ATILIM UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
DEPARTMENT OF BUSINESS ADMINISTRATION
BUSINESS ADMINISTRATION MASTER'S PROGRAMME

AN ANALYTIC HIERARCHY PROCESS (AHP) APPROACH FOR PRIORITIZING INDUSTRY 4.0'S INFLUENCE ON E-COMMERCE'S SMART SUPPLY CHAIN

Master's Thesis

Behina MORSALPOUR

Ankara-2025

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ACCEPTANCE AND APPROVAL

This is to certify that this thesis titled "An Analytic Hierarchy Process (AHP) Approach for Prioritizing Industry 4.0's Influence on E-commerce's Smart Supply Chain " and prepared by Behina MORSALPOUR meets with the committee's approval unanimously Master's Thesis in the field of Business Administration following the successful defense conducted on 17/01/2025.

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ETHICAL STATEMENT

I accept and acknowledge that I have prepared this thesis study, prepared in line with the Thesis Writing Guidelines of Atılım University Graduate School of Social Sciences;

- within the framework of academic and ethical rules;
- presented the information, documents, evaluations, and results in a way that meets the rules of scientific ethics and morality,
- I have referenced each work from which I have benefited while preparing my thesis, and that
- I hereby present a unique study.

I hereby also understand that I shall accept any loss of rights against my behalf in cases otherwise.

Date and Signature

Behina MORSALPOUR

ÖZ

MORSALPOUR, Behina. Endüstri 4.0'ın E-Ticaret Akıllı Tedarik Zinciri Üzerindeki Etkilerinin Önceliklendirilmesi İçin Analitik Hiyerarşi Süreci (AHP) Yaklaşımı, Yüksek Lisans Tezi, Ankara, 2024.

Bu araştırma, IoT, Büyük Veri, Blockchain ve Makine Öğrenimi gibi Endüstri 4.0 teknolojilerinin e-ticaret akıllı tedarik zinciri üzerindeki etkinlik, esneklik ve dayanıklılık açısından etkilerini incelemeyi amaçlamaktadır. Bu teknolojiler, günümüz tedarik zincirlerinde önemli sorunlar olan zamanında veri toplama, daha iyi karar alma ve entegrasyonu kolaylaştırmaktadır. Araştırma şu soruya yanıt aramaktadır: AHP, bu teknolojilerin akıllı e-ticaret tedarik zinciri üzerindeki görece önemini belirlemek için nasıl uygulanabilir? Bu araştırmada, operasyonel performans, maliyet, güvenlik ve güvenilirlik, ölçeklenebilirlik ve esneklik, müşteri memnuniyeti ve çevresel etki gibi en önemli faktörleri değerlendirmek için AHP uygulanmıştır. Farklı coğrafi geçmişlere sahip Türkiye, ABD, İran, Avustralya ve Pakistan'dan altı uzmana uluslararası bir bakış açısı elde etmek amacıyla yapılandırılmış bir anket uygulanmıştır. Karşılaştırmalar yapmak için Saaty ölçeği kullanılmış ve ikili karşılaştırma matrislerini geliştirmek ve tutarlılık oranlarının kabul edilebilir eşiklerin üzerinde olduğunu kontrol etmek için Microsoft Excel kullanılmıştır. Çalışma, operasyonel etkinliğin en önemli faktör (%39.54) olduğunu, çevresel etkinin ise en az önemli faktör (%3.61) olduğunu göstermektedir. Bu sonuçlar, süreçlerin iyileştirilmesi ve kaynakların gerçek zamanlı olarak kontrol edilmesinin önemini ortaya koymaktadır. Bu çalışma, çeşitli uzmanların görüşlerini dikkate alan ve çözümler sunan resmi bir karar verme aracı olarak AHP'nin etkinliğini kanıtlamaktadır. Bu çalışmanın bulguları, Endüstri 4.0 teknolojilerini uygulayarak tedarik zinciri etkinliğini ve dayanıklılığını artırmayı amaçlayan organizasyonlar için faydalı olacaktır.

Anahtar Sözcükler: Analitik Hiyerarşi Süreci (AHP), Endüstri 4.0, Akıllı Tedarik Zincirleri, E-ticaret, karar verme.

ABSTRACT

MORSALPOUR, Behina. An Analytic Hierarchy Process (AHP) Approach for Prioritizing Industry 4.0's Influence on E-commerce's Smart Supply Chain, Master's Thesis, Ankara, 2024.

This research aims to examine the effects of Industry 4.0 technologies such as IoT, Big data, Blockchain and Machine learning on e-commerce smart supply chain concerning efficiency, flexibility and robustness. These technologies facilitate timely data collection, better decision making, and integration, which are some of the significant issues in today's supply chains. This research aims to answer: In what way can AHP be applied to determine the relative importance of these technologies on smart e-commerce supply chain? In this research, AHP is applied to assess the most important factors such as operational performance, cost, security and reliability, scalability and flexibility, customer satisfaction, and environmental impact. A structured questionnaire was developed and administered to six experts from different geographical backgrounds of Turkey, USA, Iran, Australia, and Pakistan to get an international perspective. Saaty's scale was employed to make pairwise comparisons and Microsoft Excel to develop the pairwise comparison matrices and check that the consistency ratios were above the acceptable threshold. The study shows that operational efficiency is the most important factor (39.54%) and the least being environmental impact (3.61%). These results demonstrate the significance of improving the processes and controlling the resources in the real time. This paper proves the efficiency of AHP as a formal decision-making tool which considers the opinions of various experts and offers solutions. The findings of this study will be useful to organizations that aim at implementing Industry 4.0 technologies to improve the supply chain efficiency and resilience.

Keywords: Analytic Hierarchy Process (AHP), Industry 4.0, Smart Supply Chains, E-commerce, decision-making.

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INDEX OF SYMBOLS AND ABBREVIATIONS

AHP	**:**Analytic Hierarchy Process.
BC	**:**Blockchain.
BD	**:**Big Data.
CC	**:**Cloud Computing.
CPS	**:**Cyber-Physical Systems.
CR	**:**Consistency Ratio
I4.0	**:**Industry 4.0.
IoT	**:**Internet of Things.
ML	**:**Machine Learning.
n	**:Number of criteria in a pairwise comparison matrix.**
RI	**:**Random Index.
SCM	**:**Supply Chain Management.
SSCM	**:**Smart Supply Chain Management.

INTRODUCTION

Industry 4.0 represents a new vision for the global marketplace, providing a new form of differentiation to industries by changing how products are made, bought, sold, and even offered as services. This fourth industrial revolution envisions industries as systems-of-systems end-to-end at the firm and across corporate, inter-organizational, and governmental levels. It promotes supply chain coordination and fosters network cohesion, optimization, and robustness (Ralston & Blackhurst, 2020). Fundamental to Industry 4.0 is developing an integrated intelligent network of industrial value networks with smart supply chains consisting of automated systems that integrate machines, digital processes, and systems that facilitate efficient and timely product delivery, ultimately adding significant value for consumers (Athar, 2024).

About Industry 4.0, the critical areas of e-commerce business have emerged through integrating with new technologies such as the IoT, Big Data, and Blockchain, which have become crucial factors in improving services and providing customers with good experiences. IoT enhances, integrates, and real-time exchange of information concerning the supply chain stakeholders; Big Data enhances analytical decision-making customized to the individual customer (Chbaik et al., 2023).

On the other hand, security and transparency through blockchain technology enhance customer confidence and satisfaction through online shopping platforms. E-commerce platforms enable enhanced, targeted, safe, and convenient shopping, thus improving service delivery with an emphasis on customer loyalty within expanding internet market share (Athar, 2024).

Supply chain management (SCM) has grown beyond basic processes like traditional functions, such as ensuring product availability and managing inventory, to embrace demand forecasting, strategic partnerships, and continuous performance improvement. This evolution is due to the principles anchored in smart supply chain management technologies that implement advanced analytics and automation to cushion the knottiness that characterizes today's supply systems (Bouti & Khoukhi, 2023). Industry 4.0 technologies have also fueled the emergence of smart logistics that provide smart last-mile delivery solutions through the employment of the concept of gamification and, such, lower costs of energy, storage, and management (Chbaik et al., 2023). This makes it possible for firms to realize operational improvements with corresponding influence on consumer expectations. (Athar, 2024).

While there is a vast amount of literature on implementing Industry 4.0 technologies in supply chain management, there needs to be a more straightforward approach to assessing the most critical impacts on e-commerce supply chains. Current studies are primarily based on independently based technologies such as IoT with little regard given to the effects on vital measures such as productivity, customer satisfaction, and environmental sustainability (Serôdio et al., 2024).

Furthermore, most current studies need to consider specific features of e-commerce contexts, such as the required high level of system adaptability, fast decision-making, and customer-oriented approaches critical to Industry 4.0 enablers (Owolabi et al., 2023). This need for more attention to e-commerce-specific features highlights an opportunity to use AHP to prioritize impacts tailored to these unique requirements. Although AHP is known as an effective tool for multiple criteria decision-making, previous studies have used AHP mainly to rank technologies, not prioritizing their impact on e-commerce-specific factors. This presents an opportunity to use AHP to systematically identify and prioritize key impacts, such as cost containment, security, and environmental consequences (Nimawat & Gidwani, 2021).

Technology like blockchain is considered disruptive; however, its impact on e-commerce supply chain key performance indicators (KPIs), including customer satisfaction and operational performance, has yet to be widely investigated. Also, there is a growing demand for research works that could assess the ability of these tools to improve sustainability in e-commerce supply chains (Athar, 2024).

This study employs the AHP technique to select and prioritize Industry 4.0 technologies for e-commerce supply chain decision-making process improvement. Initially developed by Thomas L. Saaty in 1983, the AHP is a multi-attribute decision-making technique that decomposes a complex problem into a problem hierarchy where an objective can be formulated, and the relative pairwise comparisons are used to derive priority scales (Saaty, 1990) (Zekhnini et al., 2020). The strength of this structured method is in categorizing according to different experts' evaluations in large-field criteria, such as e-commerce supply networks' Industry 4.0 interactions where numerous intertwined technologies influence the operations, cost, security, and other aspects. The steps in AHP implemented in the current study are as follows. Initially, the study identifies a clear goal: to provide a framework to assess and sort out the Industry 4.0 technologies to improve the performance of e-commerce supply chains. This first stage is critical in establishing clear and specific objectives to which the study was designed to respond; it conforms with the general conceptualization of the AHP, as described by Saaty (1990). After this, the hierarchical model is constructed, which splits the complex decision problem into different levels in the corresponding hierarchy. This hierarchy enables the structuring of the problem into goals, criteria, and sub-criteria, thus making it easier to analyze the problem systematically and to ensure adequate consideration of all essential issues (Saaty, 1990). The third step in AHP is to develop a pairwise comparative matrix of all the criteria and sub-criteria, and Saaty's scale of 1-9 for mere psychological comparison is used. These comparisons are made considering the expert opinion, as suggested by Saaty and Nimawat (2021), to make priority weighting of the criteria systematic. Then, the consistency ratio is computed to quantify the dependability of the expert opinions. If the consistency ratio (CR) is less than 0.1, the judgments are considered consistent, thus making the results accurate (Saaty, 1990) (Nimawat & Gidwani, 2021).

Finally, local and global weights are calculated, and a final ranking of Industry 4.0 technologies according to their impact is arrived at. This phase focuses on comparing variables at each level; the results are prioritized according to the main decision-maker criterion, which helps effectively facilitate the practical operation of strategic decision-making (Saaty, 1990). Such a structure is beneficial when assessing numerous technological effects on e-commerce supply chain networks because it incorporates specific and overall points of analysis that can help with prioritization.

Research questions:

This research investigates how can the Analytic Hierarchy Process (AHP) be applied to systematically prioritize the key impacts of Industry 4.0 technologies on enhancing e-commerce smart supply chains? Therefore, this research intends to use the Analytic Hierarchy Process (AHP) to systematically rank the impacts of Industry 4.0 technologies in the context of e-commerce smart supply chains. Based on the evaluation of IoT, Big Data, Cloud Computing, Machine Learning, Blockchain, and Cyber-Physical Systems (CPS), the findings differentiate significant superiority for the e-operations of smart supply chains in terms of efficiency, supply chain transparency, cost, and enhanced data and transactional security.

