The Transformative Role of ML Algorithms in Supply Chain Management: A Systematic Literature Review

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Abstract. In recent years, the global Supply Chain (SC) has encountered numerous unexpected obstacles and risks. Consequently, manufacturing plants and delivery networks were facing serious problems due to these unexpected events. Technological advances indicate that Machine Learning (ML) and associated algorithms have changed the way to solve these problems and improve the overall resilience, agility, efficiency of SC operations, adaptability and responsiveness of SC Management (SCM) systems. This paper employs a Systematic Literature Review Method (SLRM) to explore the use of ML in SCM, analyzing research from 2014 to 2024 to examine how techniques like predictive modeling, optimization algorithms, and self-decision making (i.e., systems capable of making autonomous decisions based on real-time data without human intervention) improve SC operations. The goal is to provide practitioners and researchers with insights into ML's potential to increase efficiency, reduce risk, and drive innovation in areas such as customer planning, procurement, logistics, and order execution. Through this comprehensive review, the study aims to equip SC professionals with tools to develop effective ML applications and address critical issues within SC systems.
Keywords: Supply chain management; ML; Optimization algorithms; Systematic literature review.

1 Introduction

In recent years, global Supply Chain (SC) systems have faced multiple challenges and unforeseen disruptions, ranging from natural disasters to geopolitical tensions and pandemics. These events have highlighted the weaknesses of conventional SC systems, uncovering key gaps in production plants and distribution networks. Technological advances, in the field of Machine Learning (ML), have proved to be effective tools to enhance the resilience, agility and efficiency of the SC in dealing with these challenges [1].

The resolution of complicated SC issues has changed due to the application of ML and associated techniques. In fact, SC managers may now predict and minimize disruption chances, enhance risk management, and respond swiftly to market developments by utilizing vast volumes of data and sophisticated analytical approaches. Artificial Intelligence (AI) has become a pivotal force in transforming how businesses operate, providing innovative solutions that drive efficiency and accuracy. In a world where everything is becoming more unpredictable, these abilities are crucial to maintain the competitiveness and stability of SCs [2].

In this paper, the SLRM is adopted to extensively study the recognition and implementation of ML approaches in SCM. Examining the application of advanced analytical techniques like predictive modeling, optimization algorithms, and autonomous decision-making systems to improve different aspects of SC operations, the study explores industry research and developments from 2014 to June 2024. The main goal is to provide academics and SC professionals with a deep understanding of the revolutionary potential of ML in improving efficiency, reducing risks, and promoting innovation in order fulfillment, procurement, logistics, and customer strategy. Our study process is organized in four stages: formulation of specific research questions, creation of a comprehensive research strategy, implementation of rigorous selection and evaluation procedures, and conducting a thorough analysis and synthesis of the selected research. This methodology ensures the reliability and quality of the evidence database and simplifies the extraction of relevant data on the ability of ML to transform SC operations [3]. Our aim is to enable scientists and SC professionals to effectively create ML applications that address important issues in SC systems and stimulate further innovation by publishing our discoveries.

2 Methodology

A systematic approach of identifying, analyzing, and compiling previous research on a particular topic or field of study is the SLRM [3]. Using this methodology offers several benefits, including thorough coverage of a particular subject and the application of well-defined search algorithms that improve the review process's repeatability, reveal patterns, inconsistencies, and gaps in the literature, providing future research directions. We can also mention that SLRM reduces the research waste by identifying areas where further research is needed and avoiding unnecessary duplication of studies.

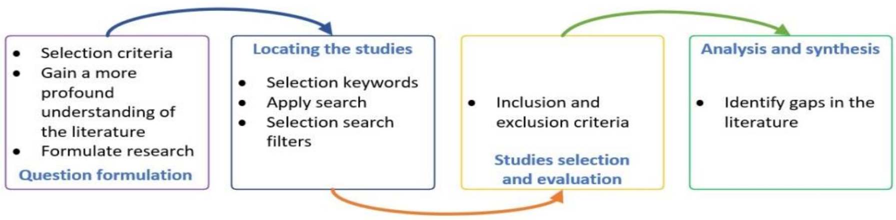

Fig. 1. SLRM

We followed the four-step process recommended by [5] to conduct our literature review, as illustrated in Fig. 1. These steps are:

- Question formulation (QF): This step aims to be specific, clear, and relevant. It is essential to guide the search process.

