Supply Chain 5.0: Vision, Challenges, and Perspectives

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***Abstract*—The recent technological advancements have transformed the modern supply chains in complex networks. Consequently, modern supply chain systems are facing several challenges, including limited visibility in both upstream and downstream supply chains, lack of trust among the different stakeholders, and transparency plus traceability. Current supply chain systems do not present the needed framework to overcome the existing challenges. On the other hand, the new paradigm of the Supply Chain 5.0 has the potential to effectively address these obstacles and incorporates the foresight of future disruptions. This paper aims to explore the emerging paradigm of supply chain 5.0 and conduct a systematic analysis of recent and relevant works related to this supply chain version. Additionally, it aims to examine its visionary aspects, analyze associated challenges, and provide insights to the potential future directions of supply chain management. We have systematically analyzed the recent and relevant works addressing this new vision of supply chains.**

***Index Terms*—Supply Chain 5.0, Internet of Things (IoT), Blockchain, Artificial Intelligence, Sustainability.**

I. Introduction

Today's supply chain management (SCM) faces ever-increasing quality demands from customers and environmental constraints alongside the growing intricacies of supply and distribution networks. Furthermore, supply chains (SC) have undergone globalization, leading manufacturers to frequently engage distinct suppliers and production facilities. Undoubtedly, the integration of advanced technologies associated with Industry 4.0, into supply chain management, often referred to as Supply Chain 4.0, has provided substantial solutions to various SCM challenges. In light of this, considerable research efforts have been devoted to unraveling the complex interaction between this emerging paradigm and transformative technologies such as the Internet of Things (IoT), Blockchain, and Artificial Intelligence (AI). Meanwhile, the emphasis has been on developing new frameworks and methodologies for optimizing the management of modern supply chain systems. Especially, with a focus on enhancing decision-making, ensuring traceability and transparency, and improving adaptability within an environment characterized by rapid technological advancements and evolving customer demands.

While the SC 4.0 paradigm is still in its early stages, significant changes in the supply chain landscape, particularly the increased emphasis on human roles and sustainability, have laid the foundation for **Supply Chain 5.0**. This can be defined as a new supply chain revolution that challenges the concept of relying solely on machines, emphasizing instead the collaboration between human skills. In another definition, it is seen as a means to harness human intelligence through innovative technological approaches [2]. Undoubtedly, highlighting the vision of SC 5.0 would offer numerous benefits, including empowering individuals and reducing reliance on machines. Conveniently, SC 5.0 leverages the same technologies as SC 4.0, including IoT, Blockchain, and AI, while also incorporating cobots and placing a strong emphasis on sustainability. In this regard, understanding this new vision, studying and reviewing recent relevant works, and identifying the associated challenges, offers a valuable framework for researchers and opens up new research directions for the future. In order to provide clear guidance for this research, a research question has been formulated as follows:

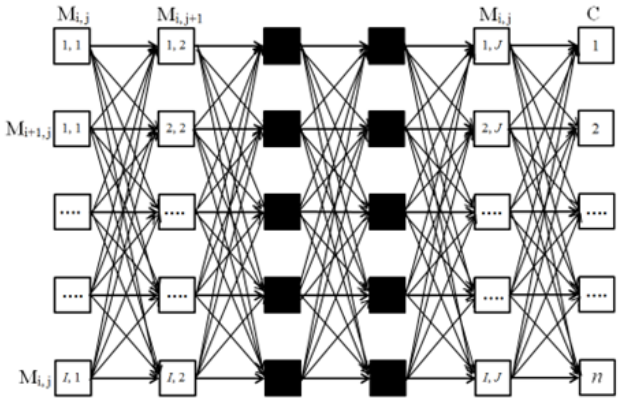

Fig. 1. Complex supply chain network [1]

- **RQ1:** What distinguishes the fundamental concept of Supply Chain 5.0 from its previous versions, and what motivations drive the transition to this new paradigm ?