Objectives of the study:

This research systematically prioritizes the key impacts of Industry 4.0 technologies on e-commerce smart supply chains using the AHP approach. It also aims to evaluate and rank the most significant impacts, such as operational improvements, cost-effectiveness, security and reliability, scalability and flexibility, customer effectiveness, and environmental impact.

Toward these goals, this research systematically ranks Industry 4.0's effects on technologies, providing actionable insights for e-commerce decision-makers. The findings will help organizations better understand various factors that should be targeted or avoided when adopting strategies for improving organizational efficiencies, enhancing supply chain value, and attaining sustainable competitive advantage in a digital and turbulent business environment.

Importance of the Study:

This study's value relates to developing new knowledge about e-commerce smart supply chains, emphasizing Industry 4.0 technologies. Sophistication continues to escalate regarding how supply chain managers can apply IoT, Big Data, Blockchain, Cloud Computing, Machine Learning and Cyber-Physical Systems.

However, using these technologies presents issues such as the high costs of implementation, the complexities of integrating them into the existing system, and the issue of managing human resources to accommodate them. To overcome these challenges, this paper uses the AHP method to systematically rank the impacts of such technologies consistent with an improved decision-making framework. Thus, it provides excellent insights that organizations can use to increase operational performance, satisfy customers, and manage environmental issues efficiently.

Study Arrangement:

This thesis consists of five parts in the form of chapters. The first part starts with an introduction, which contains an overview of the study, research questions, and the study's primary goal. The second chapter highlights the introduced concept of Industry 4.0, technologies in the context of Industry 4.0 for e-commerce, general problems, and research gaps that are also mentioned. The third chapter covers the research method used in the study, the analytic hierarchical process adopted in the research, the definition of criteria used in the research exercise, the data collection methods utilized, and the analysis method used in the research work. The fourth chapter discusses the study and provides the findings of prioritizing Industry 4.0's effects on the e-commerce supply chain. The last chapter brings closure to the dissertation, where the results are highlighted, the possible limitations of the study are discussed, and suggestions for additional research and implementation of the findings for future practice are given.

CHAPTER 1: LITERATURE REVIEW

1.1. Overview of Industry 4.0

The Industrial Revolution, which is viewed as a singular event that happened quite a long time ago in human history, is one of the subjects that can draw a change in human history, significantly modifying the way of working, transportation systems, and other innovations that resulted in the economic expansion of the people. Parallel to this, the first industrial revolution, dating back to 1760, became possible using the steam engine. This ground-breaking technology enabled a material production process to develop from the old agricultural and feudal ways to modern manufacturing methods. With the expansion of coal's utilization to generate the coherence of industrial machinery needed for the coming industrialization, the railway became the main propellent of movement of things and people over distances, and coal and railways shaped the trade of commodities and labor force. Leading industries during the period, such as textiles and metals, revolutionized manufacturing methods, thus bringing effects such as factory production, employment growth, low labor costs, and higher production output (Xu et al., 2018).

The second industrial revolution, coming towards the year 1900 through the utility of the combustion engine, initiated a period of quick and heavy industrial development involving the spread of oil and electricity in mass production. This period experienced rapid technological advancement and was responsible for sudden economic growth and cultural trends. Consequently, the economic development known as the third industrial revolution started around the 1960s, when the addition of electronic mechanisms and information science paved the way for production process automation, signifying a remarkable shift in manufacturing methodologies. The aging offshoring process, which used to need labor and effort, was then replaced by automation. As a result, things like productivity and efficiency could be easily and quickly achieved (Xu et al., 2018).

Combining the foundational advances of their predecessors, the trending future of the fourth industrial revolution, phenomenally visible because of computer-aided product design and its further development into 3D printing, is regarded as the most advanced level of industrialization, which is a tribute to the drop of borders and/or differences between the digital and the physical world due to cyber-physical systems (Xu et al., 2018).

It is called "Industry 4.0," it holds the most current advancements in automation and technology to ensure smooth manufacturing operations that cover all their processes. During the first step of this evolution, one can find that control is centralized so that cyber-physical systems form the connection between and enhance operations through improved effectiveness and flexibility. Thus, throughout its varied stages, information and communications technology is molding society's economic and social fabric as a sign of the ripe fruits we can only reap by harnessing technology for the welfare of humanity. Viewing through Industry 4.0 can be the latest and fully digital degree of industrialization, differentiated from the third industrial revolution, allowing physical and digital world matter to be on the same bridge by cyber-physical systems. Indeed, the moralistic control procedure of processes should be given more attention (Xu et al., 2018).

With the retrofit reverse, in the past, smart manufacturing was once done from the control through feedback, but now, the smart product controls the production steps, which is a modern way of manufacturing. The essential goal in the implementation of this new idea is to achieve "independent" results doing so, enabling real-time networking that provides access to certain values about early communication through physical meeting points, i.e., vertical and horizontal integration, which was probably better explained (Huang et al., 2023).

Industry 4.0 (I4.0) focuses on merging smart technologies with manufacturing, supporting the effort to tackle increasing complexities and growing competition. The authors (Bhadu et al., 2023) suggest that giving precedence to and evaluating these technologies with multi-criteria decision-making (MCDM) methods can help practitioners understand their effectiveness and adoption rates. Amongst their investigation, seven major I4.0 technologies were identified and affirmed by experts from both academic and industrial sectors. The Analytical Hierarchy Process (AHP) was applied for ranking these technologies, with the 'Cyber-Physical System' ranking highest with a weight of 0.402. Following that were "Big Data Analysis" and the 'Internet of Things,' in sequence with relative weights of 0.194 and 0.159. These results illustrate the important impact of these technologies on the modernization and automation of manufacturing organizations (Bhadu et al., 2023).

Industry 4.0 is a broader concept that encapsulates technological developments like the Internet of Things (IoT), Big Data (BD), Cloud Computing (CC), Machine

Learning (ML), Blockchain (BC), and Cyber-Physical Systems (CPS) throughout the supply chain. (Xu et al., 2018) (Al-Talib et al., 2020).

1.1.1 Internet of Things (IoT)

The Internet of Things (IoT), which is one of the most popular industry innovations, helps the current supply chain improvements, bringing to the sector not only new functions but also significant value. The phrase "Internet of Things (IoT)" was created by Kevin Ashton, a visionary and co-founder of the Auto-ID Lab at MIT, in the 1990s. It refers to an automated system within which the Internet, sensors, and transmitters are constantly connected, forming an intangible network of objects, including but not limited to Radio Frequency Identification (RFID) (Ashton & Admin, 2020).

Traditional supply chain management (SCM) used to have many problems associated with inadequate information flow and transparency in monitoring real-time program achievements. Another problem the supply chain in the fashion industry faces is the easily replicable nature of their product due to a lack of traceability in the supply chain process. Likewise, in IoT, IoT-based SCM is referred to as the advanced SCM that integrates IoT in the traditional SCM process. SCM is more transparent today since producers need help tracking the products. Similarly, it is easy to record the expenses from purchasing raw inputs to production and distribution (Taj et al., 2023).

1.1.2. Big data (BD)

In the database of Industry 4.0, data fluctuate throughout the stages of production that involve many players, including machine controllers, sensors, manufacturing systems, and people. The term "Big Data" is applied to this invariable gigabyte data, coming in at fantastic speed and in disparate formats. Data mining within an Industry 4.0 manufacturing unit for decision-making purposes based on findings relevant to innovation is based on determining patterns, models, or insights that are beneficial for the productivity of a machine (J. Lee et al., 2014).

1.1.3. Cloud computing (CC)

Cloud computing involves providing online services that offer users processing power, network capabilities, and storage resources. It is a distributed architecture with high scalability, reliability, and the pay-as-you-go concept. This architecture enables most organizations to access and utilize computing resources remotely (Bisong, 2019).

Organizations that use cloud computing can change the size and supply of the services they provide whenever needed, based on the infrastructure provided by third parties owning the infrastructure. Technological developments such as virtualization, SOA, and service/systems management transform IT to enable this computing paradigm (G. Wang, 2009).

Several elements, like the superfluous capacity of corporate data centers, wide availability of broadband and wireless networking, reduced storage prices, and continuous advancements in networking technologies, form the foundation of cloud computing. While cloud computing may completely change how computer services are designed, implemented, and delivered, it will also significantly affect communication networks' structure, design, and interactions (Katsaros et al., 2011).

1.1.4. Machine learning (ML)

Machine Learning (ML), a subfield of Artificial Intelligence (AI), should be emphasized due to its ability to discover intricate relationships in records and create truly novel information. It evolves old methods by substituting the dual channels of complex thinking and analysis used by male experts. Unlike other techniques, automation of work performed by guides that ML brings into play means that people will have more time at hand aimed at creativity, including serving customers better and discovering new market segments. Together with the professionals, ML can be initiated as a designing solution, using the artistic skills of the designers as guidance to produce the best quality. While ML works hard to provide insights, ML assists through rapid prototyping, and ML is used to evaluate the final products. Nonetheless, intricacies exist in integrating ML into organizations, while complete comprehension needs to be sufficiently assessed across design cycles, thus necessitating more extensive research and investigation (Trocin et al., 2023).

1.1.5. Blockchain

Blockchain, presented in 2008 by Bitcoin, is a data storage and transmission technology known for its staleness, transparency, security, and the distributed structure of P2P networks. Blockchain's technical architecture comprises connecting each block with the previous one through a cryptographic hash. A block contains a list of transactions, and for the nodes in the network to approve transactions, they must get a consensus (Medina et al., 2024).

1.1.6. Cyber-Physical System (CPS)

CPS encompasses collective bargaining and management of the system's hardware/software. The smart factory application networks control many physical systems, e.g., machines, conveyor belts, robots, wireless sensors, and other elements to get the digital picture of the manufacturing world. The basic concept of CPS is a smart network in which information is collected through various sources and supported by decision-making provided by the DT. CPS utilizes the DT to decide actions for the physical world with a smart network to collect and control data. This skill empowers such CPS. Treat numbers and statistics as data targets that can be met through the different. Manufacturing covers any level of management, from the strategic one. It enables data transmission for command and execution, guiding the users in their activities and compromises. The flexibility of the human-like robot in the real world is made possible through a 'real-world' evidence-based decision (Tonelli et al., 2021).

1.2. Supply Chain and E-commerce

1.2.1 Supply chain management

Along with the supply chain and supply chain management (SCM), which came into use around the 1980s, it built its fame in practice and academics. Initially, SCM was seen as overly logistics-based and external to the company. However, its definition has been constantly re-evaluated over time, now being appreciated for its broader scope (Montag, 2022).

One of the main factors of an organization's competitiveness as well as its achievement is the selection of SCM. One of the most important parts of SCM is the perception of functions. Handfield and Nichols define the supply chain as everything related to the movement and transformation of goods and information. Chopra and Mindel consider it containing all parties directly or indirectly addressing customers' needs. The phases of a conventional supply chain often involve suppliers, manufacturers, distributors, retailers, and clientele, creating a network but not a straight line. In fact, the core aim of efficient supply chain management is to combine upstream and downstream processes and operations to ensure the strategic and practical creation of value for customers and other participants in such a process (Montag, 2022).

For a long time, historically established supply chains, which exhibit diverse adaptation processes, have been viewed as the backbones of global trade, and thus, traditional supply chains are continuously being streamlined to suit dynamic market conditions and consumer requirements (Sutandi, 2018). Supply chains have allowed it to transfer from producer to user for centuries by combining different phases like design planning, production, distribution, purchase, and reverse logistics. These supply chains work as complicated interconnected nets to connect people from suppliers, distributors, retailers, and users (Sutandi, 2018). Yet, despite this, conventional supply chains usually have many weaknesses and shortcomings, which at times limit them since they often lack the ability to achieve better and glorious results in business with modern challenges and opportunities (Humski, 2022).

