sustainability

Systematic Review

Integrating Artificial Intelligence into the Supply Chain in Order to Enhance Sustainable Production—A Systematic Literature Review

Justyna Patalas-Maliszewska [1,*], Małgorzata Szmołda [2] and Hanna Łosyk [1]

[1] Institute of Mechanical Engineering, University of Zielona Góra, 65-417 Zielona Góra, Poland; h.losyk@iim.uz.zgora.pl
[2] State Archives in Zielona Góra, 65-762 Zielona Góra, Poland; m.szmolda@archiwum.zgora.pl
* Correspondence: j.patalas-maliszewska@iim.uz.zgora.pl

Abstract: Nowadays, integrating Artificial Intelligence (AI) into supply chains (SCs) is a great challenge in research and for manufacturing managers. The main goal of this study is to determine the role of AI in the context of the new SCs, according to the concept of Industry 5.0. in order to improve the level of sustainable production. The research was based on a systematic analysis of the scientific literature and application of the PRISMA methodology. Due to the relatively new vision of introducing AI into SC, it was decided to analyse the years 2021–2024. A total of 1181 research articles were identified in Science Direct, Springer and the Willey Online Library that combined AI-based methods and tools that support SCs in order to identify the impacts and challenges of integrating AI in SCs in the context of sustainable production (SP). In this study, 48 items were then analysed in detail. The results achieved highlighted the main AI-based tools applied in SCs and, secondly, revealed the main benefits of this integration for manufacturing in the following areas of manufacturing: predictive maintenance, production planning and customer relationships. The findings of our study revealed the main challenges and directions: (1) integrating digitalisation and green SP in order to build resilience to the SP, (2) create a sustainable work environment, (3) and develop a sustainable and advanced architecture for relationships with customers.

Keywords: Artificial Intelligence; manufacturing; resilience; supply chain; sustainable production

check for updates

Citation: Patalas-Maliszewska, J.; Szmołda, M.; Łosyk, H. Integrating Artificial Intelligence into the Supply Chain in Order to Enhance Sustainable Production—A Systematic Literature Review. *Sustainability* **2024**, *16*, 7110. https://doi.org/10.3390/su16167110

Academic Editor: Giada La Scalia

Received: 12 July 2024
Revised: 13 August 2024
Accepted: 16 August 2024
Published: 19 August 2024

1. Introduction

In the concept of the Industry 4.0 or even 5.0, production models are proposed that focus largely on professional practices, mainly taking into account ecology issues, an equivalent supply chain (SC) and achieving specific, measurable goals such as maximising efficiency. The well-being of employees as individuals, as is generally understood, also plays a significant role in Industry 5.0. This trend is a consequence of constant global changes, including from components such as conflicts, pandemics, and technology development, as well as the need to consider human beings as the centre of development, including technological progress. The key threat in this development is a fully responsive supply chain that uses all available Artificial Intelligence (AI)-based solutions and then further improves them [1]. Therefore, a gap in the research has been observed in examining the impacts of applying AI to the SC and designating the changes in manufacturing.

The idea of Industry 5.0 is mostly based on six main pillars: the synergy of people and machines, ecological materials and devices, digital twins, intelligent analysis and storage, the use of AI, and energy responsibility in the use of renewable energy sources [2]. The SC in this concept can be treated very dynamically, due mainly to the fact that its assumptions evolve along with changes in social and technological priorities [3]. Recent years of market disruption have shown that the SC requires a change in current business practices and managerial tasks [4]. In addition, the SC requires that problems be solved with greater speed and accuracy. The literature indicates that the SC is the field that can gain the most from the implementation of AI-based methods and tools [5], emphasising that AI-based mechanisms enable the use of comprehensive methods of visualising a variety of data at the same time. Narkhede et al. [6] indicate that the solutions offered by AI are a key support in improving operational efficiency in all phases of the SC.

Despite the numerous advantages of introducing AI into SCs in terms of the Industry 5.0 concept, many authors point to numerous threats resulting from the use of this solution. Diaz et al. [7] in their article, show that cyber threats that may appear at each stage they are introduced are highly probable in the topic discussed. Companies will have to monitor their virtual space on an ongoing basis and respond to any alarm signals. They also pay attention to the social aspect of introducing AI into the enterprise. Accordingly, the ability to manage relationships among employees is extremely important. Employees whose work will be supported by AI-based applications may feel insufficient, which will ultimately lead to social disorder, including burnout. Moreover, Boyang [8] notes that employees may experience strong anxiety, which will result in high staff turnover. Topuz et al. [9] also note that there is a significant problem in understanding AI-based solutions and translating them into real company requirements. This may result in a significant incompatibility of the systems introduced with the current profile of the company and, as a result, in significant losses. Gupta et.al [10] also point to certain limitations of applying AI, mainly on financial grounds. They point out that in this respect, blockchain technology is more effective and resilient in the financial area of SC blockchain technology, as the SC allows the authenticity and transparency of the entire process to be improved as well allowing as a continuous, unchanging record of all transactions. The entire production cycle can be recorded with blockchain, thus creating a history of flows that can be easily audited. This maximum traceability facilitates the verification of bottlenecks, as well as confirmation of compliance of the processes with the safety regulations applicable. Additionally, blockchain enables the ongoing monitoring of the location and condition of goods by all parties interested in the process, which helps reduce risk [11]. At the same time, analysis of the literature indicates that the introduction of AI-based elements into SC solutions is associated with great responsibility on the part of the entrepreneur, including the employer and the need to conduct a meticulous analysis.

Currently, the success of companies depends on the level of adaptation of their functioning to constantly changing environmental and social assumptions. Therefore, changes in SCs should be discussed in the context of sustainable production (SP), a concept which is now becoming a priority for manufacturing companies. Applying AI-based methods and tools into SCs enhances the SP level, due to the possibility of providing continuous analysis of energy and/or water usage within manufacturing [12] and monitoring systems based on green energy, indicating in which areas they can be even more energy-efficient [13].

So, the topic of AI in SCs, especially in the context of the improvement of the level of the SP, is still a new and evolving subject; therefore, the authors state that it is worth raising and analysing this theme in terms of existing literature studies. Therefore, when considering the role played by AI and the SC, three key research questions were formulated:

- RQ1: What type of AI-based methods and tools, according to the concept of Industry 5.0, were dominant in literature regarding the integration of AI into the SC?
- RQ2: When do the most important effects of integrating the AI into the SC in the context of the improvement of the level of SP occur?
- RQ3: What are the future challenges and direction for integrating AI into the SC for an improvement in the level of SP according to the concept of Industry 5.0?

The second section of the paper presents materials and methods. This study uses the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) and applies the Systematic Literature Review (SLR) and Mapping to Literature Review (MLR) methodologies for the systematic analysis of existing studies on integration of AI-based solutions which are not related to the SC. The PRISMA Checklist is added in the Supplementary Materials for review. The third section presents the results of the literature analysis and the answers to the RQ. The fourth section is a discussion on the results and current trends in the use of AI in SC. This section addresses both the advantages and concerns of implementing AI and SC. Finally, the fifth section indicates the most important conclusions resulting from the current literature on the subject and directions for integrating AI into SC for an improvement of the level of SP according to the concept of Industry 5.0.

2. Materials and Methods

2.1. PRISMA Study Characteristics

The process for selecting the source of information was defined using a PRISMA flow diagram [14] (Figure 1). PRISMA is the reporting standard for untried literature reviews and meta-analyses. Figure 1 shows the number of final records identified (Appendix A), including those both included and excluded and the main reasons for these exclusions.