A. Research Methodology

Our research employs a four-step literature review process, following the methodology established by [3], to systematically identify and analyze recent trends and developments in Supply Chain 5.0. This approach provides a well-organized, reproducible, and rigorous process for objectively synthesizing

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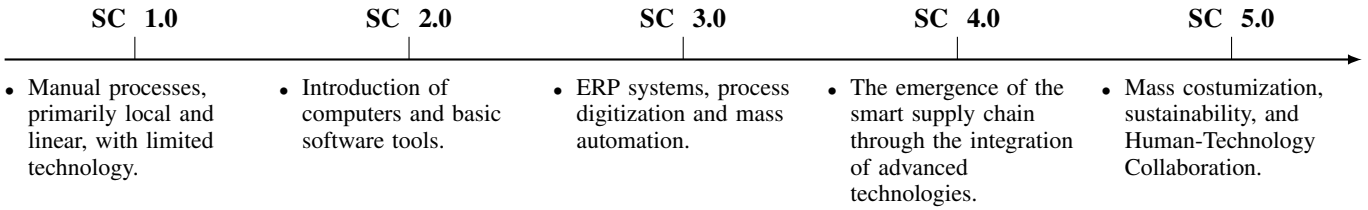


Fig. 2. The dynamic phases of supply chain development (from 1.0 to 5.0).

current data. Our analysis covers a range of sources, including IEEE Xplore, ScienceDirect, and Google Scholar, encompassing journals, magazines, and full conference papers. The data spans the period from 2018 to 2023. A thorough review and systematic categorization of the selected publications revealed significant patterns and generated invaluable insights. The methodology we employed ensures a comprehensive and up-to-date exploration of the Supply Chain 5.0 vision.

B. Organization

The structure of this paper is organized as follows. In Section II, we delve into research insights related to supply chain systems, with a specific focus on the development of supply chain versions. Section III explores the paradigm of Supply Chain 5.0 and present the research status regarding its development. This aimed to understand the fundamental concept of Supply Chain 5.0 and its differences from previous versions (**RQ1**). Section VI provides the conclusion for this paper and presents some research directions.

II. Background Insight

The modern supply chain is a dynamic and sophisticated network that includes a plethora of firms actively involved in critical logistical operations such as procurement, transformation, and product distribution. This network extends beyond the traditional boundaries of individual enterprises, incorporating value-adding operations carried out by external partners. Supply chain management, as a broad domain, includes not only the physical transfer of goods and delivering services, but also the complex interaction of information and financial transactions among its diverse stakeholders [4]. A holistic approach to supply chain management is required to address all aspects of goods and service flows, from the initial acquisition of raw materials to the final delivery of finished products or service to customers [5]. Fig.1 shows a typical complex supply chain network, where $M_{i,j}$ presents entity i in level j, C denotes customers, with i, j and n are total number of entities, levels and customers, respectively [1]. The optimization of supply-side operations is central to this approach, which is driven by the overall objective of increasing customer value and ensuring a competitive edge in the marketplace. The supply chain, with its sophisticated complexity, is a vast ecosystem that includes suppliers, manufacturers, subcontractors, retailers, wholesalers, and end-consumers. Optimal and secure exchange of material, information, and financial resources within this ecosystem is an initial vital need to sustain the entire structure of the supply chain [6, 7].