There are some disadvantages to demand-based manufacturing, such as the disconnection between production and demand, which leads to overstocking and stockout issues that can result in additional costs and customer dissatisfaction. Overall, this manufacturing system is beneficial because of the shortened lead time and reduced inventories (Obeth et al., 2015). Also, usual supply chains deal with intermediaries in bulk; thus, apparent transaction costs arise, which decreases the transparency of the overall supply chain. Also, sharing information inadequately among the supply chain partners causes delays, errors, and inefficiencies in the whole process, making the relationship among the traditional supply chain partners necessary (Obeth et al., 2015). For this reason, most conventional supply chains are faced with a situation where they are unable to cope with the breakneck pace of tech growth and evolving consumer preferences, which is pushing them to reassess their supply operation strategies and organizational structures to respond to an increasingly uncertain market environment (Obeth et al., 2015).

The existing approaches in e-commerce supply chain management utilize their advantages to improve the provided logistics management performance and profitability(Madhavi, Govindan et al., 2023). Likewise, using bee swarm optimization derived from natural experimentation accelerates these processes, and the products for final users are provided in a shorter period. Different input parameters render decision-making in supply chain logistics more effective and responsive and provide improved scope for minimal shipment delays and better tracking efficiency compared to the contemporary approach and technology (Madhavi, Govindan et al., 2023).Additionally, classic supply chain management facilitates smooth data flow between suppliers and consumers, which helps to reduce inventory amounts, cut costs, and enrich the teamwork between stakeholders (Akaydin, 2023).

Even though traditional supply chain management is supposed to ensure efficiency and speed, it is challenging. Inadequate data and transaction security, which usually jeopardize the integrity and confidentiality of the information, are among the complicated matters of primary concern. In addition, because more excellent procedures and relatively poor traceability can be a source of challenge, it's almost impossible for procedures to be effectively monitored and managed during production and transportation (Turjo et al., 2021).

Additionally, there is no easy solution to the persistent supply chain problems, including the quality and safety of the product. This factor comes with the high costs of maintaining the supply chain infrastructures. Along with other barriers around sustainability issues and the need for technology adoption, technological evolution is a significant barrier that traditional supply chains must overcome to remain competitive in the digital era (Jana, 2022).

This is in addition to the fact that the traditional supply chains have limitations that spring forth with their structural constraints. Concerning product sensitivity and added costs related to packaging (including depalletizing and repackaging) coupled with storage concerns and increased operating expenses in specialized facilities such as cold chain warehouses, traditional supply chain networks generally become more and more complicated (Pawar et al., 2022).

Accordingly, the centralized organizations of the traditional supply network cause high risks and lessen the availability of information, which defines the rigidity of these systems. As a result, inefficiencies, lack of transparency, and risk exposure are the main limitations of the traditional supply chain models concerning digital commerce logistics. So, we need constant innovation and adaptation in the rapidly changing landscape of e-commerce logistics (S. A. R. Khan et al., 2017).

The traditional management of supply chains in electronic commerce presents both pros and cons regarding decision-making and optimization. On the negative side, using nature-inspired models such as bee swarm optimization cannot enhance the decision-making capability of supply chain logistics. It cannot facilitate more efficient tracking of the logistics chain, thereby increasing delays in the delivery of shipments to users (Madhavi, Govindan et al., 2023). Furthermore, in a dual-channel supply chain, sharing demand information between the manufacturer and the seller can bring more significant economic benefits for both parties while mitigating conflicts between electronic direct and traditional selling Channels (Song et al., 2022).

The digitalization of conventional supply chain management (SCM) systems, alongside the integration of traditional technologies, presents a significant step towards addressing various challenges highlighted in research and case studies. By migrating supply chains to digital platforms, strides have been made toward enhancing environmental sustainability and advancing social causes through asset maximization, reduced energy consumption, and decreased travel time, as evidenced by manufacturer case studies (Praveenadevi et al., 2023). Additionally, the adoption of digital supply chains, leveraging Information and Communication Technologies (ICT), not only optimizes lead times but also enhances profitability and mitigates losses, indicating a clear positive impact on performance (Hammi et al., 2023).

However, the transition to digital SCM has its challenges, with security concerns emerging as a prominent challenge. Comprehensive surveys on supply chain security underscore the importance of implementing countermeasure solutions to mitigate threats arising from the digitalization of supply chains (Maha & Akram, 2022). Despite these obstacles, integrating Digital Technologies (DT) with SCM, particularly from a triple bottom line perspective, proves complex yet fruitful, enhancing the sustainability aspects of supply chains (Haikova et al., 2023). Examination of military contexts reveals that leveraging information networks and digital communication systems for strategic transport logistics management can improve cargo delivery effectiveness (I. Hasan & Habib, 2023).

Moreover, the Information and Communications Technology (ICT) revolution, encompassing the Internet of Things (IoT), blockchain technology, and digital financial flows, bridges gaps in SCM for agriculture and food supply sectors (S. Lee, 2021). While utilizing current IoT in supply chains is deemed transformative, infrastructure inadequacies and safety concerns persist. Sustainable SCM research further indicates that digital-based supply chain integration offers operational advantages for fast-moving consumer goods (FMCG) producers (Rath et al., 2022). Furthermore, the convergence of disruptive technology (DT) and the circular economy (CE) emerges as a trending approach in sustainable supply chain management, demanding collective action from supply chain members. The references and detailed examples underscore the capacity of digital solutions to address prevailing challenges, bolster sustainability, and enhance efficiency. Nonetheless, the emergence of new issues necessitates robust risk management and security measures (Rath et al., 2022).

1.2.2. Smart supply chain

Smart Supply Chain Management (SSCM) was born after the introduction of technologies to traditional supply chain management, which was later done manually and took time. This transition was primarily stimulated by sensor-based and communication equipment, the Internet of Things (IoT) application agents, resulting in good processing integrated with tracking and management (Bouti & Khoukhi, 2023).

Smart supply chain management is a response to the challenges brought up by the Fourth Industrial Revolution (commonly referred to as Industry 4.0), which involves using sophisticated technologies to harmonize all supply chain components, such as production and delivery, to continuously improve efficiency (Sharma D. S., 2023). Understanding smart supply chain management, including big data, IoT, Blockchain, AI, and AD, embraces analyzing data, market characteristics, and logistics performance internally and externally (Frankowska & Nowicka, 2018).

Along this line, these strategies would not only boost the efficiency and competence of supply chains; also, the benefits that digital technology can provide would come into play, enhancing sustainability and competitiveness (Alseqyani et al., 2023a). One of the advantages of smart supply chain management is that organizations can increase operational effectiveness and sustainability at the same time. In addition, they might make themselves more competitive (Scherbakov & Silkina, 2019).

Traditional supply chain management systems augment their performance by incorporating innovative concepts like blockchain and smart contracts, which significantly increase their data security, authentication, time management, and transaction procedures in the whole supply chain, increasing consumer trust in the overall supply chain (Turjo et al., 2021). Besides that, smart packaging in the food supply chain will increase product traceability, making it possible to be ahead of damage rather than repairing the consequences of losses and waste. However, this also presents challenges, particularly the high costs of implementing and maintaining advanced technologies. Incorporating digital systems, active components, and multifaceted linkages can spur the addition of direct and implicit connections. Costs could limit companies from truly reaping the benefits of a smart S&OP (S. Chen et al., 2020). Moreover, the overdependence on technology can threaten data security, and cyber-attacks may happen from using technology, even though there are security and data privacy programs against third-party involvement and risks brought about by technology (Hebrard et al., 2022).

However, time has proven that Smart supply chain management has the advantages of increasing productivity, being environmentally friendly, and enhancing cost-effectiveness, so there are inevitably challenges against cost, complexity, and security that must be strictly handled. First and foremost, the research findings suggest several limitations and challenges to smart supply chains. Concentrating on risks of IoT in smart supply chains, as one study points out, is highlighted, which include but are not limited to lack of information infrastructure maintenance and knowledge as the key risk factors (Grida & Mostafa, 2022).

Another study focuses on prospects the prospects and challenges of IoT-enabled supply chains where cybersecurity risks and inadequate infrastructure were determined as the main hindrances to its implementation (Thangaiah et al., 2022). Globalization and supply chain networks are characterized by complexity, uncertainty, and fragility. These issues require efficient resolution through collaboration among businesses, policymakers, and technical experts. These studies, in undeniable consensus, show that addressing risks, cyber threats, and smart supply chain challenges should be a significant priority in smart supply chain management (Nozari & Edalatpanah, 2023).

1.2.3. E-commerce

E-commerce is a role that includes several of the latest technologies, applications, and business processes that help trade artifacts and information via an electronic channel that typically occurs between organizations, clients, and some communities ("E-Commerce," 2023). The Information Technology Revolution, as the foundational element, with the invention of the integrated circuit, then promoted by numerous technological developments, and finally culminating in the development of the Internet ("E-Commerce," 2023), resulted in the digital commerce existence. However, there is only a young offspring of it in our times. The term e-commerce could be viewed as a digital channel of trade that allows simultaneous communication between the customer and commercial producers for their bargaining purposes (Mariniello, 2022).

This proportion currently goes towards business-to-business transactions while the surge in online shopping for consumer needs is rising. The shift from traditional trade to e-commerce in the evolution of e-commerce involves transitioning from conventional business transactions to exchanging goods and services over the Internet between buyers and sellers using computers, tablets, smartphones, Amazon devices, and other smart appliances (Parashar, 2022).

E-commerce has been the driving force behind the global business expansion project. Now, delivery chains are progressively starting their global outreach, emphasizing the significance of the B2C model, and integrating online broadcasting techniques and applications (Mabrur et al., 2022). The flexibility of e-commerce systems, represented by Man Kupi's business in Indonesia, displays the way a business can unfetter sellers the proceedings and convenience of buyers and sellers at their convenience without any constraint of the physical and the virtual realm (Santos et al., 2022). The speedy and world-touching character of e-commerce has turned a course on a thorough comprehension of its basic principles, theoretical grounds, and the study of new business models and good products (Muñoz et al., 2023).

The wide range of marketing schemes and accessibility of e-commerce have contributed to the concept of market segmentation and led to a more competitive landscape that only benefits from technological innovation and online marketplaces. Not only does it have its positive sides, but e-commerce also has downsides, such as security issues that are important for its outcome. In conclusion, because global e-commerce is categorized into models that contain B2B, B2C, B2B2C, C2B, and C2C, which is also clearly reflected in the tourism industry, one can see e-commerce as core to the revolution of global market spaces and business operations (Aamir, 2022).

The fundamental limitations of e-commerce today are complex, and they are caused by technical and non-technical problems that affect people and businesses worldwide. The rigid regulatory restrictions and the old tax frameworks present a significant challenge to digital commerce development, particularly in cross-border trade, which is crucial for establishing a well-functioning EU Digital Single Market (Mariniello, 2022). The development of digital commerce has brought along a range of new issues, particularly those involving privacy violations, unsolicited communications, and new forms of competition due to the cross-border circulation of personal data ("E-Commerce," 2023). Such issues give rise to a need for a global approach to their management. Consumers and businesses are also faced with the issue of the lack of trust in Internet service providers, the deficiency of supporting rules, and the absence of authoritative sites in their local languages ("E-Commerce," 2023).

These factors and the lack of a supportive network and a preference for face-to-face interactions over e-commerce platforms present unique challenges (H. U. Khan & Uwemi, 2018). However, the challenges of e-commerce in Nigeria have an enormous impact on the country's economy, even blocking many consumers from properly completing online transactions due to significant bottlenecks. In Iran, social and cultural backgrounds and low IT literacy among traditional traders have been identified as the major obstacles to implementing e-commerce (Mohanna & Yaghoubi, 2011). Along with this, advanced age can be one factor that interferes with an older person's ability to purchase something online, the choices or the platforms, and the decision-making process (Rydzewska et al., 2021).

