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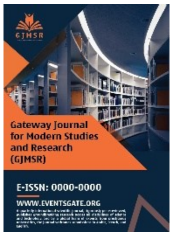

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تأثير الذكاء الاصطناعي في مرونة سلسة التوريد: مراجعة منهجية لرسم الخرائط

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الملخص: اكتسبت مرونة سلسلة التوريد اهتماما كبيرا في السنوات الأخيرة بسبب تزايد وتيرة وشدة الاضطرابات مثل الكوارث الطبيعية و الصراعات و الأوبئة. لذا، يعد تعزيز مرونة سلسلة التوريد من خلال الذكاء الاصطناعي مجالاً بحثياً ناشئاً. تقدم هذه الورقة مراجعة منهجية لرسم الخرائط لمراعاة الأبحاث الحالية حول تأثير تقنيات الذكاء الاصطناعي في تحسين مرونة سلسلة التوريد. من خلال التحليل الهيكلي للدراسات ذات الصلة، تصنف هذه المراجعة تطبيق الذكاء الاصطناعي في خصائص سلسة التوريد المختلفة وتحدد الاتجاهات و التحديات و الثغرات في الأدبيات. تكشف النتائج أن الذكاء الاصطناعي، والتعليم الآلي عملياً، والتحلسلات التنبؤية، والأتمتة، له تأثير ملحوظ على تعزيز المرونة وخفة الحركة و الاستجابة في سلاسل التوريد. ومع ذلك، هناك أبحاث محدودة حول تكامل الذكاء الاصطناعي مع عمليات صنع القرار البشرية و قوة سلاسل التوريد التي تعتمد على الذكاء الاصطناعي على المدى الطويل. وتختم الورقة بتحديد اتجاهات البحث المستقبلية و الآثار العملية لأعمال التجارية التي تهدف الى تعزيز مرونة سلسة التوريد باستخدام الذكاء الاصطناعي.

الكلمات المفتاحية: مرونة سلسلة التوريد، الذكاء الاصطناعي، المرونة، الصلابة، التعافي، التعلم الآلي، التحليلات التنبؤية، الأتمتة والروبوتات، معالجة اللغة الطبيعية.

The Impact of AI in Supply Chain Resilience: A Systematic Mapping Review

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Abstract: Supply chain resilience has gained significant attention in recent years due to the increasing frequency and severity of disruptions such as natural disasters, disruption, conflict, and pandemic. Supply chain resilience enhancement through Artificial Intelligence (AI) is an emerging research area. This paper presents a systematic mapping review to considerate the existing body research on the impact of AI technologies in improving supply chain resilience. Through a structure analysis of relevant studies, this review categorizes AI application in various supply chain function and identifies trends, challenges, and gaps in the literature. The findings reveal that AI, practically machine learning, predictive analytics, and automation, has a notable impact on enhancing flexibility, agility, and responsiveness in supply chains. However, there is limited research on the integration of AI with human decision-making processes and the long-term robustness of AI driven supply chains. The paper concludes by identifying future research directions and practical implications for business aiming to enhance supply chain resilience using AI.

Keywords: Supply chain resilience, Artificial Intelligence, Agility, Flexibility, Robustness, Recovery, Machine Learning, Predictive Analytics, Automation and Robotics, Natural Language Processing .

1. Introduction:

Supply chain resilience is the capability of a supply chain to adjust and recover from disruptions without affecting its functionality (Christopher and Peck, 2004; Ponomarove and Holcomb, 2009; Hohenstein et al., 2015; Tukamuhabwa et al., 2015; Ivanov et al., 2019; Belhadi et al., 2021; Ghadge et al., 2022; Kalusivalingam et al., 2022; Wang and Pan, 2022; Ali and Khanm 2023; Dey et al., 2023; Papadopoulos et al., 2023; Belhadi et al., 2024). Global events like the Covid-19 pandemic, trade disruptions, and climate change related risk have heightened the importance of resilient supply chains (Ivanov, 2020; Wang et al., 2020; Singh et al., 2021; Beck et al., 2023).

