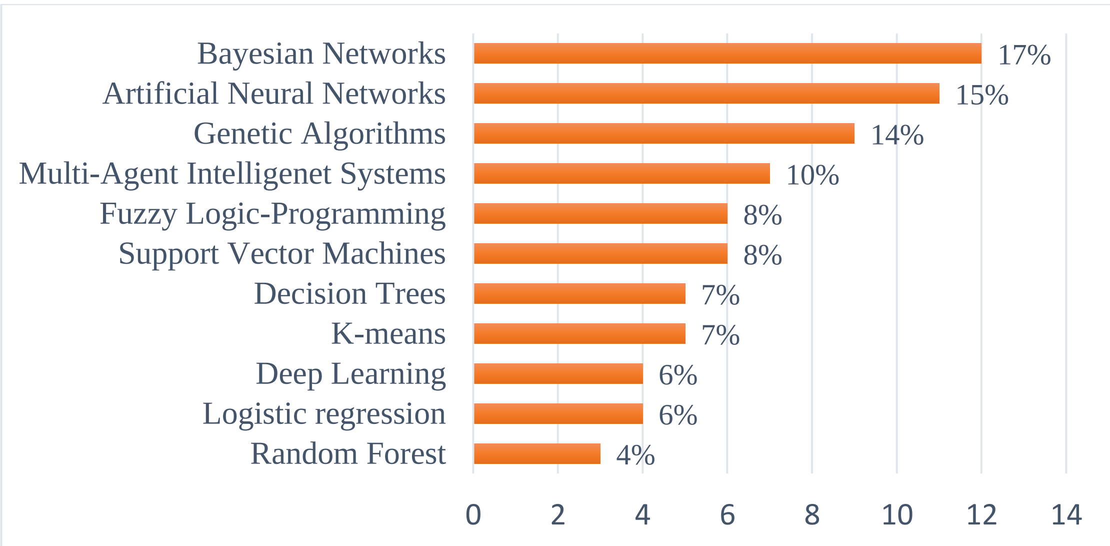

Figure 4.
Distribution of AI techniques.

Figure 4 shows that Bayesian algorithms emerge as pivotal tools, constituting the most prevalent application, with a 17% utilization rate. Researchers used Bayesian networks in quantifying risk, modeling uncertainty, and facilitating decision-making amidst structural dynamics [15, 16]. Artificial neural networks (ANNs) are the second most popular AI technique in the sample, making 15% of the contributions. ANN serves as a potent machine learning algorithm capable of recognizing nonlinear relationships between input and output variables in the management of supply chain resilience, predicting and identifying anomalies within supply chains, selecting resilient suppliers, facilitating the optimization of the supply chain network under disruption considerations, and providing timely warnings to supply chain managers about potential competitors [17-20]. Genetic algorithm (GA), constituting 14% of the sample, proves to be an integral technique in supply chain resilience studies. GA played a key role in scrutinizing the impact of agility and flexibility on supply chain responsiveness during disruptions [21] and in the strategic design and optimization of resilient supply chain networks, addressing both operational and disruption risks [22, 23]. Multi-agent intelligent systems (MAIS), contributing to 10% of the total reviewed papers, functioning as simulation tools, have further proven valuable in inventory management, cost reduction, and improved fill rate. They have addressed collaboration challenges among supply chain entities arising from uncertain supply and demand, as well as mitigated costs and the bullwhip effect in multi-stage supply chains [4].

Furthermore, techniques such as fuzzy logic, support vector machines (SVM), K-means clustering, decision trees, and logistic regression are prominent machine learning techniques widely applied in fostering SCRES.

3.4. Application of AI in diverse aspects to enhance SCRES

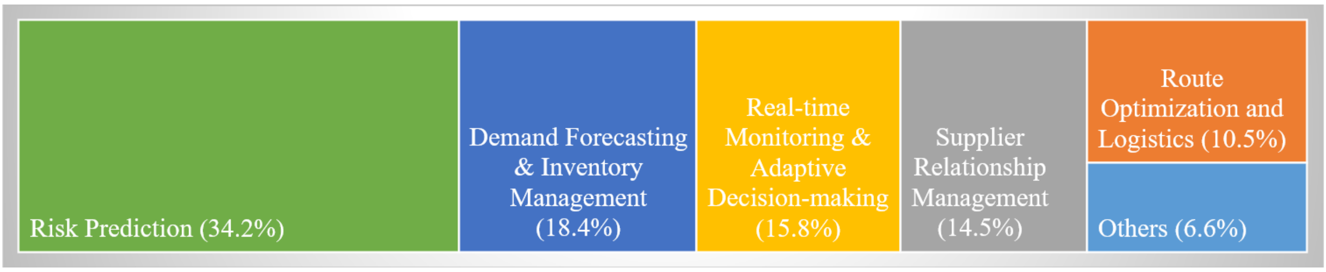

Figure 5.
Specific tasks analyzed in supply chain resilience.