However, security consideration is still one of the significant obstacles, as it is a major hindrance to the evolution of e-commerce, which presents more advantages than traditional trade (Kurniawan et al., 2022). In Jordan, the main limitations are machine security and trust, internet experience, and legal issues. Thus, the non-technical challenges are dominant (Abbad et al., 2011). While online shopping platforms have developed ways to protect customer information when logging in and authenticating the user identity, protecting such information must be considered (Rajesh & Song, 2016).

The main differences between traditional commerce and e-commerce today revolve around several key aspects: the mode of business, customer base, marketing techniques, trust and security issues, the impact of technological advancements, and the power of social and economic factors. Firstly, the buying and selling of goods and customer involvement are usually associated with physical deals in the marketplace. Even the customer presence in the market is assumed to be direct (face-to-face) in negotiations and having the chance to see and touch the product (Kurniawan et al., 2022). Unlike bricks-and-mortar stores that require physical products and consumer face-to-face interaction, e-commerce relies on the Internet to complete transactions electronically without geographic limitations (Imanova, 2023). A single website with a user-friendly interface can offer numerous products for purchase, significantly enhancing convenience and cutting down time. Another advantage of e-commerce is that it allows companies to have a worldwide market. They can now reach farther than the local boundaries, and this is not as easy in traditional commerce (X. Wang, 2022).

Digital marketing equipment such as SEO, Social Media Marketing, and PPC have become so significant for a business' survival that it cannot do without them in this age of fierce competition (Rapanoël et al., 2020). Furthermore, the opinion regarding product quality and customer satisfaction could be contrary between an Internet and a conventional transaction (A. Gupta et al., 2018). It depends on which medium one buys. In addition, trust and security are also the determining factors, as e-commerce must tackle trust issues associated with data security and the authenticity of online transactions (Mureşan, 2019).

The rise of technology and the digitalization of commerce gave bio omnichannel retail strategies that mmergeand online sale channels to create a better customer shopping experience and lower infrastructural expenses and shipping costs (Purbasari, 2017). Moreover, the economic consideration for consumers is now directing them toward buying products online through e-commerce websites, affecting the modes of payment and the purchase frequency. Finally, society's transformation to digital dependency, especially among younger people, is the challenge of the traditional markets, which implies the adaptations of service quality and market management to the new reality to stay competitive (Adamczak et al., 2018). In conclusion, the substitution of brick-and-mortar commerce with electronic commerce is characterized by alterations in payment channels, market area, marketing strategies, and the challenges of security and trust, all linked to the increasing reliance on technology and the influence of social and economic factors.

1.2.4. Interdependency of e-commerce and supply chain management

Although supply chain management (SCM), which has long been the core of business operations, has served its purpose in the past, it has no room for a simple static model. Today, e-commerce has emerged as a driving force, pushing SCM to become more flexible, responsive, and customer-centric (Atmaja et al., 2022).

The development of e-commerce technology also profoundly impacts the way traditional supply chain models operate and adds to the supply chain's operation efficiency, which makes supply relationships and demand extremely complicated. Such diversity requires a more adaptable supply chain system that can respond to uncertainties and rapid changes in the business environment to better meet customers' needs and market demands (Zhou, 2022).

Online commerce has pushed supply chain management towards digitalization. Digital technologies like Blockchain and AI show that they can be used to advance supply chain performance (Gong, 2023).

This transformation is a phenomenon that acts directly on making supply chains more robust, sustainable, and collaborative, which are so mainly driven by data analytics in SCM for making data-driven decisions that will shape the future and increase efficiency, productivity, and global transparency. With the recent integration of e-commerce into the traditional supply chain, businesses are being revised and prompted to recalibrate their supply chain strategies, explicitly highlighting the tactical and strategic purpose of SCM to e-commerce (Yusriadi et al., 2022).

However, internet technologies significantly increase competition in the e-commerce field. Supply chain integration among these companies is a significant competitive advantage for the alliance space between digital marketing and digital SCM. It is now necessary for some communication, and it should be applied functionally to ensure that strategies and policies are translated to give good results for the business (Saleeshya & Rahul, 2023).

The healthcare sector is one example of many areas that, in recent years, have moved to the more efficient personalized approach of data analysis and other issues in the supply area, being proof enough that a good and productive supply chain is vitally needed for any area (Sun, 2022). In response to the growing e-commerce business, another feature of the SCM evolution is visible in the strategic operational strategies that companies adopt to improve their profitability and competitiveness through salient supply chain strategies such as efficient and responsive supply chain strategy (Minculete & Andronic, 2022).

Through bibliometric analysis, such interdependence is obviously emphasized, ranking the dynamism in e-commerce logistics management, including operations, pricing strategy, and carbon inventory management. Thus, the interaction between online sales and SCM underlines the shift to a model of nonlinear and quick adaptation based on customer-centered value (Sheth, 2022).

1.2.5.Role of smart supply chains in e-commerce

In the context of SSCs (Smart Supply Chains), we can see them as the new promising approach to traditional supply chain management. It relies on various advanced digital technologies to improve efficiency, increase visibility, and respond faster. SSCs can be easily distinguished from traditional ones by the application of ICT, which incorporates the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, and Cloud Computing technology that is used to automate processes, optimize logistics, and real-time monitoring of the shipments (Kalkha et al., 2023).

Such technologies aid in automation, with devices and systems becoming more self-processed, increasing accuracy and reducing supervisory costs. Another notable area of the SSC (smart supply chain) use is real-time data analytics, which is based on big data and AI for trend analysis, demand prediction, and problem-solving (Gong, 2023). With this capacity, decision-makers can act faster in demand or supply changes through delivery route and schedule optimization, thus permitting efficiency (Prieto & Martín-Peña, 2023). The function of analytics data is moved beyond improving supply chain resilience, sustainability, and collaboration across the value chain as it provides the data that results in decisions based on data analytics (Nagajayanthi & Jaya Singh, 2023).

The connectedness of SSCs is the result of incorporating various Digital Technologies; therefore, the needed communication among the components would be smooth due to this (Bouti & Khoukhi, 2023). Such inter-connectedness lies in the core of agility and visibility, which modern supply chains need so much, as it makes tracking of products tracking products in transit possible and helps the exchange of information among suppliers, customers, and logistics carriers (Sun, 2022). The use of the digital twin (DT) is an example of this characteristic as the virtual properties of factories, warehouses, or transportation are mimicked in the computer letting for real-time optimization (Sun, 2022).

Moreover, the SSCs service businesses by utilizing the servitization of supply chains. This is the way of involving services in logistics operations and making them multipurpose. As a result, agility and connectivity would be promoted. Embedding of Blockchain and decentralized applications is also a manifestation that the sector is shifting to a more secure, transparent, and productive supply chain in that information will be well kept and no fraudulent transaction will occur (L. Wang et al., 2022).

Fundamentally, digital supply chains are affected by the integration of automation and accurate data analytics with networks because of applied digital technologies to streamline the supply chain (Shittu & Nabil, 2023).

Wise supply chains with sensor and IoT, Blockchain, and AI-enhanced will boost e-commerce operational agility and accuracy through speedier delivery, order accuracy, and customer satisfaction. IoT incorporation with Blockchain creates a platform for instant monitoring and control of shipments for booking and supply chain planning. This is accomplished through product identification and sorting automated technology; for example, the smart warehouse prototype rids itself of products by using RFID for segregation, ultimately optimizing the storage facilities and shortening the pick-up period, which, in turn, contributes to a higher shipping speed (Kalkha et al., 2023).

Besides, the Blockchain system has been proven to be a more secure and immutable platform that offers customers trust and compels them to be satisfied further (Nagajayanthi & Jaya Singh, 2023). The application of Big Data Analytics and Cloud Computing would bring the richness of data analysis that would enable one to predict consumer behavior, prevent delays, and optimize delivery routes (Al-Shorman et al., 2023). It is not only to boost the procedure but also to ensure the customers that they will obtain the orders as quickly as possible and the percentage of the customers' happiness will rise (Al-Shorman et al., 2023).

The digital tracker, along with the smart logistics solutions and the Blockchain-based e-commerce analytics model, permits logistic service providers to handle the complex data efficiently since it can estimate possible demand of e-commerce orders accurately, resulting in enhancing the efficiency of delivering ability and decision-making support (Praneeth et al., 2023). The leading logistics solutions, which include delivery prediction models and hybrid optimization pathways, assist in reducing delivery time and cost, which are the two significant factors that affect the growth rate of e-commerce customers (Shittu & Nabil, 2023).

This inventory optimization algorithm depends on digital supply chain and logistics, which to some extent improve inventory management, ensuring products are available when needed, reducing errors, and generally improving the whole process. In summary, smart supply chains help e-commerce because this advanced technology discovers the accuracy of items in an order, speeds the delivery, and improves customer satisfaction while making inventory management more accurate, tracking items in a secure manner, and making operational decisions effective (Ho et al., 2023).

1.3. Integration of Industry 4.0 in E-commerce Supply Chains

The Industry 4.0 blend is the integration of fourth-industrial revolution technologies. With the proliferation of new technologies in the e-commerce supply chains, several revolutionary improvements are occurring to how these chains function, enabling better savings, transparency, and customer experiences. Industry 4.0, characterized by the adoption of the Internet of Things (IoT), artificial intelligence (AI), blockchain, and other digital technologies, is pivotal in transforming e-commerce platforms by personalizing shopping experiences, securing transactions, and improving service quality (C. Chen, 2023). These technologies give real-time data acquisition and systematic processing, which is important for dealing with uncertainties and improving supply chain performance by better-integrating supply chain actors (Shouliang, 2023).

The ICT application to Industry 4.0 technologies, especially IoT and blockchain, are solutions to problems in teamwork and linkage of the global retail markets, consequently improving efficiency, resilience, and sustainability in all organizational ecosystems (Saleeshya & Rahul, 2023). A digital collaborative supply chain model based on blockchain, IoT, and cloud computing is the main factor affecting the collaborative supply chain by improving trust, traceability, and transparency, thereby reducing costs and risks (J. Zhang, 2022). With this integration, supply chain costs and system flexibility are also kept at a minimum, and the role of customer integration in these relationships is moderating (Sun, 2022).

In addition, digitization contributed hugely to processing by Industry 4.0 tools, enhancing transparency and traceability in the supply chain and strengthening inter-organizational trust and relationships. This procedure also allows us to streamline production, reduce unnecessary shipments, and use energy-saving (Atmaja et al., 2022). The Industry 4.0 slogan is knowledge-based and finds its expression through elements of the internet, data management, and networking support. Industry 4.0 technologies and the circular economy idea have also facilitated the transformation of used products into new ones, an important step toward sustainable supply chain management (He et al., 2022). Putting it all together, Industry 4.0 will see a revolution like no other in human history. Industry 4.0 in e-commerce supply chains means the shift to the new normal for the business environment, which is more effective, transparent, and customer-oriented. Using advanced digital technologies, e-commerce platforms can reach a higher level. of customer satisfaction, a higher sale, and a more sustainable operational model (Sofiah & Aisyah, 2022).

1.3.1. Integration of the Internet of Things in e-commerce supply chains

The employment of the Internet of Things (IoT) in e-commerce supply chains has been one of the most significant changes in improving decision-making and process optimization. At the same time, it also brought some challenges that need the development of robust decision-making frames, such as the Analytic Hierarchy Process (AHP) (Yuliarti, 2023). The IoT offers spot analytics and supply chains to improve efficiency and reduce costs, which leads to better customer care and satisfaction. That is where integration comes into play in companies since online and brick-and-mortar have been combined, and they offer the more significant concern of the level of security (Picoto et al., 2023).

UK retail industry research data has shown that IoT technologies have the main important features of IoT are its mediating roles of supply chain integration and capability. The combination of digitization and IoT with the supply chain begins with the IoT (Argyropoulou et al., 2023). This allows businesses to become more resilient and cohesive, and at the same time, it is incorporated with technologies like blockchain and AI to better their work performance (Shouliang, 2023).