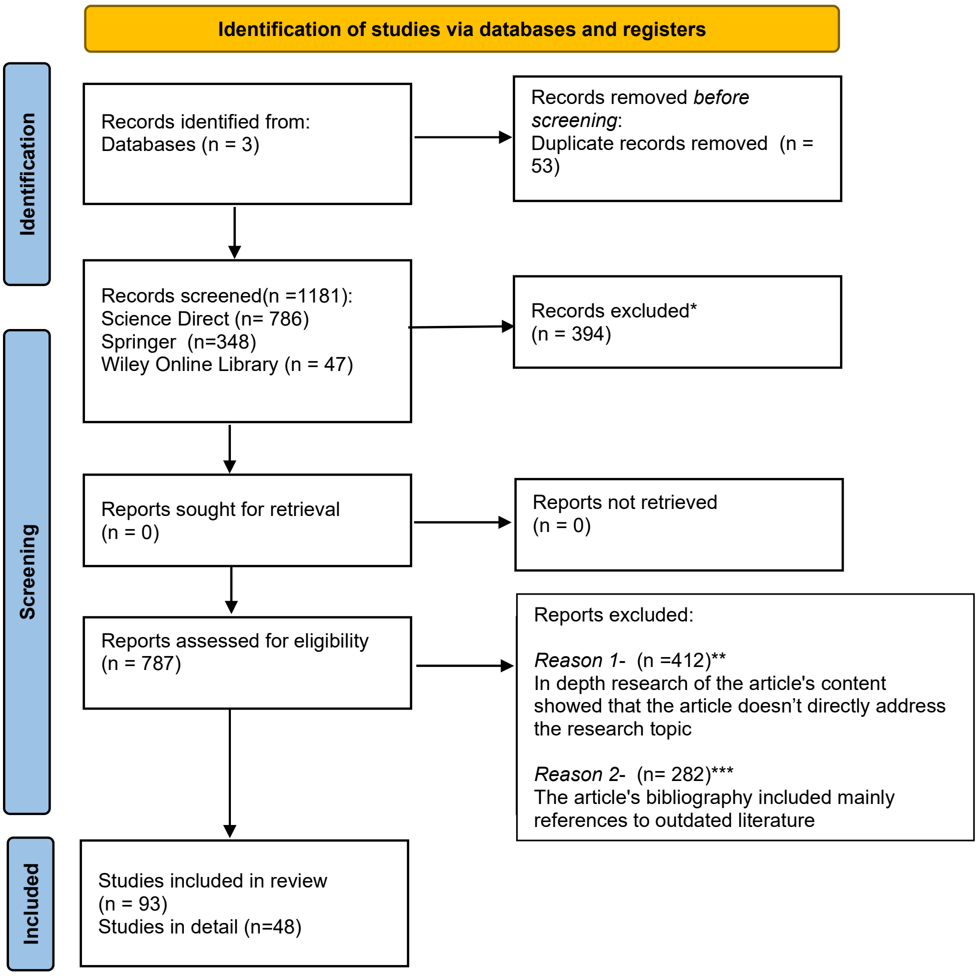

Figure 1. PRISMA flow diagram, where *—a field of research not included in the scope of the systematic review; **—in-depth research of the article's content showed that the article does not directly address the research topic, and ***—the article's bibliography included mainly references to outdated literature.

The literature analysis, according to the following research stages:

- Step 1: Defining the research objective.

The main objective of the study was to identify AI-based methods and tools applied to the SC and identify the impacts and challenges of AI integration into the SC in the context of enhancing the level of SP.

- Step 2: Carrying out the search process using identified databases, ultimately defining the final search strings and exclusion criteria.

The following key criteria were identified for selecting literature items in the field of AI-based methods in the SC: research or review articles; selected type of access: open or open archive. Only articles in English were accepted for analysis. The analysis excluded publications in the form of book chapters and post-conference materials. Three reliable databases were selected for the analysis: Science Direct—ELSEVIER, Springer, and Wiley Online Library. In the Wiley database that concerned the generally studied issue, after a thorough analysis it was found that both the detailed topics and the literature they referred to were inconsistent with the topic discussed—therefore, it was finally decided to abandon this database.

- Step 3: Conducting the analysis, after a comprehensive process of the analysis of the content of selected literature items.

When searching for articles on the topic discussed, detailed criteria described in step 2 were used. As a result, 93 scientific articles were obtained, of which 45 were rejected because they did not concern the research topic. Then, selected literature items were analysed according to the following criteria: areas of influence, research purposes, and general topic areas. In order to minimise bias and risk in the data analysis process, the G-suite tool was used.

Analysis based on the above stages allows the risk and biases in the selection of the eligible articles for the literature analysis to be reduced.

2.2. Quantitative Analysis of Selected Literature Items

During the analysis, a systematic literature selection method was used, which resulted in the exclusion of articles that did not meet the group of criteria indicated. The search used the following sets of keywords, in order to find the answers to the RQs:

- to QR1: AI in SC, AI-based methods and SC, AI-based tools and SC;
- to QR2: effects of integrating AI in SC, integrating AI in SC;
- to QR3: AI in SC, the impact of AI in SC on the level of SP.

The initial review covered the publications from the period January 2021–May 2024. 2024 was also included, due to the fact that items contain the most up-to-date information on the still-new scope of AI, its impact on the environment, and SC assumptions. The research was started in the post-pandemic year because, as the research indicates, COVID-19 indicated the weaknesses of the current SCs and the capabilities of the SP in the context of increasing SC resilience to disruptions [15–17]. Figure 2 indicates that the number of articles published is constantly increasing: 2021—15.41%; 2022—21.59%; 2023—37.85%; and until May 2024—25.15% (the number of articles published in 2024 can be estimated as twice as much by the end of the year). The results presented may be due to the fact that AI and its impact on SC have not yet been fully explored. These are new assumptions, whose effects are still taking shape.

In step 2 (see Section 2.1), after a thorough analysis and verification of the criteria, 1088 (92.13%) publications were excluded that did not meet the thematic assumptions mentioned. These publications were omitted due to the topics they cover, i.e., medicine, health, biology and migration, and they also discussed a field of research not covered by the scope of the systematic review; a thorough examination of the article content showed that the omitted articles did not directly refer to the research topic and the article's bibliography contained mainly references to outdated literature.

At the next step, the remaining 93 (7.87%) articles were processed, taking into account their title or abstract. Therefore, it was possible to determine which journals contain the most articles on the topic in the Science Direct database. Most of the articles that published literature consistent with the title and/or abstract were *Annals of Operations Research* (9.52%) and *Sustainable Production and Consumption* (9.52%). However, the distribution of journals containing articles on the topics discussed was mostly even. The issue presented is illustrated in Figure 3.