Artificial Intelligence (AI) is being increasing used by organizations to enhance their supply chain resilience (Tjahjono et al., 2017; Kamble et al., 2020; Chowdhury and Paul, 2021; Dubey et al., 2021; Singh et al., 2023). Machine Learning (ML), predictive analytics, automation, and robotics are AI technologies that have promising results in improving decision making processes, optimizing operations, and enhancing responsiveness to disruptions (Kamble et al., 2020; Dubey et al., 2021).

Although AI is widely recognized as a potential tool to improve supply chain resilience, there is no comprehensive review that consolidates and analyzes its impact on various supply chain functions (Dubey et al., 2020; Chowdhury and Paul, 2021; Ivanov, 2021). The aim of this paper is to address this gap by carrying out a systematic mapping review of the literature on the impact of AI on supply chain resilience. The review categorizes studies based on AI applications, resilience dimensions, and supply chain functions, highlighting emerging trends, challenges, and research gaps.

2. Methodology:

Systematic mapping review also known as scoping review have developed through the Cochrane Collaboration (Sheldon and Chalmers, 1994; Hemsly-Brown and Oplatka, 2015; Petersen et al., 2015). Systematic mapping reviews aim to identify the breadth and nature of research in a specific area and categorizes existing studies into various themes or topics (Arksey and O’Malley,2005; Peters et al., 2015).

2.1 Systematic mapping review process

This study conducted a systematic mapping review using the process proposed by Petersen et al., (2008). (Figure 1).

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Process Steps

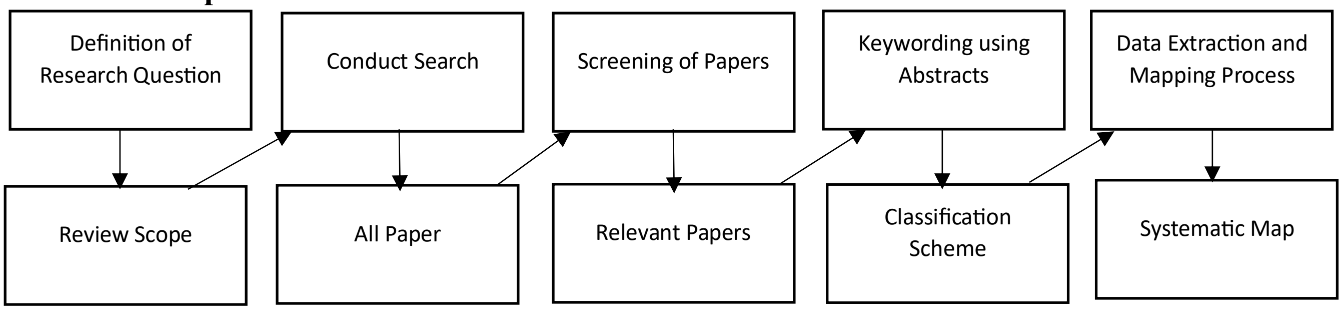

Figure 1. The systematic mapping review using the process proposed by Petersen et al., (2008).

Outcomes

Figure 1 Systematic mapping review process proposed by Petersen et al., (2008)

The study aimed to explore the literature on supply chain resilience and Artificial Intelligence. The mapping questions followed the procedure introduced by Kitchenham and Charters (2007) by identifying three mapping questions and the main motivation behind each as shown in Table 1.

The study uses a structure of the population, intervention, comparison, outcome, and context (PICOC) procedure for the Mapping questions (Kitchenham and Charters, 2007). The studies have different methodological approaches, so this paper did not compare any interventions. Furthermore, obtaining comprehensive insights into studies with divers methodologies is challenging while conducting analysis systematic (Tranfield et al.,2003). Deposit the primary use of systematic review in medical sciences, guidelines have also been developed and recommended for social sciences (Davis et al., 2014; Palmatier et al., 2018). Analyzing qualitative systematic reviews in area where methodological approaches differ can make relevant questions relevant (Grant and Booth, 2009; Palmatier et al., 2018). The mapping questions were analyzed in relation to the outcomes of specific studies that focused on addressing and examining Artificial intelligence and supply chain resilience. It's crucial to define the review strategy after identifying the mapping questions. It is important to design the review strategy in stages with a systematic and explicit method, to ensure complete coverage of the research area (Peterson et al., 2015). The next section covers the steps taken in this study:

- Search strategy
- Screening
- Extracting and synthesis
- Reporting

Table 1 Systematic mapping review questions

	Mapping Questions	Rational	Focus Area
MQ1	What are the AI technologies address with supply chain resilience?	Identifying a list of AI technologies used with supply chain resilience.	Artificial Intelligence and Supply chain resilience.
MQ2	What are the supply chain functions examined with AI application?	To identify the supply chain functions examined with AI application.	Artificial Intelligence and Supply chain resilience.
MQ3	What are the resilience dimensions enhanced by the AI?	To identify the resilience enhanced by the AI	Artificial Intelligence and Supply chain resilience.

2.1.1 Search Strategy

To address the research questions, it is important to identify and search for all possible sources of information. Identifying keywords in a critical manner is important for the development of search strings by applying them to academic data bases.

A comprehensive search was conducted in several academic databases, including: Scopus, Web of Science, Google Scholar, IEEE Xplore, and SpringerLink. Brainstorming process was used to identify keywords related to the subject based on prior articles and experts' opinions. The search strings for the selected included logical connectors such as AND,OR, and NOT.

To capture the most recent development in AI and supply chain resilience, the search was conducted on studies published between 2010 and 2023. Keywords used in the search include: "AI", "artificial intelligence", "supply chain resilience", "supply chain functions", AI applications", "AI technologies" "machine learning", "predictive analytics", "automation", and "flexibility", "agility", and "robustness".

2.1.2 Screening

The intention of this step was to locate studies that correspond to the research questions by analyzing their title, abstract, and keywords. The inclusion and exclusion criteria were utilized to evaluate the candidate studies identify during the initial search step.

- Inclusion Criteria: Studies that explore the application of AI in supply chain management, particularly those addressing resilience, agility, flexibility, and responsiveness.
- Exclusion Criteria: studies focusing on general AI applications in supply chain management without specific focus on resilience, or studies that do not provide empirical or theoretical insights.

The systematic mapping review process is shown in detail in figure 2

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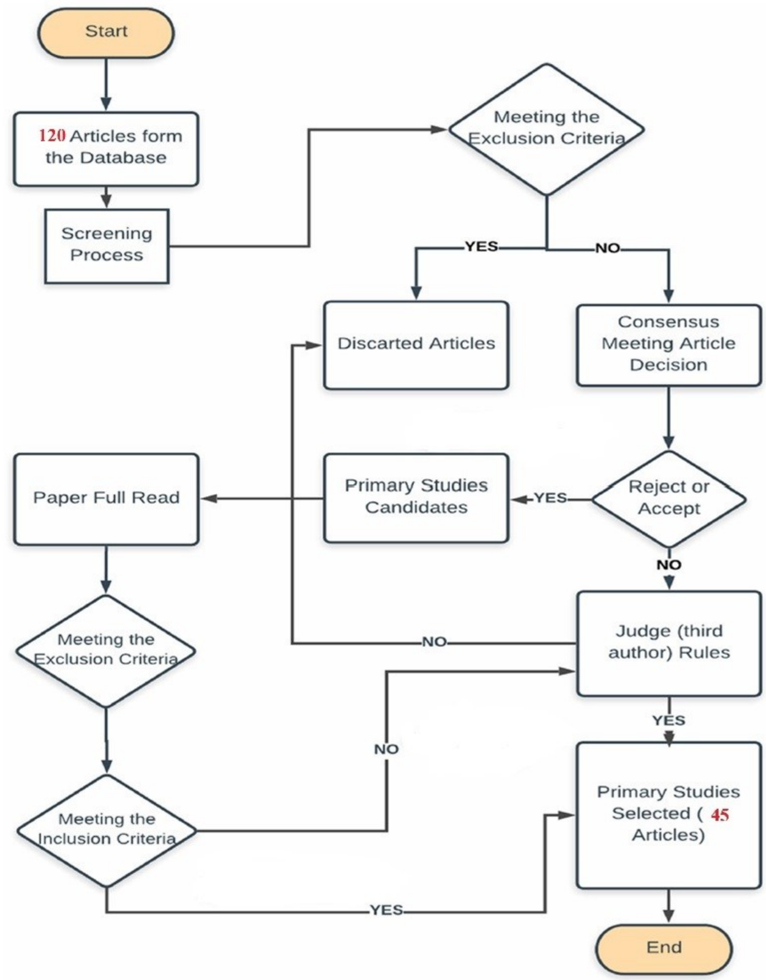