Blockchain tech and the Internet of Things (IoT), when mixed with logistics, were weaved via processes that were in a chain of functions. They built a transparent ecosystem and connected it to the Internet (Shehadeh et al., 2023). The IoT in logistics evolves automation and computerized warehouse operation computerization; hence, production and safety increase as the skilled labor shortage and high cost are the main challenges (Gowri, 2022).

It is one of the main links of the supply chain collaboration and allows the process to be more efficient and flexible, although there will be implementation challenges (Saihi et al., 2022). Currently, a supply chain system is used, modern IoT technologies are being implemented, and modern supply chain models are being implemented that can be adapted to the current situation. Cheaper, smart inventories are being implemented, and quick decisions on optimizing the supply chain are being made (Y. Khan et al., 2022a).

Overall, IoT implementation into e-commerce supply chains promises to provide big data for decision-making and optimization to various parties. This suggests that it will be challenging to develop solutions that can be implemented to fully realize IoT's potential in e-commerce supply chains if we have a complex framework like AHP in place. The application of IoT in e-commerce supply chains has led to a transformation as technology provides unique opportunities and the associated challenges that come with the process. Intelligence technologies such as AI and blockchain can increase decision accuracy, streamline stock management, and provide predictive data analytics (Gupya., 2023).

Therefore, though this technology is expanding, loopholes render its adoption incomplete, for example, the high level of awareness required and its general weaknesses (Ullah et al., 2023). The e-commerce and process industries have shared in dealing with integrated scaling and decision-making, which seem to be complex concepts, and the orchestration of human-computer decisions (Ullah et al., 2023). Security factors, especially trust and privacy, are the central elephants in the room that determine how IoT is utilized in e-commerce environments (Lara & Wassick, 2023).

1.3.2. Interrogation of Big Data in e-commerce supply chains

Big Data Analytics (BDA) embedding in e-commerce provides a clear, effective means of decision-making of the supply chain through the appraisal and usage of an enormous amount of data for rigor, cost savings, and increased rivalry. According to Hong Lin's investigation, the entities JD e-commerce, Nongfu Spring, and Tesla have achieved a high level of competitiveness in their respective sectors due to Big Data Application (BDA) that enables them to make better supply chain decisions with forecasting and speed as crucial factors, leading to greater efficiency and productivity (H. Lin, 2023).

Ming Zhao's research finding again contributes to this by providing an example of the BDA use that can curb the chain loop effect and hence demand planning through advanced forecasting technologies, which eventually culminates in the reduction of the uncertainty level and improvement of the supply chain efficiency (Zitianellis, 2023). In the COVID-19 pandemic, BDA emerged as one of the leading solutions to supply chain coordination when handling fluctuations and disturbances. Here, supply chain managers started to acknowledge the need for data-driven strategies to improve their operations by using insights extracted from the data to optimize efficiency and provide customized products and services (R. Hasan et al., 2022).

In the field of e-commerce, the influence of BDA is very notable as it helps companies to incorporate a more data-driven way of thinking; therefore, their decision-making process is better because they follow a more interpretative approach that assesses their status in the BDA framework (D. Sharma et al., 2023). The study by Vishal Goar and Nagendra Yadav enlightens on the B-DAD framework, a synthesis of big data analysis and decision-making, the basis of which has shown its worth for cognitive decision-making within the retail setting (Goar & Yadav, 2022). On the other hand, various authors note the effect of the big data technology outputs on supply chain resilience, which is especially true in stable conditions, where the technology helps make human-machine decision-making collaboration easier (H. Liu et al., 2023).

This finding is also sustained in the real-life application of BDA in e-commerce, which has shown the capacity to balance economic, social, and environmental performance and thus provides strategic value beyond mere cost reduction (Gangwar et al., 2022). As shown by Yunjing Wu's research, data-driven analytics state-of-the-edge technology helps to enhance supply chain performance allied with cost-cutting of diverse industries, such as retail and logistics (Y. Wu, 2022). Similarly, Qi Liu et al. depict a scenario where big data may direct the costs of the operation of the supply chain in e-commerce, which in turn strengthens the core competitiveness of the company by way of formulating a cost control mechanism that is comprehensive (Q. Liu et al., 2022).

In summary, e-commerce is data analytics decision-making and process optimization because it creates the actionable information required, enables the improvement of forecasting precision, increases supply chain resilience, optimizes sustainability, and reduces costs with numerous research examples of case studies.The application of big data in e-commerce supply chains has been one of the most revolutionary practices in current business worldwide. It also brings an array of benefits and challenges. Obstacles may include establishing the environment, lack of capability to master digital space, and technology gaps that are the factors of low-level adoption (Mohammadi, 2023).

1.3.3. Role of Cloud Computing in e-commerce supply chain integration

With cloud computing analytics running in the background, e-commerce businesses strive to achieve improved decision-making and supply chain optimization, as data analytics has become one of the essentials for this area. For instance, AHP, an essential application of MCDM, is what businesses use to optimize efficiency by solving consumer needs within the supply chain networks. That explains why modern supply chain challenges are complex, and businesses need sophisticated solutions like AHP to solve their issues (AbdelMouty, 2022). On its part, cloud computing opens a way for reducing supply chain costs while registering high flexibility and scalability of this infrastructure, platform, and software. It increases collaboration in the supply chain and meets infrastructure needs so the supply chain networks can be more adaptively and proactively stimulated (Yang, 2019).

On the other hand, cloud computing tends to be used for supply chain relationships and supplier management, among other issues; however, the implementation of machine learning and wisdom algorithms brings efficiencies into supplier credit systems and decision-making (W. Wang et al., 2021). Additionally, with the help of cloud computing analysis, environmentally sustainable practices can be developed in the field of the supply chain, as can be seen from the example of the optimization of e-commerce supply chains under carbon emissions constraints. Adopting this strategy, however, enables the optimization of costs and emissions and likening different decision-making methods to supply chain efficiency (Bang et al., 2023).

The need for cloud services to realize the financial success of online companies is illustrated by their primary role in streamlining business processes and supply chain management (Yi, 2020). Cloud computing analytics play a role in the AHP for choosing the most appropriate distribution logistics model for the e-commerce enterprises; this example elucidates how the integration of cloud computing analytics in the core supply chain decisions of these entities boosts their overall competitiveness (M. N. Khan & Sinha, 2022).

Therefore, implementing cloud-based data analytics, represented with the use of AHP and other decision-making strategies, allows the e-commerce supply chain to become more efficient, sustainable, and competitive by adopting more intelligent, flexible, and clever decisions (Madhavi, Govindan, et al., 2023).

Integrating cloud computing within e-commerce supply chains becomes a transforming catch-22 situation, offering both refreshing challenges and great opportunities (Lara & Wassick, 2023). Thanks to the adoption of cloud solutions, data analytics can be conducted in real-time, and such collaborative platforms with intelligent optimization will result in improved decision-making. Nonetheless, while data security, privacy risk, and effective disaster recovery plans have been proven to be some of the crucial issues, these must be considered comprehensively (Gammelgaard & Nowicka, 2023). Moreover, cloud computing can create smart supply chains by leveraging the power to reorganize, configure real-time resources, and collaborate on a shared platform amongst various stakeholders (Chauhan et al., 2023).

1.3.4. Integration of Blockchain in e-commerce supply chains

The presence of blockchain technology is a significant reference point. Indeed, its routine integration in e-commerce supply chains will certainly introduce momentous reforms to enhance decision-making and optimization while jettisoning the decision-making framework's challenges, such as the Analytic Hierarchy Process (AHP) (Mashalah et al., 2022).

Blockchain technology, with its distributed, secure, and transparent nature, as well as a consensus mechanism that is guaranteed to be made among peers, can change the way digital transactions are managed, and this impact can be seen across most sectors, including the e-commerce supply chain (Gong, 2023). This technology, being used as a robust, sustainable, and collaborative strategy for supply chain management (SCM), made businesses go digital and greatly impacted the growth of e-commerce and retail platforms (Perla & Sharma, 2023).

Peer-to-peer technology will save time, reduce costs, and increase transparency, which will boost supply chain performance (Yusriadi et al., 2022). It backs up the tactic of the business field, which is digital transformation integrated into the supply chain stages, and business integration improves performance. Also, as blockchain encryption is integrated with e-commerce, the matter of supply chain control and coordination comes to the fore, which makes the role of the leaders even more important (W. Wang et al., 2021). Though the integration of blockchain in supply chains of e-commerce has some benefits, but it also brings a few challenges. Digital transformation poses a great complexity that entails a profound knowledge of the complementary and contradictory relations of challenges that can be indicated using interpretive structural modeling (K. Wang & Zhang, 2022).

Integrating these emerging technologies into existing business models demands a brand new system of decision-making like AHP. Cryptocurrency Malefactor also: Blockchain technology can increase the climate sustainability of e-commerce supply chains by employing carbon emission constraints in supply chain scheduling. This can significantly help centralized decision-making approaches reduce emissions and energy costs (Saleeshya & Rahul, 2023).

In addition, the ecologically reflective practice of supply chain consumption further amplifies the importance of ecologists in the digital era (Kaoud, 2020). As the integration of blockchain technology in the e-commerce supply chain is standing for a significant change, it provides the ability to make decisions with a clear mind, creates optimization opportunities, and tackles challenges using frameworks such as AHP. In this manner, the decentralized system increases the performance of the supply chains and the sustainability and transparency of the e-commerce supply chains (Bheekharry, 2021).

Applying blockchain technology in e-commerce supply chains results in transformation, which is either a drastic change or a big chance. The problem comprises scalability, decision-making that should be integrated into different hierarchical layers, and even allocation of human and machine decision-makers (Gupya., 2023). While blockchain extends these capabilities in supply chain technology, its ability to enhance resilience, sustainability, and collaboration with the supply chain stakeholders is unprecedented. Applying the blockchain can help perform transactions fast enough, ensure visibility, optimize the use of resources, and lead to decision-making based on real-time data (Sofiah & Aisyah, 2022).

1.3.5. Machine Learning integration for enhancing e-commerce supply chains

Incorporating machine intelligence (ML) into e-commerce supply chains represents a new era of supply chain management that has changed how decisions are made and streamlined procedures. On the other hand, those decision-making frameworks, such as the Analytic Hierarchy Process (AHP), still need to improve despite the changes. The space and role of ML in e-commerce and process industries are differentiated. However, technically speaking, it is important in addressing common issues such as scalability, the continuous integration of decision-making across disparate time horizons, and the management of human and computer-based decision-makers (Lara & Wassick, 2023).

ML enables the use of models such as integrated supply chain operations reference, which is well illustrated by the ability of these models to predict risks with very high levels of certainty (S. Kumar & Sharma, 2023). This, in turn, provides managers and stakeholders with better decision-making options. ML tools are almost undeniably requisite in supply chain management (SCM), with strategic planning, forecasting, and competitive analysis at the stage of choice, among others, really vouching for them to reach SCM goals fast (Singh, 2023). For example, a machine-learning algorithm such as K-Nearest Neighbors (KNN) is often used for sales data analysis to designate forecasts and customer segments for inventory and production planning (Kavitha, 2023). KNN is one of the simplest and most effective supervised learning algorithms that make data classification based on the similarity of the nearest labeled data. It does this through the computation of the 'k' nearest neighbors of a particular data point and using the attributes of these neighbors to make predictions, which makes its application particularly useful in tasks such as pattern recognition of customer behavior and sales data prediction (Kavitha, 2023).

The following ML framework for inventory management that leverages AI algorithms such as Artificial Neural Network (ANN), Random Forest (RF), and Support Vector Machine (SVM) has displayed its unlimited capabilities in adjusting inventory to make the supply chain function excellently. ANNs are computational models that mimic the structure of the human brain and are used to solve various problems. They are ideal for use in demand and sales forecasting since they can recognize patterns and correlations in data. RF is an ensemble learning technique that creates many decision trees during the training process and makes the mean prediction for regression problems or the mode of the classes for classification problems, which makes it quite robust, even for complex datasets. On the other hand, the SVM is a supervised learning model used for prediction tasks on high-dimensional data because it defines the best hyperplane to classify the points. Even though the AHP method is efficient, it faces issues with expansion when the problems are large-scale (Mohamed & Saber, 2023). Using online learning algorithms, artificial intelligence addresses this issue effectively by programming the decision-makers preferences, thereby reducing time and cognitive effort and streamlining the search for optimal solutions (Alves et al., 2023).