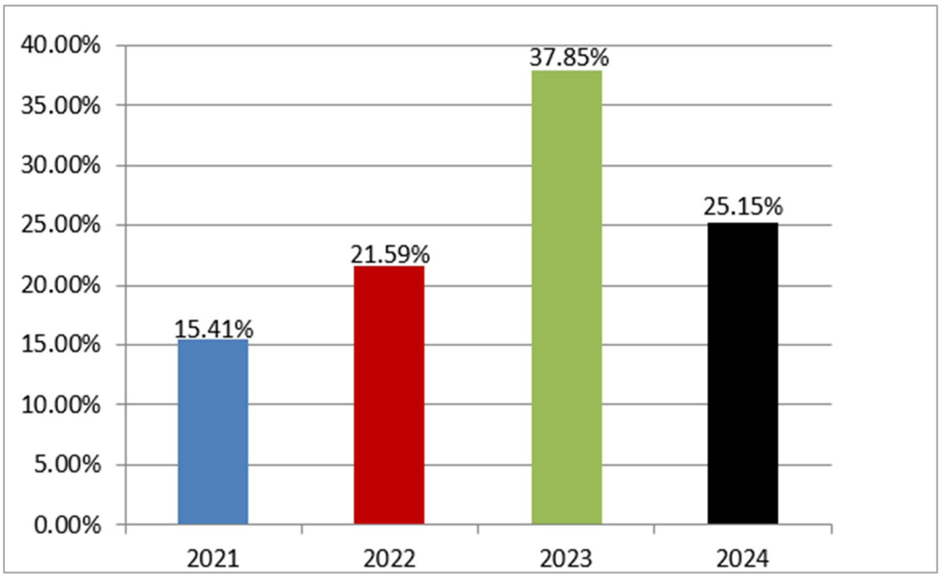

Figure 2. Number of publications in selected databases in 2021–2024.

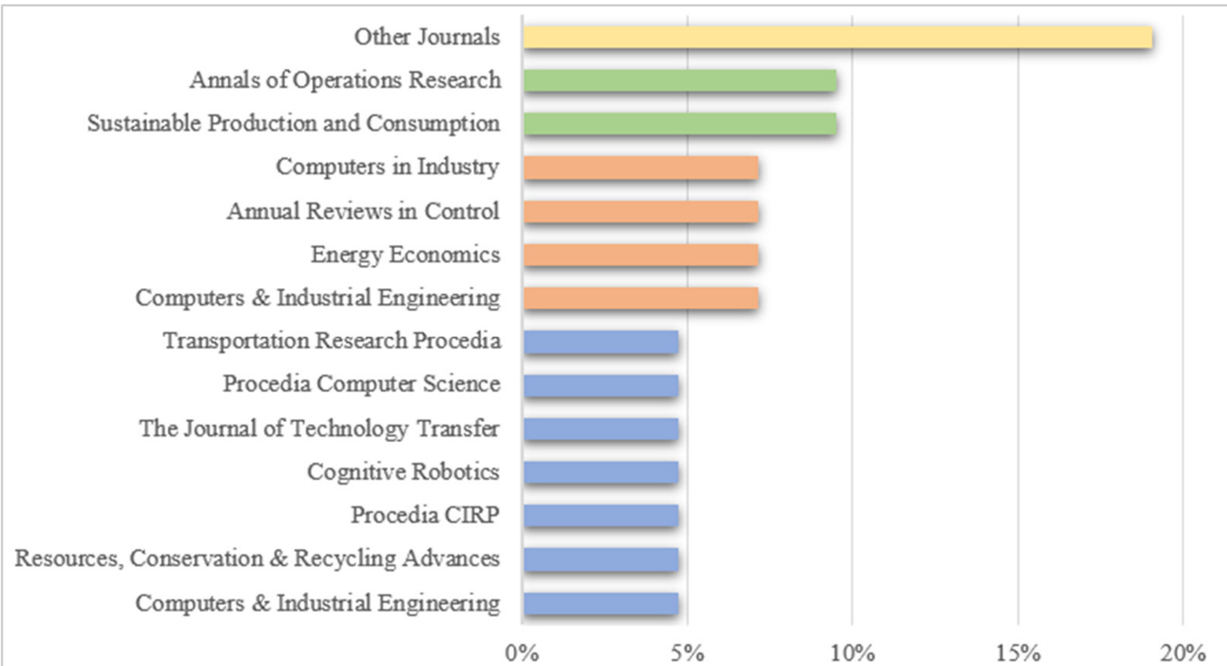

Figure 3. Literature review in the Science Direct database—compatibility of articles based on title and/or abstract.

The largest number of articles were placed in *Frontiers of Engineering Management* (15%) and *Discover Artificial Intelligence* (15%), with slightly fewer in *Operations Management Research* (10%) and *Management Review Quarterly* (10%). The obtained results are illustrated in Figure 4.

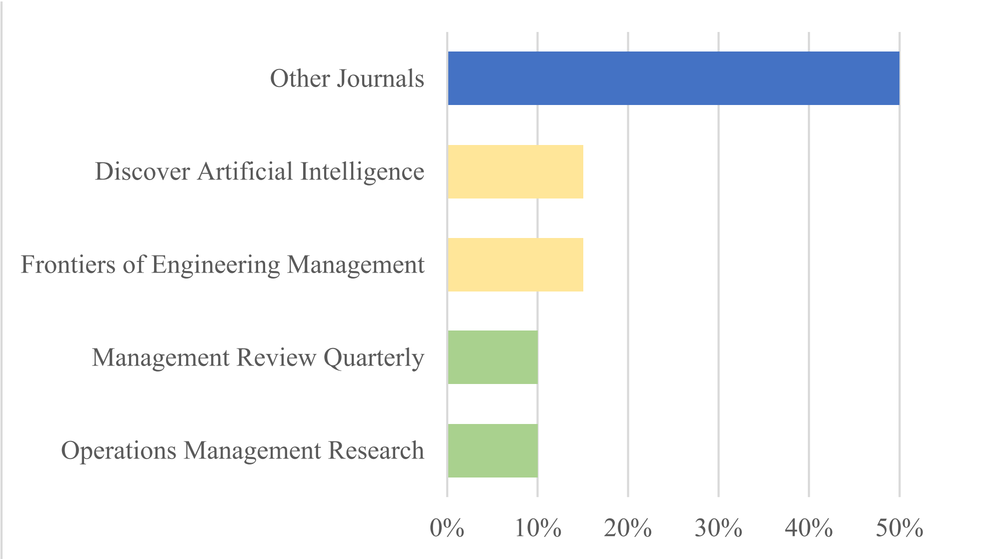

Figure 4. Literature review in the Springer database—compatibility of articles based on title and/or abstract.

2.3. *Assessment of the Full Version of Texts in Terms of Quality*

In step 3 (see Section 2.1), the content of the retrieved articles was analysed in terms of the detailed issues they raise. The above assumptions are presented in the form of a checklist (Table 1). The developed checklist supported the decision-making process at a later stage of the analysis. Each of the indicated assumptions was included in a point scale from 0 (if the content did not comply with the assumptions) to 1 (in the case of compliance of the content with the assumptions).

The list of journals from the Science Direct and Springer databases in which articles covering the subject of the review have been published is presented as Appendix B.

Table 1. Checklist.

No.	Thematic Scope	Yes	No
1	Impact of AI in SC on the level of SP		
2	Optimal AI solutions in SC		
3	A resilient SC and the effects of AI solutions		
4	Benefits and opportunities of AI		
5	AI-based methods and SC		

In the final results, it was assumed that only those items that, as a result of the analysis, would receive a minimum of 2 points, would be subject to detailed analysis. Thus, 48 articles remained in the final stage of selection, which allowed us to find answers to the research questions posed in the work (RQ1–RQ3). The characteristics of the selected literature sources accepted for the final analysis are presented in Table 2.

Table 2. Review the full text.