Figure 2 The systematic mapping review process

2.1.3 Data Extraction

The initial search yielded a total of 120 studies, and after screening, 45 studies were selected for detailed analysis. Studies were categorized based on:

- AI Technology: Machine learning, predictive analytics, automation, robotics, natural language processing
- Supply Chain Functions: Procurement, logistics, inventory management, production, demand forecasting, and distribution.
- Resilience Dimensions: Agility, flexibility, robustness, and recovery.

3. Results

3.1AI Technologies in Supply Chain Resilience:

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AI Technologies encompass a wide range of advanced technologies that enable machines, computers to carry out tasks that usually required human intelligence (Belhadi et al., 2021; Choi et al., 2022; Jain et al., 2023). The tasks involve acquiring knowledge from experience, comprehending natural language, recognizing patterns, deciding, and resolving complex problems (Kalusivalingam et al., 2022; Wang and Pan, 2022; Ali and Khanm 2023; Belhadi et al., 2024). Supply chain resilience is being significantly improved by AI technologies, which aid businesses in anticipating, responding to, and recovering from disruptions faster and more effectively (Ivanov et al., 2019; Belhadi et al., 2021;Ghadge et al., 2022; Kalusivalingam et al., 2022; Wang and Pan, 2022; Ali and Khanm 2023; Dey et al., 2023; Papadopoulos et al., 2023; Belhadi et al., 2024). AI can assist in improving forecasting, optimizing operations, and ensuring better decision making as supply chain become more complex and exposed to various risks, such as natural disasters, geopolitical tensions, economic shifts, and pandemics (Ivanov et al., 2019; Wang and Pan, 2022; Ghadge et al., 2022; Papadopoulos et al., 2023).

Several AI technologies that help enhance supply chain resilience were identified in the review:

3.1.1 Machine Learning:

Machine learning is the most commonly applied AI technology used for demand forecasting, predictive maintenance, and anomaly detection (Ni et al., 2020; Akbari, 2021; Riahi et al., 2021; Trikolaee et al., 2021; Ghauhan et al., 2022; Ghazal et al., 2022; Akhari et al., 2023). The use of machine learning can improve supply chain resilience by enhancing forecasting, optimizing operations, and enabling proactive decision making (Choi et al., 2020; Ni et al., 2020; Akbari, 2021; Riahi et al., 2021; Trikolaee et al., 2021; Ghauhan et al., 2022; Ghazal et al., 2022; Akhari etal., 2023; Yang et al., 2023). Machine learning enhances the precision of demand forecasting by examining historical data to uncover patterns and more accurately anticipate future demand compared to conventional techniques. It assists companies in preventing both overstock and stock shortages by predicting variations in demand (Buyukozkan and Gocer, 2018; Choi et la., 2020; Kalusivalingam et al., 2022; Younis et al., 2022). Furthermore, machine learning takes into consideration factors such as seasonality, promotional activities, and market dynamics, thereby offering more accurate insights to synchronize inventory levels with genuine demand (Buyukozkan and Gocer, 2018; Choi et la., 2020; Akbari, 2021; Younis et al., 2022; Akhari et al., 2023).

On the other hand, machine learning algorithms improve inventory management by optimizing stock quantities while considering elements such as demand fluctuations, lead times, and storage expenses. By forecasting demand trends, companies can ensure they hold the appropriate inventory levels, thus preventing both shortage and excess stock. Furthermore, machine learning facilities automated replenishment, allowing for real time recording driven by demand indicators and existing stock level, thereby minimizing human error in inventory management decisions (Buyukozkan and Gocer, 2018; Choi et la., 2020; Akbari, 2021; Younis et al., 2022; Akhari et al., 2023).