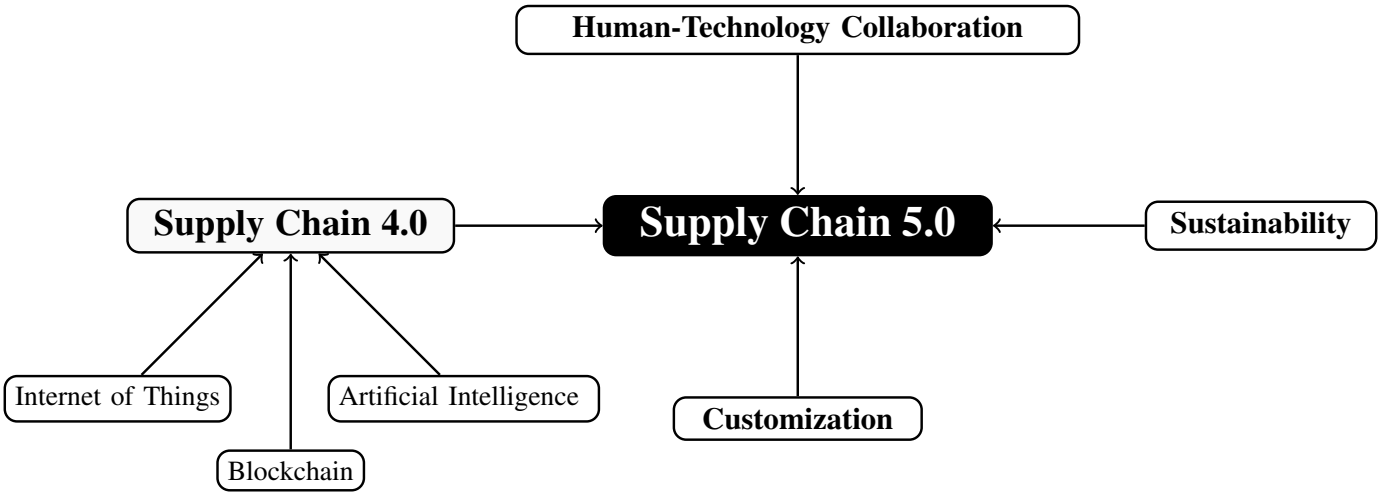
A. Supply Chain's Evolution from 1.0 to 5.0

As is well-known, the evolution of industry is typically categorized through the lens of different industrial revolutions, spanning from Industry 1.0 to Industry 5.0 [8]. This progression has been seamlessly integrated into supply chain systems, illustrating their generational shifts and advancements.

- *Supply Chain 1.0:* The earliest phase of supply chain management was characterized by the development of new manufacturing processes, albeit with limited technology, and a focus on basic inventory management. It was a time when supply chains were primarily local and linear.
- *Supply Chain 2.0:* The second phase was characterized by a technological revolution and the introduction of rudimentary software tools. This facilitated increased production and prompted the exploration of enhanced transportation and distribution methods, alongside improved inventory management and optimization. Furthermore, supply chains started expanding beyond geographical boundaries.
- *Supply Chain 3.0:* The third phase witnessed the integration of supply chain processes with Enterprise Resource Planning (ERP) systems, as well as process digitization and mass automation.
- *Supply Chain 4.0:* This phase introduced the concept of the 'smart' or 'digital' supply chain, characterized by the use of advanced technologies such as IoT, big data analytics, blockchain, and artificial intelligence [9]. During this phase, supply chains became more data-driven, adaptable, and responsive. Moreover, SC 4.0 brought about a significant improvement in terms of transparency and traceability.
- *Supply Chain 5.0* This is the latest and current phase in supply chain management, integrating advanced technologies and sustainability while emphasizing human-machine collaboration [2]. This phase will be further described throughout the rest of the paper.

III. Supply Chain 5.0 Vision

Supply Chain 5.0 represents an innovative vision that aims to enhance existing 4.0 supply chain systems by incorporating human and social considerations, customization, and



sustainability. Given that Supply Chain 5.0 is a recent research field, the literature on the subject remains limited. This section explores the motivations for moving from SC 4.0 to SC 5.0 and provides a detailed discussion of the components of the Supply Chain framework as presented in Fig. III.

A. Motivation for Transitioning to SC 5.0

An evolving technology landscape and business demands are driving the transition from Supply Chain 4.0 to Supply Chain 5.0. In Supply Chain 4.0, IoT, AI, and Blockchain technologies have been utilized to enhance supply chain efficiency and increase traceability and transparency. However, as the industry evolves, new challenges and opportunities emerge, leading to the emergence of Supply Chain 5.0. The primary motivation for transitioning to Supply Chain 5.0 is the acknowledgment of the increasing significance of human-technology interaction and sustainability. While SC 4.0 primarily centered around technological advancements, Supply Chain 5.0 recognizes that the synergy between people and technology can unlock even greater potential. In this context, recent research suggests that incorporating parallel intelligence, DAOs (Decentralized Autonomous Organizations), and foundational models like ChatGPT and HOOS in the next generation of supply chains has the potential to revolutionize the operational framework. This could lead to the establishment of efficient, secure, and intelligent human-centric operating systems [8, 10]. Thus, it becomes crucial to develop a successful adaptability and continuous learning process to effectively navigate the dynamic landscape of SC 5.0.