Source (Appendix A)	Tools and Methods	The Impact of AI in SC on the Level of SP
1	review	Yes
2	review	Yes
3	review	Yes
4	interpretive structural modelling technique	Yes

Table 2. *Cont.*

Source (Appendix A)	Tools and Methods	The Impact of AI in SC on the Level of SP
5	integrated system for traceability of operations over time, semantic network of things, IoT, intelligent CPS, LAsim Smart FActor Plus reference framework	Yes
6	IoT, blockchain	Yes
7	blockchain, digitalisation, convenience sampling method, standardised mean square root residual	No
8	review	Yes
9	distributed data analytics, embedded computing, IoT, CPS, software engineering, edge and Cloud technologies	Yes
10	-	No
11	review	No
12	lean maintenance, lean manufacturing	No
13	review	No
14	review	Yes
15	ML (ALRC)	Yes
16	review	Yes
17	mathematical formulation for own model	Yes
18	review	Yes
19	CPPS	Yes
20	digitization, IoT	No
21	review	No
22	ChatGPT	No
23	HR systems support, NN	No
24	intelligent identification, ANAFIS, genetic algorithms, hidden Markov models	No
25	digitisation, XAI	Yes
26	HRM, Cloud manufacturing, IoT, predictive analytics, DT	Yes
27	-	Yes
28	IoE, Cobots, Smart sensors, 3Dprinting	Yes
29	DT, IoT	No
30	ML, DL, Collaborative Robots, tracking technology, blockchain, DT	No
31	IoS, CPS, Big Data Analytics, DM, Blockchain, AR, Cobots	Yes
32	ML, bibliometric, IoT	Yes
33	Cobots, ML, intelligent algorithms	Yes
34	Cloud computing	No
35	statistical methods, data	
36	distributed data analytics, embedded computing, IoT, CPS	
37	Bayesian Best Worst Method	No
38	review	Yes
39	Digital cognitive clones	Yes
40	review	Yes
41	TVP-SV-VAR methodology	No
42	IoT	No
43	questionnaire, OMEGA method	No
44	Big Data Analytics, AHP, GRA methodology	Yes
45	review	No
46	ontological model, MATLAB, JAVA, IoT	Yes
47	survey	Yes
48	review	Yes

explanations of abbreviations: ML—machine learning; DL—deep learning; NN—neural networks; DT—digital twin; DM—Data Mining; CPS—Cyber Physical Systems; CPPS—Cyber–Physical Production Systems; IoT—Internet of things; ANFIS—fuzzy inference systems; HRM—human resource platforms; AHP—analytic hierarchy process; GRA—grey relational analysis; ALRC—Adaptive Logistic Regression Classifier; XAI—explainable artificial intelligence.

3. Results

A total of 48 articles were taken into account, which were chosen by a detailed analysis of both their content and the literature to which reference could be found in the text. The authors wanted the most up-to-date knowledge of the topic in question, especially in the aspect of the post-COVID-19 time, which forced many significant changes on companies in the manufacturing industry. In addition, the authors of the article wanted to demonstrate research gaps and directions for further research.

Answering the first RQ, we found that the following AI-based tools, according to the concept of Industry 5.0, were dominant in the literature regarding the integration of AI into the SC: ChatGPT4, Google Bard, Chatsonic, Midjourney, DALL-E, SlidesAI, Alli AI, Hubspot Free AI Content Writer, Paradox, Synthesia, aiXcoder, TabNine, DeepBrain AI, SecondBrain, Textio, Wordtune, Figstack, and Descript. The tools distinguished are applied to the SC to support process automation and data analysis.

Next, text mining features were adopted for article analysis and used to visualise the network of the co-occurrence of key terms using the programme VOSviewer version 1.6.20 (Figure 5). On the basis of the network (Figure 5) of connections generated and the analysis of the results of the accepted articles, the authors responded to the RQ2 and RQ3 posed in the paper.

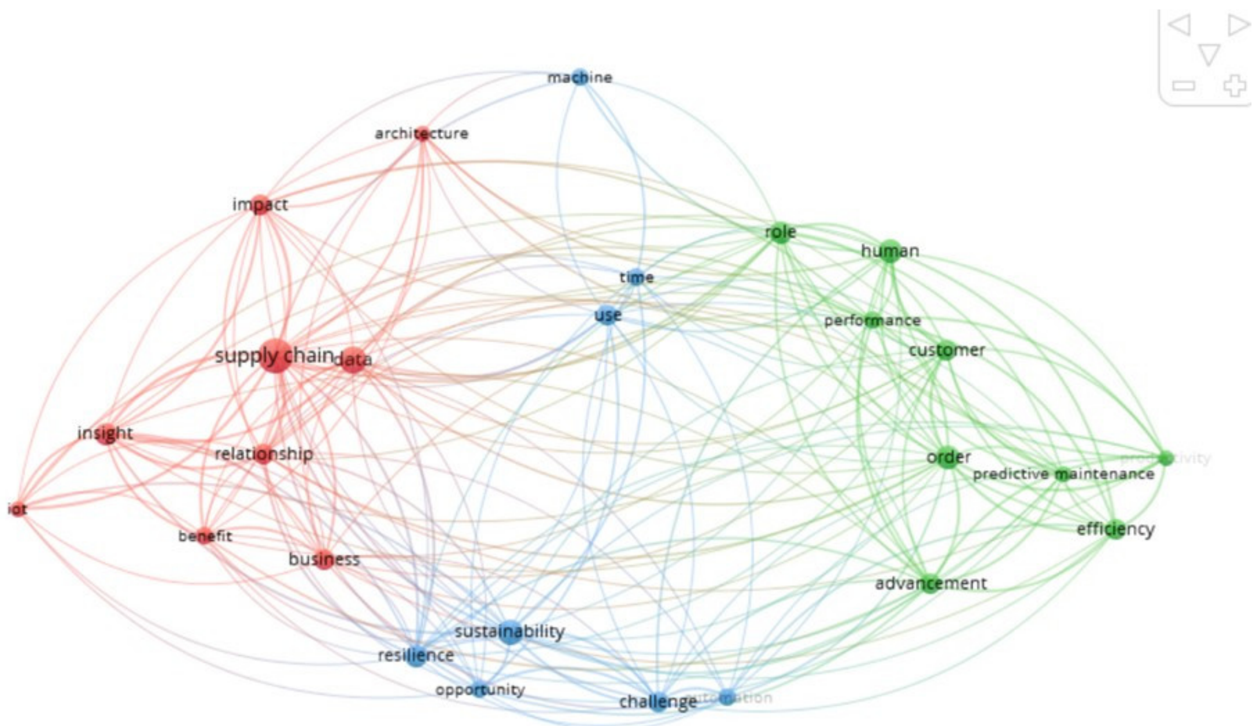

Figure 5. Networks for selected databases.

The network of connections (Figure 5) shows the degree of intensity and strength of connections among the sources analysed. Cluster analysis, marked in red, indicates variables that have a significant impact on the research topic in the sources analysed. Thus, it is indicated that the main trend of AI in the SC is building strong relationships with contractors, changing the architecture, and analysing the benefits and impact of AI on the functioning of the SC. The second cluster analysis, marked in blue, indicates variables that have a strong but non-dominant influence on AI activities in the SC. This cluster indicates the importance of activities aimed at improving such elements as resilience, time, and the level of sustainability of SC through the use of technical means (e.g., machines). The third cluster analysis, marked in green on the chart, indicates the relationships between variables. The last cluster in the network indicates the important role of AI in the SC in the context of changing the role of humans in SCs and thus the effectiveness and efficiency of processes, as well as customer expectations and the possibility of progressive predictive maintenance. Thus, the map of connections presented allows us to determine the business and the strategic and technical challenges that enterprises encounter in the process of implementing AI in SCs. Answering RQ 2, the most important effects of integrating AI into the SC in the context of the improvement in the level of SP occur when they are linked to the following areas of manufacturing:

- predictive maintenance, which reduces costs and saves time,
- production planning (orders), which increases efficiency and performance,
- customer relationships, which increases advancement.