- Locating the studies: Its purpose is to develop a complete search method to pick out relevant research.
- Studies selection and evaluation: It assesses the fine and danger of bias of included studies using appropriate equipment or frameworks. This allows ensure the reliability of the proof base.
- Analysis and synthesis: Synthesize findings from included studies using the appropriate strategies. This may additionally involve thematic evaluation, statistical meta-analysis, and other different tactics.

3 Question formation and locating the studies

A successful systematic literature review is dependent on a well-formulated, answerable question that guides the study. To acquire the targets of the studies, our established review aims to answer the following research questions:

- Does ML have critical impact on SCM?
- Which ML techniques are most commonly used in SCM research?
- Which subfields of SCM have shown development in the utility of ML techniques?

After formulating the questions, the next step aims to identify and locating the studies that will helps us to construct the core of this review. Thus, several steps will be applied to achieve this goal.

3.1 Time horizon

This study was conducted on pilot Scopus and ScienceDirect to highlight the production of scientific articles in the domain. Based on the research, 2014 was selected as the starting point for the time horizon and the period from 2014 to June 2024. Since most scientific publications and a large number of new trends and applications that address the multi-disciplinarity of ML and the management chain theme were published during this period, we have limited the analysis to scientific papers published between 2014 and 2024.

3.2 Database selection

Keywords serve as the cornerstone of effective article investigation, supporting to find relevant content material successfully and correctly. By knowledge how to use keywords efficiently, you can streamline your search procedure and discover the wanted data faster. To discover the research in the database, we grouped the SCM and ML-associated keywords. The final set of seek phrases is given as follows:

“ML algorithm” AND “SC”, “ML” AND “SC optimization”.

3.3 Inclusion and exclusion criteria

Analyzing a quote from an article is a very common assessment method to evaluate its impact. In order to find publications on the SC and the use of ML in this topic, we focused on some research criteria in this study, as related on Table 1.

Table 1. Inclusion and Exclusion criteria in review process.

Inclusion	Exclusion
(i1) Research must be conducted in the application of ML in SCM.	(e1) Research from conference proceedings, book chapters, magazines, news, and posters are excluded.
(i2) Research must be published between 2014 & June 2024.	(e2) Research not related to SC management and ML.
(i3) Research must be published in peer reviewed journals.	(e3) Research conducted in other languages.
(i4) Research must be reported in English.	
(i5) Based on the keywords defined	
(i6) open access	

In the process of conducting the SLRM, we implemented the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. This protocol, serves as a robust framework that offers recommendations and criteria for the clear and thorough documentation of systematic reviews, ensuring a high level of transparency. [8-9]. Fig 2 shows the selection and evaluation process.

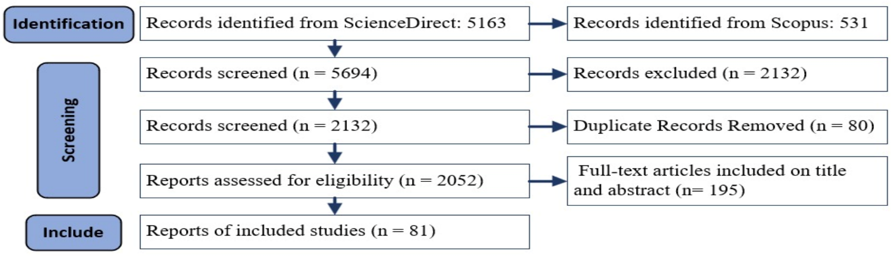

Fig. 2. The selection and evaluation review process.

4 Analysis and synthesis

4.1 Publication by year

Over the past decade, there has been a dynamic rise in the research field regarding the use of ML algorithms in SCM, with scientific publications predicting a dramatic increase between 2014 and June 2024, as depicted in fig. 3.