3.1.2 Predictive Analytics:

Predictive analytics frequently employed for managing risk, forecasting demand, and predicting disruption. Predictive analytics empowers organizations to recognize and evaluate potential risk within the supply chain, including geopolitical events, natural disasters, or supply disruptions. By analyzing historical risk data alongside real time information, such as weather trends and political unrest, predictive models can provide advance alerts, allowing companies to implement proactive strategies (Christopher and Peck, 2004; Baryannis et al., 2019; Soni et al., 2019; Hirsch et al., 2024).

Moreover, productive analytics enables organizations to enhance their demand forecasting by examining historical data, seasonal patterns, customer behaviors, and external influences such as economic conditions and market trends. By achieving more precise demand forecasts, companies can effectively synchronize their inventory management, production timelines, and transportation logistics, thereby reducing the risks of stockouts excess inventory delays (Waller and Fawcett, 2013; Hubner et al., 2016; Kumar et al., 2022; Sharma et al., 2022; Oliveira and Pereira, 2023; Hirsch et al., 2024).

3.1.3 Automation and Robotics:

Automation and robotics used to improve warehouse management, delivery logistics, and production scheduling. Automation and robotics play a crucial role in enhancing supply chain resilience by improving efficiency, speed, and adaptability. There technologies optimize processes like order picking, sorting, and packaging, facilitating quicker response times and continuous operations. Additionally, real time tracking systems and predictive analytics enhance inventory management and allow for proactive measure against disruptions. Automated systems provide increased flexibility, enabling rapid modifications to production lines and lessening the effects of labor shortage or supply chain disruptions. By decreasing reliance on manual labor, organizations can sustain operations during crises, resulting in a more agile and cost-efficient supply chain (Akbari and Do, 2021; Rahman et al.,2022; Al Bashar et al., 2024).

Furthermore, automation enhances supply chain visibility, data driven decision making, and risk management. Timely data enables organizations to detect bottlenecks and inefficiencies at an early stage, while robotics enhance safety by handling dangerous tasks. Moreover, automation fosters sustainability by maximizing resource utilization and minimizing waste. Although there are obstacles, including substantial initial costs and integration difficulties, the enduring advantages such as enhanced scalability, shorter lead time, and increased agility by positing automation as crucial facilitator of robust and future ready supply chain (Chaudhari, 2019; Nitsche, 2021; Martinez, 2023).

3.1.4 Natural Language Processing:

Natural language processing used to enhance supply chain communication and decision making through sentiment analysis and communication automation. Natural language processing plays a significant role in enhancing supply chain resilience by improving communication, decision making, and risk management. By examining unstructured text data from various sources, natural language processing facilitates demand forecasting, sentiment analysis, and market intelligence. This capability allows organizations to better predict fluctuations in demand and shift in market conditions. Moreover, it's been found that natural language processing aids in optimizing supplier relationship management by automating contract evaluations and enable real time communications, thereby improving responsiveness to potential disruptions. Furthermore, natural language processing technologies can identify emerging risks by analyzing textual information for early indicators of supply chain risk, such as natural disasters (Agarwal, and Jayant, 2019; Zhou et al., 2021; Aslam, and Calghan, 2023; Janjua et al., 2023).

On the other hand, natural language processing plays a significant role in optimizing operations, including the automation of document processing to expedite customers clearance and inventory management, as well as, improving customer services virtual assistants. It enhances supply chain visibility by consolidating and summarizing data from various functions, which promotes improved collaboration across departments and accelerates decision making processes. Nevertheless, issues such as data quality, integration challenges, and privacy concerns must be tackled. Overall, natural language processing strengthens supply chain resilience by providing valuable insights, enabling proactive risk mitigation, and improving efficiency and agility in response to disruptions (Agarwal, and Jayant, 2019; Zhou et al., 2021; Kalusivalingam et al., 2022; Aslam, and Calghan, 2023; Janjua et al., 2023).