B. Supply Chain 5.0 Framework Components

1) Supply Chain 4.0: Supply Chain 4.0 serves as the foundation for Supply Chain 5.0, leveraging cutting-edge technologies, including IoT, Blockchain, and AI. Following, we highlight each of these technologies, with a focus on emphasis on recent research efforts.

- *Internet of Things for SC 5.0*: The IoT technology introduces a vast network of interconnected devices that communicate and share data via the Internet. These devices range from smart appliances to industrial equipment, all incorporating sensors and actuators to enhance their connectivity. Furthermore, IoT is a technological evolution rather than a subversive revolution that undermines existing techniques, promoting efficiency, availability, productivity, and security [11]. In the context of the supply chain, IoT has been the subject of several research efforts in various areas of supply chain management. For instance, in [12], the authors aim to integrate a hybrid IoT-based decentralization framework into the company's logistics and supply chain management networks. In another study [13], an AI and IoT-driven solution is introduced, which creates a transactional relationship connecting different stakeholders in the supply chain systems. With the transition to SC 5.0, IoT sensors would become increasingly intelligent, learning from their close environment. In a nutshell, IoT has the potential to enhance operational efficiency and reliability within the supply chain environment. Additionally, the combination of IoT with other technologies, such as digital twins, 5G, and edge computing, might offer significant advantages in real-time data sharing across the Supply Chain 5.0 phase, enabling better visibility, transparency, optimized production processes, and improved product quality. Figure III-B1 shows the various IoT applications that can be implemented in SC 5.0 systems.
- *Blockchain for SC 5.0*: Given the complex network of supply chain systems, the need for seamless information exchange among stakeholders, substantial challenges and risks associated with data transmission, and the lack of trust between stakeholders, blockchain technology has the potential to improve supply chain management efficiency. In fact, blockchain-based supply chains offer numerous advantages, including enhanced tracking, traceability,

information accessibility, alignment of information and material flow, reduced rule violations, and increased transparency. According to [14], the blockchain enables efficient and transparent supply chain data management as well as authorization and verification of transactions without the need of third parties. As Supply Chain 5.0 prioritizes sustainability, customization, and human-technology collaboration, blockchain serves as a foundational technology to achieve these objectives.

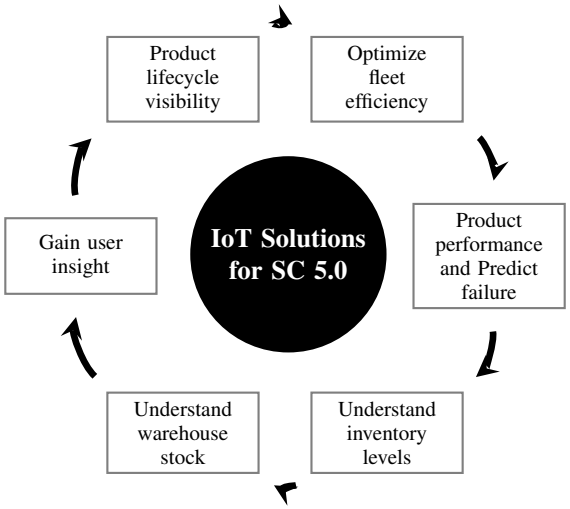


Fig. 3. IoT applications for supply chain systems [15].