The fusion of blockchain technology and machine learning improves the digitalization of supply chain processes, providing timely decision support during daily operations. It also makes it possible to manage data of varying sizes while forecasting demand in e-commerce orders in real-time (Ho et al., 2023).

The inception of ML into Agile supply chain management deals with the revelation of early risk identification and material planning, as well as quantifying both the benefits and challenges of ML in supply chain management. This integral role of ML in the e-commerce supply chains is not restricted to the process of refining operations but creates a better platform for decision-making processes, which are now evidence-based and efficient (Ghabak & Seetharaman, 2023).

Integrating a machine learning component in e-commerce supply chains is promising yet demanding and possesses certain challenges and limits. However, even though AI can raise supply chain efficiency a notch with the help of decision-making processes, issues like scalability, the interoperability of various time zones, and the orchestration of human and machine decision-makers persist (Adobor et al., 2023).

1.3.6. Integration of Cyber-Physical Systems in e-commerce supply chains

The embedded Cyber-Physical Systems (CPS) in e-commerce supply chain management create a paradigm shift, bringing decisions and process optimization, which is done by navigating through issues related to the supply chain and adopting frameworks such as the Analytic Hierarchy Process (AHP). CPS, which provides a platform for the apparent real-time data compilation and evaluation, is the one to eliminate the supply chain opacity and simultaneously aid in the responsiveness of a supply chain (Gong, 2023). This supply chain's responsive data handling makes it possible to quickly adapt and optimize performance in a world of dynamic e-commerce (Perla & Sharma, 2023).

Studies have proved through digitalizing supply chains that managers of organizations should fully utilize the available technologies, such as CPS, to enhance analytical and data-driven decision-making (Mashalah et al., 2022). These tools provide companies with the opportunity to improve their business processes, lowering operational costs, and increase supply chain transparency (K. Wang & Zhang, 2022).

Additionally, the involvement of CPS within e-commerce supply chains is of much significance because it provides the possibility to calculate the entire environmental impacts and enhance strategy for minimizing their impacts (W. Wang et al., 2021). Nevertheless, although the mentioned interventions proliferate with the development of thinking models like AHP, which are used in supply chains, specific problems imply these systems. Among the challenges are the challenges arising from massive data handling, significant technological investments, and the skill sets and expertise needed to understand the data and its evaluation. On top of that, the decentralized approach to decision-making among e-commerce supply chains can complicate the optimization process, thus increasing carbon emissions (Saleeshya & Rahul, 2023).

Although CPS integration into e-commerce supply chains still faces obstacles, analytical tools such as the AHP can pave the way toward more effective, rapid, and sustainable supply chains that operate with less waste. Not only does this approach improve the decision-making process and the optimization system, but it also aligns them with the evolving needs of e-commerce platforms, thus making them more assertive in their competition for the best market share (Y. Wang et al., 2018).

Game changers like cyber-physical systems (CPS) in transportation or manufacturing also have their share of problems and benefits for e-commerce supply chains. CPS supports the development of higher-level planning and smart decision-making in enterprises. On the other hand, issues like scaling, the integration of decision-making that determines the relevant timeframes over either horizon and the orchestration of human and computer-based decision-makers persist in either industry (Gupya., 2023). Digital transformation in India's supply chains, no doubt, has impediments such as technology infrastructural restrictions, technological disparities, and digital education gaps (Sofiah & Aisyah, 2022).

Integrating Industry 4.0 technologies in the e-commerce sector has undoubtedly led to significant advancements in streamlining supply chain management and decision-making processes. Fusing these technologies has not just enhanced overall client satisfaction rates. It has also led to a significant boost in sales, owing to improved client experience and service quality on e-commerce platforms (Chbaik et al., 2023).

Furthermore, service customization on these platforms has made significant progress with the adoption of Industry 4.0 technologies. E-commerce businesses have effectively utilized a broad range of tools and solutions to optimize their operational efficiency and elevate their customer service standards, all thanks to the integration of these cutting-edge technologies (Marinagi et al., 2023).

Thus, the e-commerce industry has experienced an unbelievable transformation thanks to the seamless integration of Industry 4.0 technologies, generating numerous opportunities for improved decision-making processes and supply chain optimization (Arias et al., 2022).

1.3.7. Applications of Industry 4.0 technologies in e-commerce smart supply chains

IoT and CPS for real-time tracking and predictive maintenance

The application of the Internet of Things (IoT) and Cyber-Physical Systems (CPS) in supply chain and inventory management has also improved overall operations and mainly efficiency by enabling real-time tracking and reducing decision time (Anozie et al., 2024). Sensors and RFID (Radio Frequency Identification) tags are used in IoT devices with the help of which they can collect and analyze data all the time, and that is very useful to maintain the proper levels in stock, avoid extra purchasing, and thereby minimize waste to improve efficiency (Anozie et al., 2024). This real-time monitoring capacity offers the visibility acquirer, throughout all supply chain layers, to positive decision-making and the ultimate aim of conforming to the set regulatory requirements (Udeh et al., 2024).

In manufacturing, IoT also enables what is known as predictive maintenance. IoT products scan the healthiness of equipment and changes in their condition, helping manufacturers change or repair faulty equipment in advance, saving a lot of time and increasing the lifespan of the machines, enhancing operational efficiency (Anozie et al., 2024).In addition, several studies revealed that the use of IoT in the supply chain enhances demand forecasts that aid in the turnover of inventory, which is critical to remain competitive within ever-evolving markets (Hasyim & Bakri, 2024). Nevertheless, issues like the cost of implementing and integrating with existing structures and data security are significant barriers organizations must recognize to harness IoT's full potential (K & B, 2024). In conclusion, the management of the IoT and CPS technologies in the supply chain enables the efficiency of the supply chain processes and a higher level of decision support where new resilience and sustainable SCs are to be developed. (Yesodha et al., 2023).

Amazon systematically elevates the art of mainline operations through the Internet of Things (IoT), real-time tracking, and considerable data management efficiency. For example, through IoT devices such as GPS trackers and sensors, Amazon can track products at every stage of the supply chain and make decisions in advance. (Udeh et al., 2024). Maintenance forecasting also enhances the predictability of the maintenance, and demand forecasting prevents extra stock from accumulating and later going to waste to ensure customers' needs in terms of the product are met (Yesodha et al., 2023). Altogether, the key considerations in IoT integration and Amazon's extensive phased actions seem to add guidelines for efficiently using such opportunities. Despite the clear weaknesses of IoT-driven initiatives, including high implementation costs and cybersecurity concerns, Amazon's phased IoT integration strategies highlight crucial considerations and potential approaches to the efficient use of such opportunities (S. Pethe et al., 2024).

BMW and Tesla apply CPS for supply chain synchronization concerning Industry 4.0 concepts. CPS assists the combination of digital and physical systems, facilitating smart, flexible logistics networks (Klotzer & Pflaum, 2015). For example, Tesla'ss demand planning is based on AI and aims to optimize inventories and how it works. At the same time, BMW actively utilizes systems to reduce lead times and improve precision in logistics (Adesoga et al., 2024). Despite these challenges, these companies exhibit how CPS creates differentiation, productivity, and business advantage in the supply chain (Suárez-Riveros et al., 2021).

Big Data and CPS implementation for cost reduction

Integrating Big Data and Cyber-Physical Systems, or CPS, strongly influences cost efficiency, delivery path optimization, and resource distribution across several domains such as logistics, shipping, and the supply chain. Big Data analytics leads to the production of efficient algorithms like the non-dominated sorting genetic algorithm II (NSGA-II) used in formulating shipping routes and organizing resources, hence increasing the efficiency of transportation by trimming the time taken from 15, 10 hours to 11, 89 hours, hence cutting costs (Y. Zhang, 2024).

In addition, applying quantitative models in city logistics systems can adequately address the high variability of resource demand, vehicle routing, and resource allocation by excluding high-risk options through statistical models (Y. Chen et al., 2021). The effectiveness of the Internet of Things and data analysis in supply chains increases its efficiency by way of real-time monitoring and optimizing inventory, which lowers operation costs (Ikevuje et al., 2024). In complex multi-agent systems, at once providing resource allocation and optimization of communication channels, methods minimize communication costs and computational overheads, confirming resource dynamics' practicability (Srivastava & Salapaka, 2017). Also, logistic management systems capturing energy-efficient algorithms like the Dixie have demonstrated potential for a concomitant cost reduction in distribution, estimated to be in the range of a maximum of 80 percent, relating to the efficiency of these technologies (Zhao & Tie, 2022).

Chief among the ways that DHL uses big data analytics is to reduce transportation and logistics costs due to varying aspects of its supply chain processes. Integrating big data technology allows DHL to compound the plan routing optimization, improve transportation factors, and cut operational costs. (Shuo et al., 2024). By employing a big data intelligent platform, DHL can determine the general framework of the global supply chain costs to grasp the total amount of various factors that may affect the costs and, through intelligent analysis approaches, explore the new value of the existing data for comprehensive cost control and management. (S. Chen & Kumari, 2024).

Blockchain and Cloud integration for security and transparency

This is by integrating blockchain technology with cloud computing to improve and complement the strengths of the two to provide robust data security, high transparency, and high levels of trust in the supply chain systems (Nwariaku et al., 2024). Since blockchain is decentralized and its data is stored in a blockchain, it is beneficial in recording transactions that need to be checked on their veracity in supply chain (Oriekhoe et al., 2024).

This is especially important for companies that sell food, medicines, and clothes, using blockchain as a prevention tool against counterfeiting and guaranteeing proper sourcing (Revathi et al., 2024). However, cloud computing supports blockchain by providing elastic and pay-as-you-go resources, thus enabling supply chain blockchain to address the significant data challenges (Fadhil & Zeebaree, 2024). These technologies are integrated to cover problems like data authenticity, resource utilization, and safety to improve the supply chain (Choubey et al., 2024).

Despite the inherent strengths of blockchain technology, its applications are particular, for instance, using smart contracts to automate payment and inventory where the human interface tends to complicate issues, creating room for error and, thus, hiking up regulatory measures (Prakash, 2024). In addition, blockchain offers protection against fraud by serving as a digital identity of the products where owners can generate a unique code (Oriekhoe et al., 2024).

Nevertheless, issues that crop up with openness include finding ways of scaling and integrating the solution with other business systems, not to mention compliance concerns (Nwariaku et al., 2024). Moreover, the cost of deploying blockchain solutions and the issues related to data access and compatibility remain to be solved to unlock the value of blockchain applications for supply chain efficiency (Vignesh & Elakya, 2024). Future directions involve integrating blockchain with artificial intelligence and the Internet of Things for unique industry applications; the experimental hybrid blockchain is also used to associate with the existing impediments (Oriekhoe et al., 2024).

Blockchain deployment can improve Walmart's food supply chain traceability and security through a distributed register of the transactions occurring at every stage of the food chain (S. V. S. Kumar et al., 2024). This approach helps cope with the emerging problem of food safety and fraud as it avails full disclosure of food cycle information on a real-time basis to farmers, suppliers, manufacturers, distributors, and food retailers (S. V. S. Kumar et al., 2024). The blockchain structures make it easy to digitize information on the production, processing, distribution, and retailing of products through QR codes for traceability by consumers (S. V. S. Kumar et al., 2024). Besides enhancing the quality and level of supply chain transparency and accountability, this paper presents a traceability framework based on blockchain that enables consumers to make informed decisions regarding the food they consume and enhances food safety and security (Sugandh et al., 2023).