3.2 Supply Chain Functions and AI Application

AI applications were found across various supply chain functions:

3.2.1 Logistics and Distribution

AI in logistics and distribution is employed to enhance flexibility and responsiveness by optimizing routes, forecasting demand, and managing inventory. AI enhance route planning, fleet management, and delivery scheduling by utilizing real time data. Machine learning algorithms are capable of forecasting traffic trends, weather related disruptions, and fluctuations in demand, thereby improving route efficiency (Agarwal et al., 2022; Wang et al., 2022; Mariappan et al., 2023; Wang et al., 2022).

3.2.2 Procurement

In procurement, AI assists organizations in selecting suppliers, negotiating agreements, and evaluate supplier performance. Natural language processing is capable of examining contract provisions, identifying potential risks, and recognizing patterns in supplier activities (Muller et al., 2020; Pournader et al., 2021; Guan et al., 2022). Additionally, AI enhances supplier risk management by monitoring geopolitical, economic, or operational factors that impact supply chains (Guan et al., 2022).

3.2.3 Inventory Management

AI improves inventory forecasting, optimizing stock levels and reducing disruptions. AI driven systems have the capability to enhance inventory management by continuously analyzing sale data, supplier efficiency, and demand indicators. Theres AI solutions forecast stock needs and streamline the reordering process, enabling companies to sustain ideal inventory levels (Wong et al., 2021; Wamba et al., 2021; Choi et al., 2022; Li et al., 2022; Zhu etal., 2022; Wang and Zhang, 2022).

3.2.4 Production and Manufacturing

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AI driven predictive maintenance, process optimization, and automation enhance production resilience. AI applications enhance agility and flexibility, minimize disruptions, and improve resilience by allowing manufacturers to quickly respond to changes in demand, equipment performance, or external chain challenges (Ivanov et al., 2021; Wamba et al., 2021; Kumar et al., 2022; Jain et al.,2023).

3.2.5 Demand Forecasting

The accuracy of demand forecasting has been significantly improved by AI technologies, such as machine learning and deep learning, which assist companies in managing uncertainty. AI used historical data, external factors, and real time information to forecast demand with high accuracy. Machine learning algorithms are capable of analyzing previous patterns and modifying their forecasts in response to changing elements such as seasonal variations, market dynamics, or economic fluctuations (Kondapaka , 2021; Wamba et al., 2021; Muthukalyani, 2023).

3.3 Resilience Dimension Enhanced by AI

AI was found to contribute several dimensions of supply chain resilience:

3.3.1 Agility

Real time decision making is enabled by AI, which allows supply chains to quickly adapt to changing conditions and disruptions. AI improve agility by enabling quick responses to unexpected changes or disruptions within supply chain. Utilizing real time data analytics, machine learning and predictive analytics, AI can quickly identify shifts in demand, supply chain bottlenecks or recognizing production inefficiencies. For instance, AI powered systems can dynamically modify production schedules, redirect shipments, or change suppliers in response to evolving circumstances. This capability enables organizations to quickly adjust to disruptions such as unexpected demand increases, material shortages, or interruptions in the supply chain, thereby maintaining a responsive and adaptable operational framework (Ivanov et al., 2020; Choudhury et al.,2021; Wamba, 2022; Belhadi et al.,2024; Ma and Chang, 2024).

3.3.2 Flexibility

The use of AI tools enhances the flexibility of supply chains to adapt to changing demand and supply conditions. AI improves flexibility by allowing systems to quickly respond to changing conditions, which include modifying production methods, finding new suppliers, or integrating advance technologies. Tools such as predictive maintenance, AI driven process optimization, and digital twins allow organizations to rapidly reorganize production lines, investigate alternative materials, or modify workflows with little interruption. AI-driven system assists manufacture in adjusting production strategies for various product versions, meeting emerging market demands, or transitioning to new business models with reduced lead times (Ghobakhloo, 2020; Modgil et al., 2022; Ghobakhloo et al., 2023; Khan et al., 2024).