- *Artificial Intelligence for SC 5.0*:
  The integration of artificial intelligence within Supply Chain 5.0 is a transformative force, significantly enhancing various facets of supply chain management. First, *operational efficiency* is markedly improved through the automation of mundane and repetitive tasks, allowing human resources to focus on more strategic activities. AI-powered analytics enable data-driven decision-making, ensuring that resources are allocated more effectively and processes are optimized for peak performance. Choi et al. [16] offers industry-specific insights into AI applications in fashion supply chains, presenting a range of models with the caveat of potential complexity and niche focus. *Adaptability* is another critical area where AI plays a pivotal role. Machine learning algorithms analyze trends and patterns in supply chain data, predicting potential disruptions and suggesting preventive measures. This proactivity ensures that the supply chain is resilient, able to adapt quickly to market changes, and responsive to unforeseen challenges [17].
  Cost-effectiveness is achieved by minimizing waste and optimizing resource utilization. AI-based solutions can identify inefficiencies in the supply chain, help make decisions, and even implement changes autonomously. This leads to a leaner, more efficient supply chain, reducing operational costs and enhancing the overall value delivered to the customer. highlighting its impact on reducing operational costs while ensuring consistent value delivery to customers. Pournader et al. [18] emphasize the value addition aspect, discussing how AI not only reduces costs but also enhances the quality of customer service. In a practical context, Helo and Hao [19] offer case studies demonstrating AI's tangible benefits in various industries, providing real-world insights into its cost-effectiveness.

2) Human-Technology Collaboration: Effective collaboration between humans and technology is crucial for the success of Supply Chain 5.0. In this scenario, IoT based sensors continuously monitor and collect data from various nodes in the supply chain [20]. Humans, in partnership with advanced data analytics and AI technology, make enhanced decisions for predictive maintenance, optimal scheduling, and efficient task assignment. Moreover, supply chains are increasingly including cobots. In order to ensure faster and more precise operations, the robots undertake repetitive tasks and humans supervise robots and handle the exceptions. Furthermore, the contemporary supply chain networks that are transparent and safe are built using blockchain technology. Humans interact with the blockchain systems to record and confirm transactions, enhancing traceability and lowering deception. Additionally, the technology and human resources interact in supply chain 5.0 to offer a smooth and personalized client service. To conclude the core idea behind the supply chain 5.0 is to develop a more adaptable, responsive, and effective supply chain system using an effective human-technology collaboration.

3) Sustainability: At present, sustainability issues have become a major concern in many industrial sectors, prompting the development of new eco-friendly solutions. According to [21], supply chain sustainability can be defined as : *the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements.* Several recent research efforts have been undertaken to propose and explore innovative ideas for a sustainable supply chain in the future. Tam and Lung [22] focused on investigating the impacts of COVID-19 on the fashion supply chain and reviewed sustainable supply chain practices. Another study [23] presents a comprehensive overview of sustainable SCM practices and the value chain. The seamless integration of environmentally-friendly practices throughout the supply chain process is one of the key objectives of Supply Chain 5.0. This might involve the use of innovative technologies to optimize energy consumption, curtail waste, and mitigate adverse environmental impacts. Furthermore, AI-based techniques can be used to analyze vast amounts of supply chain data, providing predictive models that anticipate disruptions and optimize resource utilization [24]. In addition, AI technology can also be used to analyze real-time data and make adjustments to reduce energy consumption.

4) Customization: Supply Chain 5.0 significantly propels the capabilities for mass customization and mass personalization of products. In fact, the new supply chain systems seamlessly integrate customer specifications directly into both production and supply networks, fostering an environment that encourages the synchronization of all involved stakeholders. Such integration is instrumental in empowering manufacturers to efficiently produce customized products on a substantial scale. Consequently, this evolution necessitates the adoption of more versatile production and transportation processes, specifically designed to meet the diverse and individualized demands of customers. In addressing the complexities associated with such customization, blockchain technology emerges as a promising solution. Its decentralized and flexible management capabilities lay a robust foundation for overcoming the challenges tied to customization in future supply chain systems [25].

IV. Research agenda for Supply Chain 5.0

Drawing on the qualitative and quantitative analyses conducted in our study, we have outlined a future research agenda for the Supply Chain 5.0 framework, focusing on key dimensions that demand further investigation.