Cloud Computing and CPS for flexibility and adaptability

As far as supply chains are concerned, cloud computing and cyber-physical systems (CPS) improve operational agility and adaptability to various conditions and demand trends. Cloud computing is, hence, a perfect model of a flexible environment where one can acquire resources and easily support market requirements changes without acquiring harsh fixed assets and infrastructure (Amajuoyi et al., 2024). This capability is important in supply chain management since it allows for decision-making based on the real-time information processed and analyzed (Tanque & Foxwell, 2017). The synchronization of CPS with cloud computing takes these edges to the following level: increasing compatibility and real-time tracking of logistics chains. CPS uses information technology skills in resource management, sharing resources, and making logistics practices more sustainable (Aron et al., 2023). Furthermore, cloud computing and CPS complement the creation of highly flexible supply chains crucial for continuity and operating effectiveness enhancement in response to variability and disruption (Holloway, 2024). Further developments in cloud services, including multi-cloud and hybrid cloud, enable organizations to place their workloads in different clouds, eliminating risks and enhancing the availability of key services (Amajuoyi et al., 2024).

In addition, adopting heterogeneous cloud computing in CPS proactively solves the management problem of resources by using approximate algorithms to solve task distribution problems and improve the system's sustainability. Service delays are then solved (Gai et al., 2017). These boosts in technology act in unison to give supply chains greater future flexibility, lower costs, and increase enhancement, thereby positioning the supply chain to counter challenges and meet the demands of consumers more effectively in today's volatile business climate (Gai et al., 2017).

Alibaba uses available cloud infrastructure by consuming several reserved instances and other reserved cloud capacities and using more competent capacity management to meet the fluctuating traffic during the Singles'' Day event. The company likely uses reserved instances to meet its base demand, complemented by supplementary contracts to handle the unpredictable surges typical of such large-scale events (S. Chen et al., 2024). This approach allows Alibaba to optimize costs by purchasing capacity through standard reservation contracts and utilizing a secondary marketplace for trading excess capacity, which is a strategy that can be more cost-effective than relying solely on cancellation options. (S. Chen et al., 2024).

Also, Alibaba can utilize machine learning methods to identify and categorize the pulsing of processing loads to optimize resource utilization and preserve application availability and responsiveness (Segalin et al., 2015). The elasticity of services like cloud computing makes Alibaba able to efficiently adjust the resource to an up position or down position depending on the real-time changes of the demand without facing so much overhead, thereby delivering the services as visualized (Segalin et al., 2015). Alibaba can then improve resource management by dividing processing demands and organizing job distribution between the cloud and local cloud servers. That positive impact awareness and resource management give Alibaba additional flexibility to scale its on-demand resources while maintaining stability even in extreme traffic circumstances like Singles'' Day (S. Chen et al., 2024). It is not limited to meeting the needs of demand fluctuations but also enhances the usage of resources to their most tremendous potential with the least costs (S. Chen et al., 2024).

IoT and Machine Learning for customer satisfaction

Leading e-commerce and retail giants like Amazon, Alibaba, and Walmart harness IoT and machine learning to drive customer satisfaction by enhancing personalization and optimizing delivery. Machine learning algorithms analyze vast datasets—such as customer behavior, purchasing history, and demographics—to create personalized recommendations and dynamic pricing strategies, which improve engagement and conversion rates (Amosu et al., 2024).

For instance, deep learning models, including Convolutional Neural Network (CNNs) and Recurrent Neural Network (RNNs), empower Amazon's predictive shipping and targeted marketing, boosting click-through and conversion rates (Amosu et al., 2024). Machine learning also supports inventory management and demand forecasting, which are essential for timely deliveries and cost efficiency (Tuli et al., 2024).

IoT complements these efforts by providing real-time operational data, enhancing supply chain efficiency and responsiveness ("Data-Driven Retail", 2024). However, these advancements raise privacy concerns, as personalized services require extensive customer data, warranting robust regulations and ethical frameworks (Tuli et al., 2024). Additionally, implementing these technologies demands considerable computational resources and technical expertise, which can pose operational challenges, particularly for smaller enterprises (Amosu et al., 2024).

Despite these hurdles, oT and machine learning are the key advantages for e-commerce companies enhanced by these hurdles. In tackling privacy and integration concerns, such technologies can promote sustainable enhancement of customer satisfaction and firm flexibility amid intensifying competition (Wilson et al., 2024).

Machine learning operates in Amazon to analyze enormous amounts of data used in identifying customer needs to improve user experiences and boost commerce. The obtained data includes browsing history, buying patterns, and demographic details of users that are processed by efficient algorithms to generate relevant products and possible variable prices (G et al., 2024).One brilliant innovation I found is Amazon's approach to identifying high-level shopping intentions, like camping or birthday parties and providing diverse offers. They all utilize a deep learning model to match online behaviors to shopping intents, which has boosted business metrics by 10% (Shen et al., 2023).

In the same way, Amazon uses graph convolutional networks to build customer representations and improve Alexa traffic routing based on deeper contextual information from customers' experience with skills. Such a pattern has been credited with high gains in predictiveness of the outcomes and enhancing the user experience (Shen et al., 2023). These personalization techniques enhance clients' satisfaction and enable loyalty and development in the firm and competitive context of e-commerce by utilizing machine learning algorithms. (G et al., 2024).

Big Data, Blockchain, and Cloud for environmental impact

This paper shows that big data analytics and blockchain technology help supply chain, and manufacturing industries eliminate waste and lower emissions for sustainability goals. The study shows that Big Data improves smart supply chain management provides a deeper understanding of supply chain activities to increase the efficiency of supply chain decisions and minimize companies' carbon footprints (Anozie et al., 2024). For example, considerable data-driven predictive maintenance in manufacturing makes it possible to optimize machinery use, minimize energy use in cases of a likely breakdown, and minimize emissions from faulty machinery. Also, Big Data in production enhances mobility by eradicating traffic, brilliant weather, and fuel consumption, resulting in improved delivery routes and minimal pollution (Anozie et al., 2024).

Blockchain technology supports them by increasing transparency, providing better traceability, and securing data in supply chains. It offers undisputed documentary evidence of transactions and establishes credibility among users to optimize management with a minimum incidence of fraud. It is vital to ensure that consumers distinguish between real, sustainable activities and fake ones to achieve less environmental harm (Nwariaku et al., 2024).

Blockchain enables the idea of a circular economy where one organization's output becomes another organization's input, thus limiting the generation of waste (Ventura et al., 2024). Blockchain-supplied supply chain analytics increase LARGS (lean, agile, resilient, green, and sustainable) supply chain performance (Espahbod et al., 2024).Thus, implementing supply chain management innovations with low emissions levels with the use of blockchain technology has a positive impact on improving environmental indicators, helps organizations achieve improved financial performance, and shows business success (Bhattacharjee et al., 2024).

Big data analytics are effective in the enhancement of transportation systems to achieve minimum carbon emissions and the results of several studies bear testimony to this effect. Such real-time transport planning through big data analysis can lead to a considerable reduction in fuel usage and emissions, which is good for the environment and makes business sense for transport enterprises (Zrigui et al., 2023).

Cloud computing is central to realizing the sustainability goals of e-commerce through improving resource utilization and decreasing the adverse environmental effects. Resources are centralized in cloud computing, and it has been noted that the expense of climate change and power outages is absorbed in cloud computing, contrary to on-premises infrastructure. This is supported by implementing FinOps, which acts as a guide to efficiently utilizing cloud services without overusing bandwidth, reducing power consumption (A. Gupta et al., 2022).

This is complemented by green cloud computing-enhanced practices such as efficient hardware, green energy, and smart resource utilization to generate minimal carbon footprints and power consumption (Tyagi et al., 2024). Considering the e-commerce technologies, cloud computing allows for reducing the dependence on tangible environments, so it decreases energy intensity and material consumption(A. Gupta et al., 2022).

Also, autonomous maritime and last-mile transport delivery in e-commerce operations are the promise of cloud-based geospatial technology that helps improve the sustainability of the supply chain by decreasing fuel consumption and emissions (Andrei et al., 2024). Green cloud computing is a potential competitive advantage and an ethical way towards sustainable market value projections (A. Gupta et al., 2022). These advances proactively epitomize the essence of the cloud computing paradigm in pursuit of green e-commerce initiatives. They can provide a theoretical and practical roadmap for future research and practices (Andrei et al., 2024).

Table 1 summarizes the key impacts of Industry 4.0 technologies on e-commerce smart supply chains, highlighting their roles in operational efficiency, cost-effectiveness, customer experience, scalability, flexibility, security, reliability, and environmental sustainability. It also provides references to support the findings for each criterion and associated technology.

Table 1: Key Impacts of Industry 4.0 Technologies on E-Commerce Smart Supply Chains

Criterion	Technology	Summary	References
Operational Efficiency	IoT, CPS	IoT enables real-time tracking, predictive maintenance, and inventory optimization, while CPS facilitates synchronized logistics networks to reduce lead times and improve precision.	(Anozie et al., 2024) (Adesoga et al., 2024)
Cost Effectiveness	Big Data, Blockchain	Big Data optimizes logistics and transport routes, reducing costs. Blockchain increases transparency and reduces fraud, supporting cost control.	(Shuo et al., 2024) (Nwariaku et al., 2024)
Customer Experience	Machine Learning, IoT	Machine Learning enables personalized recommendations and dynamic pricing, enhancing user experience. IoT improves delivery efficiency and responsiveness through real-time operational data.	(Amosu et al., 2024)

Scalability and Flexibility	Cloud Computing, CPS	Cloud Computing supports resource scalability and decision-making in real time. CPS enhances logistics adaptability, ensuring flexible responses to supply chain disruptions.	(Amajuoyi et al., 2024) (Aron et al., 2023)
Security and Reliability	Blockchain, Cloud Computing	Blockchain ensures secure data storage and transaction traceability, while Cloud Computing provides elastic resources for secure data management and integration.	(Nwariaku et al., 2024) (Fadhil & Zeebaree, 2024)
Environmental Impact	Blockchain, Big Data, Cloud Computing	Blockchain promotes sustainability via traceability and circular economy practices. Big Data minimizes emissions through route optimization. Cloud Computing reduces energy consumption through centralized resources.	(Espahbod et al., 2024) (A. Gupta et al., 2022).

CHAPTER 2: METHODOLOGY

2.1 Research Design

Research design is a conceptual map that describes the strategies and methods needed to achieve the goals of a particular study. It also outlines the approaches for compiling and analyzing information to appropriately respond to the research questions. Research design is critical in grounding any study, guaranteeing the research's dependability and effectiveness in delivering the outcomes (Zhou, 2022).

In view of the nature of this study, we deployed a quantitative research method. Quantitative research encompasses a scientific approach by using numerical data to search for facts about measurable aspects impartially. We can use it to analyze formatted data and draw research-relevant statistical conclusions (Mohammadi, 2023). This was considered appropriate because it offers an orderly means to assess and rank multiple criteria, which is critical in resolving the research problem.

To achieve the study's objectives, this paper used the Analytic Hierarchy Process (AHP) to measure the relative importance of Industry 4.0 technology on e-commerce smart supply chain decisions based on a quantitative decision-making method known globally. Consequently, AHP is a comprehensive, hierarchical modeling methodology that facilitates reducing exponential decisions into symbols for subsequent assessment and resolution (Saaty, 1990). This method was selected because it allows subjective expert opinions to be assessed and systematically converted into quantifiable priority weights.

In data collection, the authors sought opinions from scholars of Industry 4.0 technologies and scholars in e-commerce. These experts provided pairwise comparisons of six key criteria: Some of the important criteria include operational efficiency, cost, security and reliability, scalability and flexibility, customer experience, and environmental impact. The pairwise comparisons have been made on Saaty's 1–9 scale, in which 1 means equal importance and 9 means extreme importance (Saaty & Kearns, 1985).

All the analyses were done with the help of Microsoft Excel. The questionnaire comprised the Nine Success Factors and was analyzed using Excel software to build pairwise comparison matrices of data normalization and priority weight calculation and check the consistency ratio (Alves et al., 2023).