Initially, Research progress was limited, with only few publications exploring the potential of ML in SCM. However, the period between 2017 and 2020 experienced a notable increase in ML usage, highlighting significant efforts and innovative applications. This rise can be attributed to growing awareness of ML's ability to enhance decision-making, efficiency, and cost reduction in SCs. From 2020 onwards, the number of publications continued to grow steadily, emphasizing SC resilience and adaptation to global challenges like the COVID-19 pandemic. By 2024, research is expected to surpass expectations, highlighting the critical role of ML in driving future breakthroughs and transforming SC processes, as illustrated by the increasing number of publications over this period.

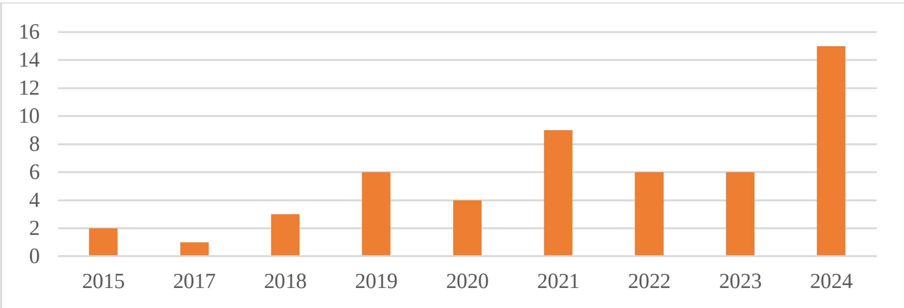

Fig. 3. Number of publications by year.

4.2 Bibliometric analysis

Data from the articles were analyzed and summarized using advanced statistical and graphical classified tests, with particular attention paid to their spatio-temporal aspects. The use of this method guarantees more reliable and systematic results on the selected topic, reducing the risk of overlooking prior research contributions [10].

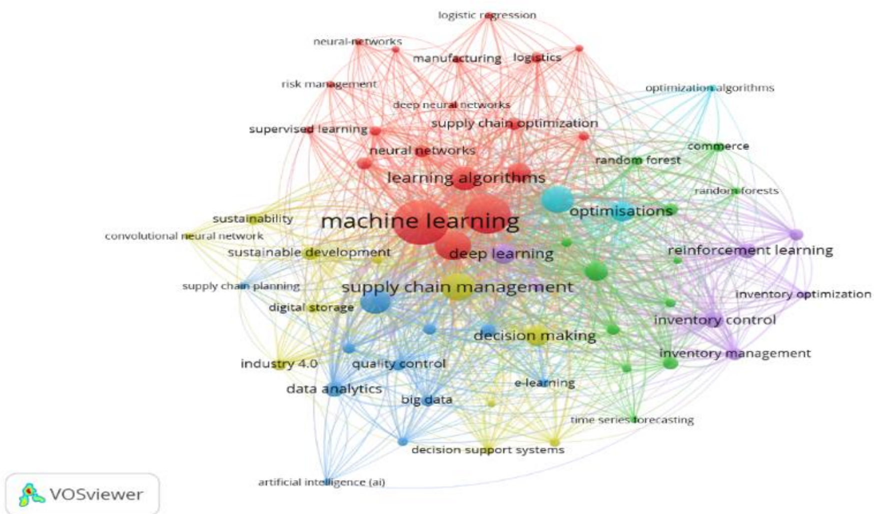

Fig. 4. Visualization of the bibliometric network of keywords.

The current analysis used VOS viewer (Visualization of Similarities) software [11]. This software has simplified the determination and setting up of subjects on a two-dimensional map, thus providing a precise representation of their resemblance or connection. The VOS mapping method has been used in this regard. In addition, the monkeys were grouped using the VOS grouping algorithm, each category being represented by a unique color [12-13]. Fig. 4 shows the VOSviewer keyword map.