Next, looking for the answer to RQ3, the implementation of AI in SC, drives actions towards improving SP in manufacturing, to develop the SC resilience. Therefore, the main future challenges and direction for integrating AI into SCs for an improvement in the level of SP according to the concept of Industry 5.0 are the following: (1) strengthening SC resilience by integrating digitalization with SP assumptions, (2) creating a sustainable work environment, and (3) developing a sustainable and advanced architecture for relationships with customers. The first of the assumptions is based to a significant extent on the introduction of digital tools based on ecological SP, in such a way as to maximise the resilience of SP to all likely threats, both external and internal, by means of the use of materials with a higher level of environmental acceptance and the introduction of IT solutions that will continuously monitor the impact of production on ecology.

Another aspect, i.e., creating a sustainable work environment, is an area focussing on introducing balance in the context of work and organisation. It is crucial to examine the environmental characteristics of an individual in relation to the environmental characteristics of work and their impact on satisfaction and the development of professional attitudes. Introducing balance into the productive work environment allows autonomy in the working environment to be increased, and improves the organisational climate [18]. The last assumption, i.e., developing a sustainable and advanced architecture for relationships with customers, places greater emphasis on introducing AI solutions into contacts with customers. A larger number of data that can be analysed using AI allows interaction with the customer in real time and maximum adaptation to their needs [19]. All these aspects are crucial in maintaining an ecological and sustainable SP, with the help of AI.

4. Discussion

The literature analysis indicated that an efficiently operating SC aimed at optimal profit requires continuous and dynamic adaptation to changes in the context of SP, applying AI-based methods and tools. As shown in the work [15], the SP concept can help build the resilience of enterprises in the face of global crises. Today's SC should therefore be characterised by a balance that allows joint action in line with changing social and environmental trends [3]. A systematic literature review presented in [20] explains that AI-based solutions implemented in the SC such as machine learning, intelligent applications, digital twins and smart things [21], facilitate the ongoing and continuous detection of errors and enable their quick elimination. In our work we distinguish the main AI-based tools applied in the SC. Despite the advantages of implementing AI in SCs, as indicated in the paper, doubts are also pointed out related to the potential threats that AI can generate [7], especially in the area of cybersecurity. AI tools and methods implemented in SCs are undoubtedly a necessity that creates new opportunities for enterprises, but actions are necessary to identify potential threats. Currently, solutions are being sought that will be the industry's response to the needs of the environment and global society [22] especially in the area of the SC, which is of key importance in post-pandemic times.

A great example of confirming that AI in SCs brings tangible benefits and that there is a need to develop areas related to it is the European project "knowlEdge—Towards Artificial Intelligence-powered", which combines a focus on production services, processes, and products throughout the entire life cycle, and takes into account the human aspect. The authors of this project indicate that strategies based on AI in the SC should constantly adapt to rapidly changing conditions, including customer needs, while optimizing all processes taking place in the company [23].

According to the benefits of the integration of AI into the SC for production discovered so far, in the next stage of our research, human–robot co-operation (HRC) should be developed, which will facilitate effective predictive maintenance, production planning and customer relationships. The main goal of HRC is to create a collaborative environment that will allow harmonious and safe work between people and robots.

Due to the dynamic development of HRC, it is necessary to search for solutions that improve safety in this area. The literature review indicates that safety in HRC is not limited only to the technical shaping of the work environment, but also takes into account psychophysical and social aspects. Many solutions implemented in HRC to improve the comfort and safety of the work environment are based on artificial neural networks or deep learning algorithms [Appendix A, ref. 36]. It is necessary to point out the key role of collecting data from sensors and their integration and processing in order to achieve a full picture of the working environment and its impact on the operator [24]. Moreover, the literature indicates the important role of deep learning methods, which allow for the ongoing recognition and identification of working conditions, as well as optimal matching of tasks to the robot and its operator [25]. The indicated methods support the shaping of the working environment in the new HRC space in the social, technical and environmental context.

Previous SC management was labour-intensive and focussed on manual processes. HRC opens up new possibilities in the SC area because it supports or replaces staff in performing repetitive, uncomfortable and non-ergonomic operations. In addition, collaborative intelligence can combine human creativity with the speed and accuracy of equipment, making up for the shortcomings of each manufacturing method. The potential of HRC, including the integration of technological innovations such as AI-based automation and AR, allows new foundations for warehouse operations to be defined. HRC may be a paradigm that will completely change the face of industry and enable full collaboration between the environment and society [26]. The role of HRC in shaping a safe working environment should also be emphasised, as over the past decade safety has been the most frequently cited topic in the literature on collaborative robots. Therefore, this area requires further actions that will permit better understanding of the implementation of HRC in the SC. Figure 6 provides a research insight for enhancing sustainable production due to integrating AI into the SC.

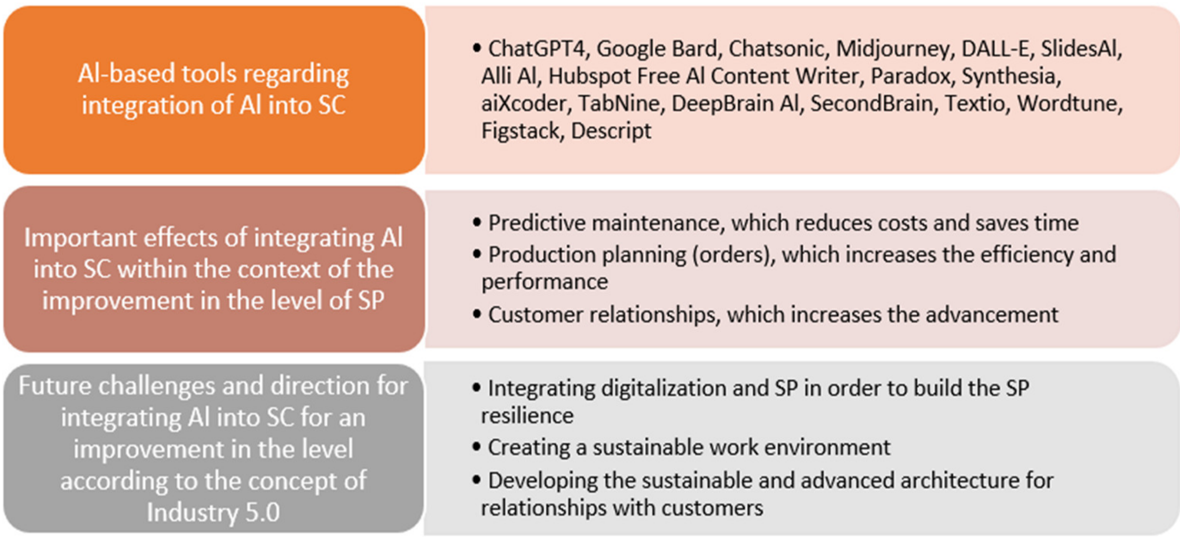

Figure 6. Research insights for enhancing sustainable production due to integrating AI into SCs.

The limitations of this research are, firstly, a limited number of searched databases and a limited number of keywords, and, secondly, the still developing topic of AI in SCs. This is an aspect that is constantly evolving, which greatly affects the availability of literature that presents current data regarding the production environment.

The main challenge is how we can improve the resilience of SCs, which can be determined as the "ability to maintain, execute and recover (adapt) planned execution along with achievement of the planned (or adapted, but yet still acceptable) and is therefore the next objective property of the supply chain" [27]. Resilience in the SC should be built on an approach based on stability and acceptance, through the integration of broadly understood protection and significant adaptability [28]. In order to maximise the resistance of the SC to disruptions and the period after the disruptions, it is crucial to adopt appropriately selected resilience strategies [29] built through appropriate communication and co-operation at all levels, together with innovation and visibility and sharing of information. The key issue in building the resilience of SC is the appropriate management of its processes, including the creation of flexibility and various scenarios for solving potential problems. SC tools, such as SC mapping, material allocation and stocks around the world and scalability, and human resources that will be able to respond to potential threats and take appropriate actions, are also very important in building resilience [30].