Figure 5 presents diverse aspects where AI has been utilized to strengthen supply chain responsiveness and recovery capabilities. The majority of research (34.2%) focused on risk prediction, emphasizing the use of AI to anticipate potential disruptions. This is followed by demand forecasting and inventory management (18.4%) and real-time monitoring with adaptive decision-making (15.8%). Supplier relationship management accounts for 14.5% of the studies, while route optimization and logistics represent 10.5%. The remaining 6.6% fall into other categories.

3.5. Challenges in Implementing AI for Supply Chain Resilience

Despite huge benefits, applying AI in supply chain recovery also presents several challenges. Firstly, researchers highlighted the difficulty in integrating AI technologies with legacy systems [24]. AI heavily relies on vast datasets, raising concerns about protecting sensitive information. Establishing robust safeguards and complying with privacy regulations becomes imperative to mitigate potential risks associated with data breaches and unauthorized access [25]. Secondly, the lack of standardized data formats and data quality issues pose substantial hurdles for effective AI implementation. Excessive data volume, often referred to as "big data" can be overwhelming to manage and analyze accurately without sophisticated tools and expertise, potentially leading to inaccurate forecasts or decision-making paralysis [26]. Thirdly, the initial investment for sophisticated technological solutions can be significant, potentially posing a barrier for small and medium-sized enterprises (SMEs). Finally, there can also be a skill gap; the workforce may require extensive training to use these new technologies effectively [27]. In summary, the challenges associated with applying AI to enhance supply chain resilience are multifaceted, involving technological, organizational, and ethical considerations. Addressing these challenges requires a comprehensive strategy that draws insights from previous research and focuses on integration, data quality, security, and trust establishment to realize AI's full potential in resilient supply chain management.

3.5.1. Research Gaps and Future Directions

Through content analysis of the reviewed papers, we found several research gaps and future directions in the application of AI to enhance SCRES as follows:

- Firstly, the research primarily focuses on how AI can be applied to foster SCRES in a general context, with a notable lack of detailed exploration into the specific measurements of SCRES capability as well as different phases of SCRES. Future research can investigate more details about how AI can take advantage of each phase and each SCRES measurement criterion, especially the phases and criteria relating to adaptability and growth during disruptions [28].
- Secondly, there is a lack of research to compare how AI can be carried out in different supply chains with their unique characteristics. Future research can focus on real-world case studies of specific supply chains and make comparisons to gain more insights into this research field [29].
- Thirdly, most research focuses on large corporations, overlooking the unique challenges and resource constraints faced by SMEs in implementing AI for supply chain resilience. SMEs dominate the business world, and it will make a huge impact if it is feasible to apply AI. It calls for future research to look deeper, explore opportunities, and find solutions for SMEs in applying AI to build resilient supply chains [30].
- Finally, many emerging AI techniques, such as generative AI, have appeared recently, in addition to traditional ones. Researchers can often update and investigate the application of these emerging AI techniques in enhancing SCRES.

In addition, integrating AI with other techniques like blockchain, IoT, and digital twins is a research interest in the future [30, 31].

4. Conclusion

This study analyzed high-quality journal papers in the literature to explore the landscape of AI applications in strengthening SCRES. The notable increase in publications, particularly driven by unprecedented events like the COVID-19 pandemic, demonstrates that AI techniques hold significant promise for advancing SCR in today's dynamic business environment. There were 11 AI techniques frequently applied in the literature for SCRES enhancement. Bayesian networks emerged as the most discussed and mature, followed by artificial neural networks and genetic algorithms. These technologies are predominantly used for capabilities like risk prediction, automated reasoning, optimization, and decision support. While AI offers substantial benefits such as enhanced decision support and demand forecasting, it also brings challenges like the need for integration with legacy systems, highly skilled personnel, investment costs, and data-related risks. Our review has several limitations to improve in future research. Firstly, the study did not incorporate various organizational theories like dynamic capabilities theory, improvisational theory, resource-based view, and contingency theory, all of which have significant bearings on SCRES. Future research could benefit from exploring these theories in the context of AI-enhanced SCRES. Secondly, this review is based primarily on qualitative content analysis; future research can apply modern tools to conduct quantitative content analysis to uncover the literature and gain more data-intensive insights.

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