A. Standardization

To achieve seamless integration and interoperability within SC 5.0, the research agenda prioritizes the establishment of standardized protocols and frameworks. This includes developing unified standards for data formats, communication protocols, and interfaces. The goal is to formulate interoperability guidelines for technologies such as AI, BC, and IoT, ensuring smooth interaction. Furthermore, exploration extends to regulatory frameworks, dynamic standardization models, and security standards, aiming to foster collaboration and enhance security in the SC ecosystem.

B. Safety and Trust

In the evolving landscape of Supply Chain 5.0, prioritizing safety and trust is crucial. The research agenda addresses safety protocols for autonomous systems, explores ethical AI practices, and investigates blockchain for trust and transparency. The investigation extends to stakeholder management, strategies to build consumer trust, and the intersection of safety, trust, and regulatory compliance.

C. Human-Technology Collaboration

In the era of Supply Chain 5.0, optimizing human-technology collaboration is imperative. This involves exploring the augmentation of the workforce with AI and robotics, strategies for training and upskilling, and the design of user-friendly interfaces. The exploration extends to human-centric automation, decision support systems, and ethical considerations related to job displacement and privacy concerns.

D. Integration of More Advanced Technologies

Efficiently integrating cutting-edge technologies, including AI, Blockchain, and IoT, is crucial for enhancing overall efficiency and resilience [26] in the Supply Chain 5.0 era. This involves optimizing the synergy among these technologies to unlock their full potential within the supply chain ecosystem.

E. Sustainability

Examining the role of emerging technologies in optimizing resource allocation and operational efficiency [26] within supply chains is a key focus. The goal is to leverage these technologies to create a more sustainable and eco-friendly Supply Chain ecosystem, exploring strategies to minimize environmental impact while maximizing efficiency in the utilization of resources.

F. Customization

A focus on leveraging data analytics and customer insight will enhance customization in Supply Chain 5.0. This involves exploring the best strategies, models, and techniques for efficiently utilizing these insights to tailor products to individual customer preferences. Furthermore, future research should delve into the implications of personalization on supply chain flexibility, aiming to develop agile supply chain strategies capable of adapting to changing personalization requirements in real-time.

G. Supply Chain 5.0 transition challenges

Investigating the primary obstacles impeding the transition to Supply Chain 5.0 is paramount for understanding the challenges in adopting advanced technologies and evolving industry practices. Identifying and addressing these barriers is essential to ensure a seamless and effective transformation of supply chain systems.

V. Study Limitations

While our study provides a comprehensive analysis of the emerging paradigm of SC 5.0 and its potential impact on supply chain management, it is important to acknowledge its limitations. Firstly, the scope of this work is primarily focused on recent works and developments related to SC 5.0, which may not encompass all aspects of this evolving concept. Additionally, the paper does not provide an in-depth practical implementation challenges and real-world case studies of Supply Chain 5.0. Therefore, while this paper provides valuable insights, future research needs to consider a broader range of perspectives and incorporate ongoing advancements in the field of supply chain management.

VI. Conclusion & and Perspectives

Supply Chain 5.0 has emerged as a visionary concept, reshaping the current landscape of supply chain operations. This concept seeks to integrate advanced technologies previously utilized in Supply Chain 4.0, such as AI, blockchain, IoT, and big data analytics. Furthermore, SC 5.0 places a specific focus on integration of sustainability, customization, and collaboration between humans and technology. As a result, It offers

numerous advantages related to transparency, traceability, cost reduction, eco-friendly aspects, and an enhancement of the customer experience. While the concept of Supply Chain 5.0 is still in its early stages, it is essential to assess its potential advantages and obstacles. The potential of supply chain 5.0 is vast, though not without its challenges. A major challenge is the transition from legacy processes to these highly interconnected and data-driven systems. Furthermore, ensuring the security and privacy of the vast amounts of data exchanged in these interconnected systems is also challenging, as it exposes systems to potential cyber threats and data breaches. Moreover, given that SC 5.0 promises to ensure sustainability in future supply chain systems, the demand for substantial initial investments and the necessity for a skilled personnel represent significant hurdles. Nonetheless, the ongoing development of new technologies and the growing recognition of their value in supply chain management suggest a future where these challenges are mitigated, and the full potential Supply Chain 5.0 is realized.

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