5. Conclusions

Research results indicate that AI in SCs allows the level of SP in the enterprise to be strengthened and contributes to building the resilience of a sustainable SC. It is important to take actions in manufacturing that will allow the selection of the best AI-based techniques in SCs, especially in the context of SP, which seems to be a key element in building the resilience and competitiveness of the enterprise. Therefore, it is crucial to analyse possible solutions and propose specific practical actions with AI-based methods to support manufacturing companies in the event of unexpected variables. Applying AI-based methods to SCs allows the achievement of the assumptions of SP strategy, e.g., reducing the amount of waste, selecting appropriate parameters and tools for improving the SP level, determining the market demand, and estimating the possibility of reducing energy cost.

Further research should focus on presenting exemplary case studies and defining a catalogue of good practices. It is also important in future analyses that the AI-based methods and tools supporting HRC in the SC determine whether AI support for HRC should be further developed, as well as identifying components that may negatively impact the optimal introduction of AI tools into HRC in the SC.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16167110/s1, PRISMA 2020 Checklist.

Author Contributions: Conceptualization, J.P.-M. and H.Ł.; methodology, J.P.-M., M.S. and H.Ł.; software, H.Ł. and M.S.; validation, J.P.-M. and H.Ł.; formal analysis, J.P.-M., H.Ł. and M.S.; investigation, J.P.-M., H.Ł. and M.S.; resources, J.P.-M., H.Ł. and M.S.; data curation, H.Ł. and M.S.; writing—original draft preparation, J.P.-M., H.Ł. and M.S.; writing—review and editing, J.P.-M.; visualization H.Ł. and M.S.; supervision, J.P.-M.; project administration, J.P.-M.; funding acquisition, J.P.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by a program of the Polish Ministry of Science under the title 'Regional Excellence Initiative', project no. RID/SP/0050/2024/1.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article and Supplementary Materials.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A Literature Research Results

1. Abirami Raja Santhi & Padmakumar Muthuswamy (2023), Industry 5.0 or industry 4.0S? Introduction to industry 4.0 and a peek into the prospective industry 5.0 technologies, *International Journal on Interactive Design and Manufacturing* (IJIDeM) Volume 17, pp. 947–979.
2. Susana Garrido, Jorge Muniz Jr. Vagner Batista Ribeiro (2024), Operations Management, Sustainability & Industry 5.0: A critical analysis and future agenda, *Cleaner Logistics and Supply Chain*.
3. Moin Khan, Abid Haleem, Mohd Javaid (2023), Changes and improvements in Industry 5.0: A strategic approach to overcome the challenges of Industry 4.0, *Green Technologies and Sustainability*, Volume 1, Issue 2.
4. Morteza Ghobakhloo, Mohammad Iranmanesh, Muhammad Faraz Mubarak (2022), Identifying industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values, *Sustainable Production and Consumption*, Volume 33.
5. Joaquín Ordieres-Meré, Miguel Gutierrez, Javier Villalba-Díez (2023), Toward the industry 5.0 paradigm: Increasing value creation through the robust integration of humans and machines, *Computers in Industry*, Volume 150.
6. Weihua Liu, Yang He, Jingxin Dong &Yuenan Cao (2023), Disruptive technologies for advancing supply chain resilience, *Frontiers of Engineering Management*, Volume 10, pp. 360–366.
7. Ying Li, Dakun Li, Yuyang Liu &Yongyi Shou (2023), Digitalization for supply chain resilience and robustness: The roles of collaboration and formal contracts, *Frontiers of Engineering Management*, Volume 10, pp. 5–19.
8. Özge Albayrak Ünal, Burak Erkayman, Bilal Usanmaz (2023), Applications of Artificial Intelligence in Inventory Management: A Systematic Review of the Literature, *Archives of Computational Methods in Engineering*, Volume 30, pp. 2605–2625.
9. Stefan Walter (2023), AI impacts on supply chain performance: a manufacturing use case study, *Discover Artificial Intelligence*, Volume 3, 18.
10. Bill Cope, Mary Kalantzis, (2022), Artificial intelligence in the long view: from mechanical intelligence to cyber-social systems, *Discover Artificial Intelligence*, Volume 2,13.
11. Bukhoree Sahoh, Anant Choksuriwong (2023), The role of explainable Artificial Intelligence in high-stakes decision-making systems: a systematic review, Volume 14, pages 7827–7843, *Journal of Ambient Intelligence and Humanized Computing*.
12. Alim Al Ayub Ahmed, Arumugam Mahalakshmi, K. Arul Rajan, Joel Alanya-Beltran & Mohd (2023), Naved Integrated artificial intelligence effect on crisis management and lean production: structural equation modelling frame work, *International Journal of System Assurance Engineering and Management*, Volume 14, pp. 220–227.
13. Anthony D. Scaife (2024), Improve predictive maintenance through the application of artificial intelligence: A systematic review, *Results in Engineering*, Volume 21.
14. Mario Angos Mediavilla, Fabian Dietrich, Daniel Palm (2022), Review and analysis of artificial intelligence methods for demand forecasting in supply chain management, *Procedia CIRP*, Volume 107, pp. 1126–1131.
15. Basim Aljabhan (2023), Economic strategic plans with supply chain risk management (SCRM) for organizational growth and development, *Alexandria Engineering Journal*, Volume 79, pp. 411–426.
16. Mohsen Soori, Behrooz Arezoo, Roza Dastres (2023), Artificial intelligence, machine learning and deep learning in advanced robotics, a review, *Cognitive Robotics*, Volume 3, 2023, pp. 54–70.
17. Subhajit Saha, Adel Fahad Alrasheedi, Md. Al-Amin Khan, Amalesh Kumar Manna (2023), Optimal strategies for green investment, sharing contract and advertisement effort in a supply chain coordination problem, *Ain Shams Engineering Journal*.
18. Marek Pawlicki, Aleksandra Pawlicka, Rafał Kozik, Michał Choraś, Advanced insights through systematic analysis: Mapping future research directions and opportunities for