Application of ML techniques in SCM

ML is a field within AI that works on creating algorithms and methods for computers to learn and make predictions or decisions from data. ML algorithms can be divided into three categories: supervised, unsupervised, and reinforcement learning [14] (Fig. 5 shows a classification of AI branches).

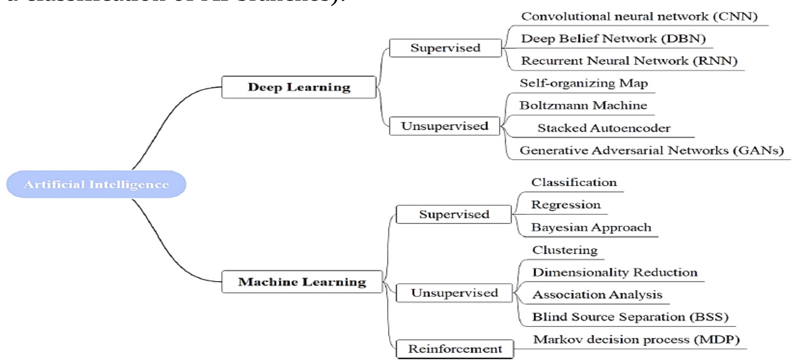

Fig. 5. AI Branches [4]

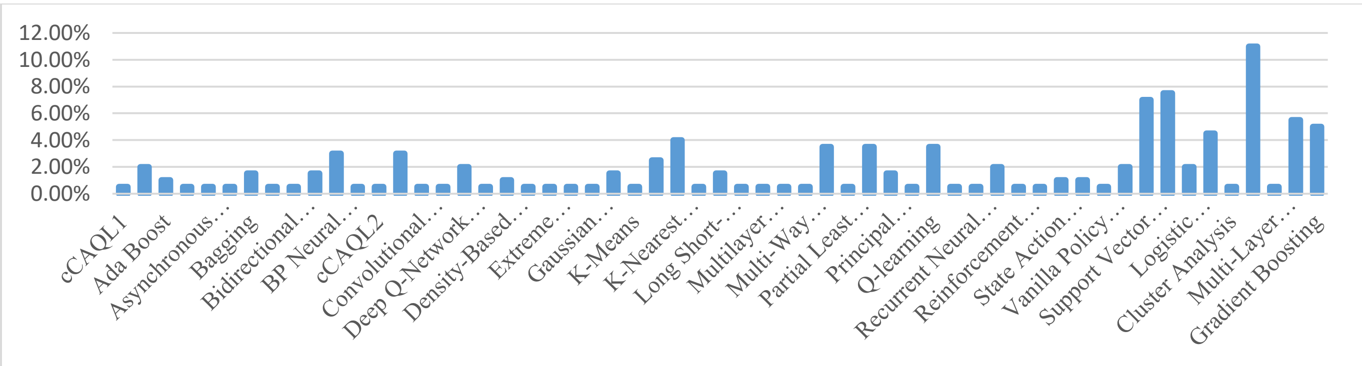

Fig. 6. ML algorithm used in SCM.

In supervised learning, the process uses labeled datasets to train models for classifying information or predicting outcomes accurately. Some examples include Linear Regression (LR) (2%), Logistic Regression (LR) (2%), Decision Trees (DT) (11%), Random Forests (RF) (5.5%), Support Vector Machines (SVM) (7%), and

Artificial Neural Networks (ANN) (7.5%). In unsupervised learning involves training algorithms on unlabeled dataset, and its goal is to detect patterns, structures, and relationship within the data, it is used in clustering problems and involves a range of techniques such as K-means Clustering (K-MC) (2.5%), Particle Swarm Optimization (PSO) (3.5%) and others. The last type of categories is reinforcement learning, it learns through trial and error, receiving feedback from its environment in the form of numerical rewards. The primary objective of the algorithm is to develop a policy that maximizes the cumulative reward over time [15]. Our review highlighted the ML algorithm which includes deep learning most widely used in SC are showing in fig .6.