3.3.3 Robustness

While less common, AI is used to improve the overall robustness supply chain by enhancing risk mitigation strategies. AI improves robustness by bolstering an organization's capacity to endure and sustain performance during disruptions. Tools such as real-time monitoring, predictive

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analytics, and process optimization enable the identification of weaknesses in supply chains and production processes prior to their escalation into significant problems. Through the continuous analysis od data from diverse sources, AI can recognize anomalies or deviations in performance at an early stage, empowering businesses to implement corrective measure before a disruption adversely affects operations. The capability of AI enhances production efficiency, minimize downtime, and maintain quality control contributes to the overall resilience of manufacturing systems and supply chains (Baryannis et al.,2019; Ghobakhloo, 2020; Ivanov et al., 2020; Yang et al., 2022; Wang et al.,2024).

3.3.4 Recovery

AI applications in recovery process, such as post disruption analysis and contingency planning, remain limited but are growing in importance. AI enhances recovery efforts by facilitating the rapid detection of issues and the execution of solutions, thereby enabling supply chains and production systems to resume normal operations more quickly. AI powered scenario planning and simulation models equip businesses with the ability to assess the potential effects of disruptions, formulate recovery strategies, and automate recovery procedures. Furthermore, AI driven tools assist in making real time modifications in production, inventory management, and distribution during system disruptions, ensuring a quicker restoration of operational stability (Baryannis et al.,2019; Ghobakhloo, 2020; Ivanov et al., 2020; Kalusivalingam et al., 2022; Modgil et al., 2022; Ghobakhloo et al., 2023; Khan et al., 2024).

4. Discussion:

The result of this systematic mapping review highlights the significant potential of artificial intelligence to strengthen multiple aspects of supply chain resilience. Among various AI technologies, machine learning and predictive analytics are the most commonly utilized, especially in enhancing agility and flexibility within supply chains (Baryannis et al., 2019; Choi et al., 2020; Ni et al., 2020; Akbari, 2021; Riahi et al., 2021; Trikolaee et al., 2021; Ghauhan et al., 2022; Ghazal et al., 2022; Akhari etal., 2023; Dey et al., 2023; Yang et al., 2023). Nevertheless, the incorporation of AI into human decision-making process, particularly in the context of human AI collaboration for decision support, is an area that requires further investigation. Furthermore, although AI has proven beneficial in bolstering short term resilience during disruption, additional research is necessary to understand its long-term effects on supply chain robustness and the sustainable integration of AI technologies into supply chain operations (Baryannis et al., 2019; Belhadi et al., 2021; Zamani et al., 2023; Belhadi, et al., 2024).

Supply chain resilience is becoming increasingly dependent on the evolution of Artificial Intelligence (AI). In spite of the promising applications, there are still many areas need to be explored and investigated.

Further investigations into AI and supply chain resilience must focus in several important areas. Firstly, it is essential to examine the collaboration between humans and AI in supply chain management, particularly how AI can enhance the decision-making capabilities of human operators to improve resilience. Understanding the dynamics between human expertise and AI capabilities will be crucial for maximizing the benefits of both in complex decision-making processes. Secondly, additional research is necessary to evaluate the long-term effects of AI on the robustness of supply chains, especially its capacity to handle persistent disruptions over extended periods, such as continuous resources shortages or long-term environmental changes.

Furthermore, the application of AI in crisis recovery, specifically its contribution to disaster recovery strategies and post pandemic recovery are presents a significant opportunity for further study. Research should focus on how AI enable tools can facilitate rapid recovery, refine response strategies, and bolster resilience during emergencies. Lastly, the ethical implications and governance surrounding the implementation of AI in supply chain require more comprehensive examination. This encompasses ensuring transparency in AI decision making, addressing ethical issues related to bias and fairness, and establishing governance structures to regulate AI usage in supply chain activities. These topics are essential for enhancing the role of AI in creating resilient, ethical, and sustainable supply chins.

5. Conclusion:

The impact of AI on supply chain resilience is explored through this review. AI technologies have a significant impact on the agility and flexibility of supply chains during disruptions. More research is needed to integrating AI with human decision making for long-term. The paper emphasizes AI’s potential in building stronger, adaptable supply chains for researchers and practitioners.

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