xAI in deep learning and artificial intelligence used in cybersecurity, Neurocomputing, Volume 590, 2024, 127759, ISSN 0925-2312.
19. István Mezgár, József Váncza (2022), From ethics to standards—A path via responsible AI to cyber-physical production systems, *Annual Reviews in Control*, Volume 53, pp. 391–404.
20. Andrea Szalavetz (2022), The digitalisation of manufacturing and blurring industry boundaries, *CIRP Journal of Manufacturing Science and Technology*, Volume 37.
21. Khlood Ahmad, Mohamed Abdelrazek, Chetan Arora, Arbind Agrahari Baniya, Muneera Bano, John Grundy (2023), Requirements engineering framework for human-centered artificial intelligence software systems, *Applied Soft Computing*, Volume 143.
22. Gianclaudio Malgieri, Frank Pasquale (2024), Licensing high-risk artificial intelligence: Toward ex ante justification for a disruptive technology, *Computer Law & Security Review*, Volume 52.
23. Juha Sipola, Minna Saunila, Juhani Ukko (2023), Adopting artificial intelligence in sustainable business, *Journal of Cleaner Production*, Volume 426.
24. Kabita Das, Manaswini Pattanaik, SmitimayeeBasantia, Radhashyam Mishra, Debashreemayee Das, Kanhucharan Sahoo, BiswaranjanPaital (2023), Informatics on a social view and need of ethical interventions for wellbeing via interference of artificial intelligence, *Telematics and Informatics Reports,* Volume 11.
25. Kiarash Sadeghi R., Divesh Ojha, Puneet Kaur, Raj V. Mahto, Amandeep Dhir (2024), Explainable artificial intelligence and agile decision-making in supply chain cyber resilience, *Decision Support Systems*, Volume 180.
26. Morteza Ghobakhloo, Hannan AmoozadMahdiraji, Mohammad Iranmanesh& Vahid Jafari-Sadeghi, (2024), From Industry 4.0 Digital Manufacturing to Industry 5.0 Digital Society: a Roadmap Toward Human-Centric, *Sustainable, and Resilient Production, Information Systems Frontiers*.
27. Sachin Modgil, Rohit Kumar Singh & Soni Agrawal (2023), Developing human capabilities for supply chains: an industry 5.0 perspective, *Annals of Operations Research*, 2023.
28. Rahardjo, B., Wang, FK., Lo, SC. et al. (2023), A Sustainable Innovation Framework Based on Lean Six Sigma and Industry 5.0. *Arabian Journal for Science and Engineering*.
29. Jiménez-Partearroyo, M., Medina-López, A. & Juárez-Varón, D. (2023), Towards industry 5.0: evolving the product-process matrix in the new paradigm. *The Journal of Technology Transfer*.
30. Agrawal, S., Agrawal, R., Kumar, A. et al. (2023), Can industry 5.0 technologies overcome supply chain disruptions?—a perspective study on pandemics, war, and climate change issues, *Operations Management Research*.
31. Kazancoglu, Y., Mangla, S.K., Berberoglu, Y. et al. (2023), Towards Industry 5.0 Challenges for The Textile and Apparel Supply Chain for The Smart, Sustainable, and Collaborative Industry in Emerging Economies. *Information Systems Frontiers*.
32. Rana, J., Daultani, Y. (2023), Mapping the Role and Impact of Artificial Intelligence and Machine Learning Applications in Supply Chain Digital Transformation: A Bibliometric Analysis. *Operations Management Research* 16, pp. 1641–1666.
33. Jiewu Leng, Xiaofeng Zhu, Zhiqiang Huang, Xingyu Li, Pai Zheng, Xueliang Zhou, Dimitris Mourtzis, Baicun Wang, Qinglin Qi, Haidong Shao, Jiafu Wan, Xin Chen, Lihui Wang, Qiang Liu (2024), Unlocking the power of industrial artificial intelligence towards Industry 5.0: Insights, pathways, and challenges, *Journal of Manufacturing Systems*, Volume 73, pp. 349–363.
34. Xiaowen Wang, Mingyue Chen, Nanxu Chen (2024), How artificial intelligence affects the labour force employment structure from the perspective of industrial structure optimisation, *Heliyon*, Volume 10, Issue 5.
35. Marta Daroń, Monika Górska (2023) Enterprises development in context of artificial intelligence usage in main processes, *Procedia Computer Science*, Volume 225, pp. 2214–2223.

36. Stefan Walter (2023), Impacts of AI driven manufacturing processes on supply chains: the contributions of the knowlEdge project, *Transportation Research Procedia*, Volume 72, pp. 3443–3449.
37. Tazim Ahmed, Chitra Lekha Karmaker, Sumaiya Benta Nasir, Md. Abdul Moktadir, Sanjoy Kumar Paul (2023), Modeling the artificial intelligence-based imperatives of industry 5.0 towards resilient supply chains: A post-COVID-19 pandemic perspective, *Computers & Industrial Engineering,* Volume 177.
38. Hassan Alimam, Giovanni Mazzuto, Nicola Tozzi, Filippo Emanuele Ciarapica, Maurizio Bevilacqua (2023), The resurrection of digital triplet: A cognitive pillar of human-machine integration at the dawn of industry 5.0, *Journal of King Saud University—Computer and Information Sciences*, Volume 35, Issue 10.
39. Mariia Golovianko, VaganTerziyan, Vladyslav Branytskyi, Diana Malyk (2023), Industry 4.0 vs. Industry 5.0: Co-existence, Transition, or a Hybrid, *Procedia Computer Science*, Volume 217, pp. 102–113.
40. Giovanni Francesco Massari, Raffaele Nacchiero, Ilaria Giannoccaro (2023), Digital technologies for resource loop redesign in circular supply chains: A systematic literature review, Resources, *Conservation & Recycling Advances*, Volume 20.
41. Yufei Zhong, Xuesheng Chen, Zhixian Wang, Regina Fang-Ying Lin (2024), The nexus among artificial intelligence, supply chain and energy sustainability: A time-varying analysis, *Energy Economics*, Volume 132.
42. Martijn Koot, Martijn R.K. Mes, Maria E. Lacob (2021), A systematic literature review of supply chain decision making supported by the Internet of Things and Big Data Analytics, *Computers & Industrial Engineering*, Volume 154.
43. SospeterOlewe, Melina Finke, Julia Belke, Florian Dyck, Christian Kürpick (2023), Use Case Catalog and Assessment for AI Applications in Intralogistics of Manufacturing Companies, *Procedia CIRP*, Volume 118, pp. 74–79.
44. Raj, R., Kumar, V. & Verma, P. (2023), Big data analytics in mitigating challenges of sustainable manufacturing supply chain. Operations Management Research 16, pp. 1886–1900.
45. Alsolbi, I., Shavaki, F.H., Agarwal, R. et al. (2023), Big data optimisation and management in supply chain management: a systematic literature review. *Artificial Intelligence Review*, (Suppl 1), pp. 253–284.
46. Alahmadi, D.H., Jamjoom, A.A. (2022), Decision support system for handling control decisions and decision-maker related to supply chain. *Journal of Big Data* 9, 114.
47. Akbari, M., Hopkins, J.L. (2022), Digital technologies as enablers of supply chain sustainability in an emerging economy. *Operations Management Research* 15, pp. 689–710.
48. Durugbo, C.M., Al-Balushi, Z. (2023), Supply chain management in times of crisis: A systematic review. *Management Review Quarterly* 73, pp. 1179–1235.

Appendix B

Science Direct	Number of Articles
Ain Shams Engineering Journal	1
Alexandria Engineering Journal, Volume	1
Annual Reviews in Control	1
Applied Soft Computing	1
CIRP Journal of Manufacturing Science and Technology	1
Cleaner Logistics and Supply Chain	1
Computer Law & Security Review	1
Computers in Industry	1

Science Direct	Number of Articles
Decision Support Systems	1
Energy Economics	1
Green Technologies and Sustainability	1
Heliyon	1
Journal of King Saud University—Computer and Information Sciences	1
Journal of Manufacturing Systems	1
Operations Management Research	1
Procedia CIRP	1
Procedia Computer Science	1
Resources, Conservation & Recycling Advances	1
Results in Engineering	1
Sustainable Production and Consumption	1
Telematics and Informatics Reports	1
Transportation Research Procedia	1
Cognitive Robotics	2
Computers & Industrial Engineering	2
Journal of Cleaner Production	2
Total	28
Springer	**Number of articles**
Annals of Operations Research	1
Arabian Journal for Science and Engineering	1
Archives of Computational Methods in Engineering	1
Artificial Intelligence Review springer	1
Computers & Industrial Engineering	1
International Journal of System Assurance Engineering and Management	1
International Journal on Interactive Design and Manufacturing	1
Journal of Ambient Intelligence and Humanized Computing	1
Procedia CIRP	1
The Journal of Technology Transfer	1
Discover Artificial Intelligence	2
Frontiers of Engineering Management	2
Information Systems Frontiers	2
Journal of Big Data	2
Operations Management Research	2
Total	20

References

1. Darko, E.O.; Vlachos, I. Creating Valuable Relationships with Third-Party Logistics (3PL) Providers: A Multiple-Case Study. *Logistics* **2022**, *6*, 38. [CrossRef]
2. European Commission, Publication Office of European Union, Brussel. *Industry 5.0. Towards a Sustainable, Humancentric and Resilient European Industry*; European Commission: Brussels, Belgium, 2021; pp. 8–9.