ML capabilities utilized

ML methods have various potential capabilities that can be exploited in SCMs. The second category used to evaluate the sample was based on the ML skills used in applied in adopting methods to analyze SCM contexts. The most commonly used ML capabilities in the sample include prediction, automated reasoning, grouping, decision-making, decision support, and optimization [16]. The Fig 7 (Bottom) shows the distribution of the sample concerning to the ML capabilities utilized.

Types of used ML algorithms

In SCM, various ML algorithms have been leveraged to enhance operational efficiency and decision-making capabilities. Supervised learning algorithms (64.81%), such as SVM, ANN, DT and RF, are primarily used for procurement, production, and distribution [17], demand forecasting [18], transportation [19] and customer management [20]. Unsupervised learning algorithms (5.56%), including K-Nearest Neighbor (K-NN), Bayesian Network Methodology (BNM), K-MC, help in logistics[17], inventory management [21] and customer management [22]. Reinforcement learning algorithms (16.67%), such as Q-learning (Q-L), Neural Network (NN) and Deep Neural Network (DNN), used in Order execution [23], production [24], distribution [25] and inventory management [26], fig 7 (Upper) illustrates types of ML algorithms utilized.

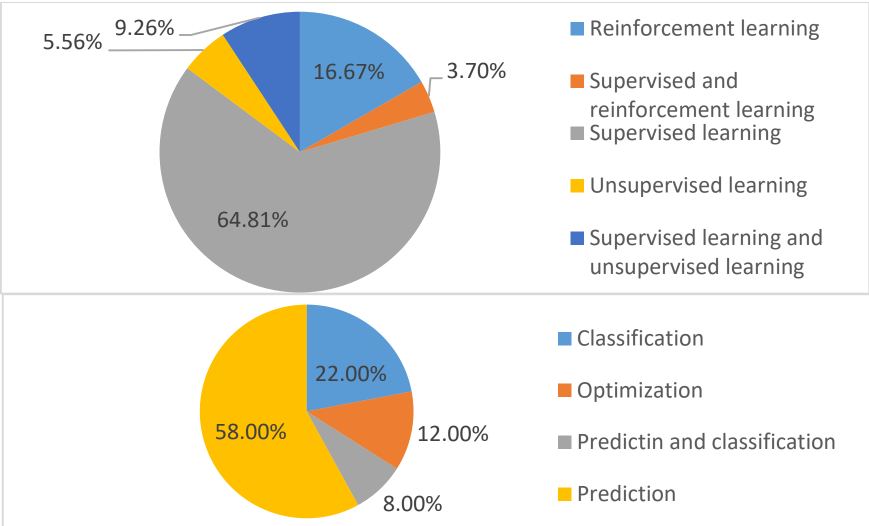

Fig. 7. Types of ML algorithms utilized (Upper) and The ML capabilities utilized (Bottom)

5 Conclusion

Using ML and related techniques, solving complex SC problems has profoundly evolved. SCM can now leverage large amounts of data and advanced analytical approaches to anticipate and reduce disruption risks, improve risk management, and respond quickly to market changes. Having these skills is crucial to preserve the competitiveness and stability of SCs in a world increasingly characterized by uncertainty.

SLRM was used in this paper to identify and comprehensively use ML techniques in SCM from 2014 to 2024. By closely examining industry research and advances, the study revealed how advanced analytical techniques such as predictive modeling, optimization algorithms, and self-determination systems improve various aspects of SC operations, such as customer planning, procurement, logistics, and order execution. The results enable logistics' specialists and researchers to better understand the transformative potential of ML to improve efficiency, reduce risks and encourage innovation.

The implementation of a four-stage research process - the development of specific research questions, the design of a comprehensive research strategy, the establishment of rigorous selection and evaluation procedures, as well as in-depth analysis and synthesis has ensured the reliability and quality of the evidence database. The implementation of this approach has simplified the acquisition of relevant data on the impact of ML on SC operations. However, it is important to acknowledge that the limitations in accessing certain open-access articles may have constrained the comprehensiveness of the study's findings. Despite this, the approach implemented has simplified the acquisition of relevant data on the impact of ML on SC operations.

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