3. Machado, C.G.; Winroth, M.P.; Ribeiro da Silva, E.H.D. Sustainable manufacturing in Industry 4.0: Anemerging research agenda. *Int. J. Prod. Res.* **2020**, *58*, 1462–1484. [CrossRef]
4. Sharma, R.; Shishodia, A.; Gunasekaran, A.; Min, H.; Munim, Z.H. The role of artificial intelligence in supply chain management: Mapping the territory. *Int. J. Prod. Res.* **2022**, *60*, 7527–7550. [CrossRef]
5. Jung, D.; Choi, Y. Systematic review of machine learning applications in mining: Exploration, exploitation, and reclamation. *Minerals* **2021**, *1*, 148. [CrossRef]
6. Narkhede, P.; Walambe, R.; Mandaokar, S.; Chandel, P.; Kotecha, K.; Ghinea, G. Gas detection and identification using multimodal artificial intelligence based sensor fusion. *Appl. Syst. Innov.* **2021**, *4*, 3. [CrossRef]
7. Diaz, R.; Ungoa, R.; Smithb, K.; Haghnegahdara, L.; Singha, B.; Phuonga, T. 5th International Conference on Industry 4.0 and Smart Manufacturing Applications of AI /ML in Maritime Cyber Supply Chains. *Procedia Comput. Sci.* **2024**, *232*, 3247–3325. [CrossRef]
8. Chen, B.; Wu, Z.; Zhao, R. From Fiction to Fact: The Growing Role of Generative AI in Business and Finance. *J. Chin. Econ. Bus. Stud.* **2023**, *21*, 471–496. [CrossRef]
9. Topuz, K.; Zengul, F.D.; Dag, A.; Almehmi, A.; Yildirim, M.B. Predicting graft survival among kidney transplant recipients: A Bayesian decision support model. *Decis. Support. Syst.* **2018**, *106*, 97–109. [CrossRef]
10. Gupta, S.; Modgil, S.; Choi, T.M.; Kumar, A.; Antony, J. Influences of artificial intelligence and blockchain technology on financial resilience of supply chains. *Int. J. Prod. Econ.* **2023**, *261*, 108868. [CrossRef]
11. Akram, M.W.; Akram, N.; Shahzad, F.; Rehman, K.U.; Andleeb, S. Blockchain technology in a crisis: Advantages, challenges, and lessons learned for enhancing food supply chains during the COVID-19 pandemic. *J. Clean. Prod.* **2024**, *434*, 140034. [CrossRef]
12. Zechiel, F.; Blaurock, M.; Weber, E.; Büttgen, M.; Coussement, K. How tech companies advance sustainability through artificial intelligence: Developing and evaluating an AI x Sustainability strategy framework. *Ind. Mark. Manag.* **2024**, *119*, 75–89. [CrossRef]
13. Mehmood, M.U.; Chun, D.; Han, H.; Jeon, G.; Chen, K. A review of the applications of artificial intelligence and big data to buildings for energy-efficiency and a comfortable indoor living environment. *Energy Build.* **2019**, *202*, 109383. [CrossRef]
14. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, 71. [CrossRef]
15. Patalas-Maliszewska, J.; Łosyk, H. Changes in Sustainable Development in Manufacturing in Cases of Unexpected Occurrences—A Systematic Review. *Sustainability* **2024**, *16*, 717. [CrossRef]
16. Moosavi, J.; Fathollahi-Fard, A.; Dulebenets, M. Supply chain disruption during the COVID-19 pandemic: Recognizing potential disruption management strategies. *Int. J. Disaster Risk Reduct.* **2022**, *75*, 102983. [CrossRef] [PubMed]
17. Raj, A.; Mukherjee, A.; Lopes de Sousa Jabbour, A.; Srivastava, S. Supply chain management during and post-COVID-19 pandemic: Mitigation strategies and practical lessons learned. *J. Bus. Res.* **2022**, *142*, 1125–1139. [CrossRef]
18. Kühner, C.; Stein, M.; Zacher, H. A person-environment fit approach to environmental sustainability in the workplace. *J. Environ. Psychol.* **2024**, *95*, 102270. [CrossRef]
19. Li, F.; Xu, G. AI-driven customer relationship management for sustainable enterprise performance. *Sustain. Energy Technol. Assess.* **2022**, *52 Pt B*, 102103. [CrossRef]
20. Barmer, H.; Dzombak, R.; Gaston, M.; Palat, V.; Redner, F.; Smith, C.; Smith, T. Human-Centered AI. SEI White Paper. 2021. Available online: https://kilthub.cmu.edu/articles/report/Human-Centered_AI/16560183/1?file=30632667 (accessed on 11 July 2024).
21. Maternowska, M. Nowe technologie i ich wpływ Na łańcuchy dostaw. Sztuczna inteligencja. In *Studia Ekonomiczne*; Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach: Katowice, Poland, 2019; Volume 388.
22. Raman, R.; Sreenivasan, A.; Ma, S.; Patwardhan, A.; Nedungadi, P. Green Supply Chain Management Research Trends and Linkages to UN Sustainable Development Goals. *Sustainability* **2023**, *15*, 15848. [CrossRef]
23. Walter, S. Impacts of AI driven manufacturing processes on supply chains: The contributions of the knowledge project. *Transp. Res. Procedia* **2023**, *72*, 3443–3449, ISSN 2352-1465. [CrossRef]
24. Nikolakis, N.; Sipsas, K.; Makris, K. A cyber-physicalcontext-aware system for coordinating human-robot collaboration.51st CIRP Conference on Manufacturing Systems. *Procedia CIRP* **2018**, *72*, 27–32. [CrossRef]
25. Wang, L.; Gao, R.; Vancza, J.; Kruger, J.; Wang, X.V.; Makris, S.; Chryssolouris, G. Symbiotichuman-robot collaborative assembly. *CIRP Ann.* **2019**, *68*, 701–726. [CrossRef]
26. Almusaed, A.; Yitmen, I.; Almssad, A. Reviewing and Integrating AEC Practices into Industry 6.0: Strategies for Smart and Sustainable Future-Built Environments. *Sustainability* **2023**, *15*, 13464. [CrossRef]
27. Ivanov, D. *Structural Dynamics and Resilience in Supply Chain Risk Management*; Springer: New York, NY, USA, 2018.
28. Ivanov, D. Two views of supply chain resilience. *Int. J. Prod. Res.* **2023**, *62*, 4031–4045. [CrossRef]

29. Ivanov, D.; Sokolov, B. Control and system-theoretic identification of the supply chain dynamics domain for planning, analysis and adaptation of performance under uncertainty. *Eur. J. Oper. Res.* **2013**, *224*, 313–323. [CrossRef]
30. Fabbe-Costes, N.; Ziad, Y. Improving Supply Chain Robustness & Resilience. Lessons from a case study in the automotive industry during the first wave of COVID-19. In Proceedings of the 28th EurOMA Conference, University of Sussex, Sussex, UK; Berlin, Germany, 5–7 July 2021.