The AHP methodology was carried out in a series of structured steps:

1. Formation of the Goal: The study aimed to prioritized influence of Industry 4.0 technologies on e-commerce smart supply chains (Nimawat & Gidwani, 2021).
2. Hierarchical Structuring: The decision-making problem was also divided into the following hierarchy: a goal at the top and six criteria (Nimawat & Gidwani, 2021).
3. Development of Pairwise Comparisons**:** The specialists' judgments were gathered and transformed into pairwise comparison matrices (Nimawat & Gidwani, 2021).
4. Calculation of Priority Weights**:** Priority weights were computed due to normalization to establish the significance of each criterion (Nimawat & Gidwani, 2021).
5. Consistency Check**:** To simplify the analysis, the consistency ratio (CR) was computed to determine the reliability of the judgments. Accepting the criterion-related scale validity requires a CR below 0.1 for the present study as per the research (Nimawat & Gidwani, 2021).

The application of the AHP method and the use of Excel in calculations ensured that this research design provided a manageable and accurate method of interpreting data. The quantitative analysis helped to substructure the identification and sorting of impacts in a coherent and representative manner.

2.1.1. Criteria identification:

The criteria for this study were selected based on a literature review and consultation with experts in the field. The factors that were identified to measure key performance of smart supply chains include: These factors were chosen due to their frequency in research and centrality to e-commerce operations (R. K. Singh, 2013). This study seeks to rank different technologies according to their impact on significant aspects of supply chain management using the Analytical Hierarchy Process (AHP). The primary criteria used in this analysis are the following Industry 4.0 technologies:

A. Operational Efficiency

IoT and CPS, for instance, enhance operation performance since the system gathers information and makes real-time decisions. For example, CPS eliminates supply chain secrecy and increases receptiveness by providing podiums for timeliness. Amazon decided that IoT devices for tracking inventories and other associated chores optimize some operations, eliminate unnecessary fluff, and maintain regulatory compliance (Anozie, Obafunsho, et al., 2024) (Gong, 2023).

B. Cost Effectiveness

Industry 4.0 benefits for cost totality area reduction come from inventory management, energy consumption, and route optimization. Facilitating efficient use of resources Big Data Analytics and Cyber-Physical Systems (CPS) enhance decision-making processes concerning transportation and logistics by lowering associated costs; various programs by DHL, such as effective routing, enhance delivery time and cost (Shuo et al., 2024) (Y. Zhang, 2024).

C. Security and Reliability

Blockchain technology improves transaction confidentiality and data credibility by acting as a distributed database. Cloud computing also adds to data reliability and scalability in supporting the secure management of the supply chain's data. For example, Walmart applies blockchain to enhance the food supply chain, as well as to minimize fraudulent practices and increase customers' trust (S. V. S. Kumar et al., 2024) (Medina et al., 2024)

D. Scalability and Flexibility

Due to the evolving customer needs, the supply chain for e-commerce is expected to have high levels of scalability. CPS and cloud computing give changeable frameworks that help immediately monitor, decide, and redeploy resources. Another fascinating instance of cloud services deployment is Alibaba during events such as Singles' Day – the application of scalable, effective solutions reflects the orientation to changes in the supply chain demands (Segalin et al., 2015) (Amajuoyi et al., 2024).

E. Customer Experience

Enhancing customer satisfaction is always a significant supply chain strategy supporting e-commerce businesses. Other technologies, including Big Data and Machine Learning, will help organizations understand customer trends and respond appropriately. For their part, IOT and blockchain enable tracking and add accountability, reliability, speed, and accuracy to deliveries, making for a seamless customer experience (Amosu et al., 2024) (Shen et al., 2023).

F. Environmental Impact

Higher satisfaction levels are the basic foundation of any e-commerce business model. Customers' information profiles are created with the help of Big Data techniques and Machine Learning for the individual approach and custom pricing. The usage of IoT and blockchain provides a way for real-time tracking and increasing trustful deliveries to customers. Predictive shipping in Amazon and traffic routing of

Alexa also reveal the strength of these technologies in increasing consumer satisfaction (Anozie et al., 2024) (Espahbod et al., 2024) (A. Gupta et al., 2022).

Table 2 presents the criterion codes and their descriptions for evaluation:

Table 2: Criteria Codes

Criteria Code	Criteria
C1	Operational Efficiency
C2	Cost Effectiveness
C3	Security and Reliability
C4	Scalability and flexibility
C5	Customer Experience
C6	Environmental Impact

2.2. AHP Questionnaire Design

The AHP questionnaire for this study was designed meticulously to capture the relative importance of six critical criteria that influence the performance of e-commerce smart supply chains. These criteria—operational efficiency, cost-effectiveness, security and reliability, scalability and flexibility, customer experience, and environmental impact—represent areas where Industry 4.0 technologies can have a transformative impact. The design follows Saaty's (1990) structured AHP methodology, which enables the systematic collection of expert judgments in a measurable and interpretable manner. The questionnaire was divided into two main sections:

General Information Section: This section collected background details about the experts, including their names, countries, years of experience, and specific areas of specialization. This information ensured the participants' relevance and provided context for their responses.

Pairwise Comparison Section: Participants were asked to evaluate the relative importance of the six criteria through pairwise comparisons. Using Saaty's (1990) 1-to-9 scale, they were assigned scores where 1 indicated equal importance, and nine indicated extreme importance of one criterion over another.

To ensure that the participants were voluntary, we told the specialists participating in the study that they could leave anytime without explaining themselves to us while doing the study. The voluntary participation form was included as part of the questionnaire package. Of this form, the respondent specifically responded that his role was to advance Industry 4.0 technologies, and his answers would be used only for research purposes. Respondents were informed of the anonymity of their responses and were made to append their signatures to the form before completing the questionnaire. This step was taken to check if the study was ethical and to remind each participant that the study was voluntary.

2.3. Data Collection

For the convenience of experts, the AHP questionnaire was administered in online . Another modification was that questions were presented in the form of a questionnaire—in electronic format where the expert could download it as a PDF—or a Google Forms link was provided for the expert, which increased engagement and responses. This created versatility that let the participants choose the formats suitable for their type of work.

A link to the questionnaire was sent out through email by reconnecting with connections through LinkedIn and other equivalents. Studying the LinkedIn profiles of the participants allowed us to filter out experts familiar with Industry 4.0 technologies and smart supply chains. Moreover, personal contacts are also opened for direct communication to ensure that the study has appropriate participants internationally. Professionals from Iran, Turkey, the U.S., Australia, and Pakistan were included to increase the geographical distribution and generalisability of the study findings (Atlı, 2024).

This approach is consistent with the study's methodological approach while also aiming for academic and real-world relevance. The study successfully collected various and reliable expert opinions and integrated statistical analysis to prioritize Industry 4.0 technologies in e-commerce innovative supply chains through successful targeted survey promotion (Ayyildiz & Gumus, 2020).

2.4. Selection of Experts

The choice of the experts is a very important step in the AHP approach since the quality and relevance of the judgments produced by the experts determine the quality of the study's outcome. In this respect, six subject-matter experts were selected with the aim of their rich expertise in Industry 4.0 technologies and e-commerce smart supply chains (Bhadu et al., 2023).

The criteria followed during the selection process were rigorous so that quality data could be gathered (Bhadu et al., 2023). The diverse backgrounds and great experience of the selected panel ensure the AHP's reliability and give a better understanding of how Industry 4.0 technologies affect the performance of e-commerce smart supply chains. Therefore, the study is more generalizable given the variation used to increase its reliability, as discussed in other similar studies (Bhadu et al., 2023).

To conduct this research, the experts had more than 10 years of work experience in sectors connected to Industry 4.0 technologies like IoT, Big Data, Cloud Computing, ML, Blockchain, and Cyber-Physical Systems (CPS). This criterion was established to guarantee that the participants had substantial knowledge of the technological and operational aspects and the strategic impact of these innovations on e-commerce supply chain performance. In addition, their academic accomplishments, educational levels, and certifications were also considered (Anis, 2022).

Candidate selection also focused on the diversity of the experts' professional occupations and places of work. Experts from the academic field and practitioners were part of the panel to ensure that the research contains objectives from both sides of the fence. Theoretical perspectives, concepts, and up-to-date literature findings were sourced from academic participants. In contrast, industry participants provided the real-life applications of Industry 4.0 technologies in e-commerce smart supply chains. This combination of knowledge enriched the coverage and relevance of the identified results of the study (Bhadu et al., 2023).

Table 3 summarizes the profiles of the selected experts, highlighting their years of experience, areas of expertise, and professional roles:

Table 3: Profile of participants

	Country	Years of Experience	Area of Experties
Expert 1	Pakistan	13	IoT & CC & CPS
Expert 2	The USA	16	IoT & ML & BC & CPS
Expert 3	Iran	15	IoT & ML
Expert 4	Iran	27	CC & ML& CPS
Expert 5	Australia	20	IoT & BD & ML& BC

Expert 6	Turkey	27	IoT & BD & ML

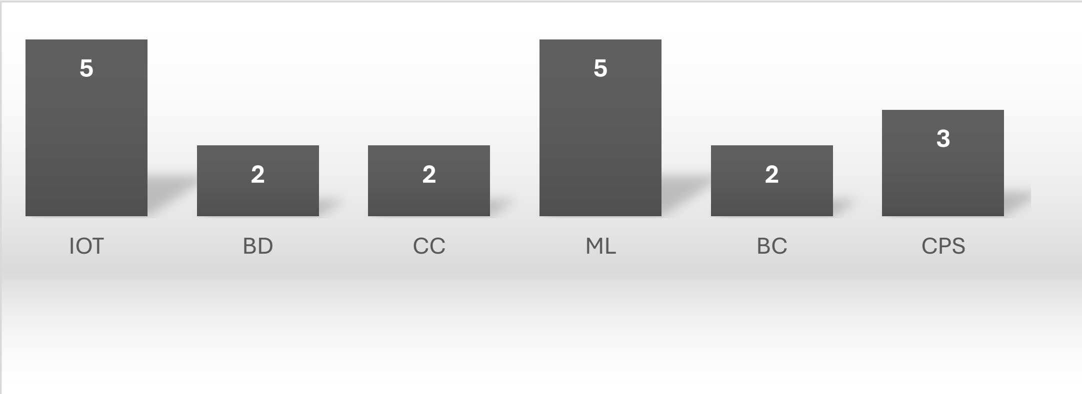

Figure 1: Area of expertise.

2.5. Analysis

The next step after data collection is to examine the data.; this involved the use of quantitative analysis of the collected data. This paradigm category aims to deliver a rigorous, organized, and systematic solution to the problem under analysis by converting all issues into measurable and solvable numerical problems, hence the importance of quantitative data (Anis et al., 2022). The AHP technique was employed in this study to formulate priorities of Industry 4.0 technologies on e-commerce initiatives in supply chains. Since this was a pairwise comparison method, Microsoft Excel was used as a forcing function to build the pairwise comparison matrices and normalize the data, priority weights, and consistency ratio (Saaty 1990).

The analysis was carried out according to the steps of the AHP methodology in order to achieve a rational approach. All steps were applied quantitatively to increase the credibility of the results (Saaty & Vargas, 1985).

Step 1: Formation of goal.

At the initial stage of AHP, a clear goal is always identified in the problem under consideration (Saaty, 1990). This study aims to determine the prioritized influence of Industry 4.0 technologies on e-commerce smart supply chains.

Step 2: Formation of the decision-making issue into a hierarchy model.

In this step, the decision problem is transformed into a hierarchical model (Saaty, 1990), which allows the complex problem to be broken down into more manageable levels. The hierarchy consists of several stages reflecting the goal, criteria, and potential sub-criteria or factors affecting the issue. For this study, a hierarchy is established with the overall goal at the top, followed by six main criteria related to Industry 4.0's impact on the smart supply chain. This structured approach ensures that all critical aspects of the decision problem are represented and analyzed systematically.

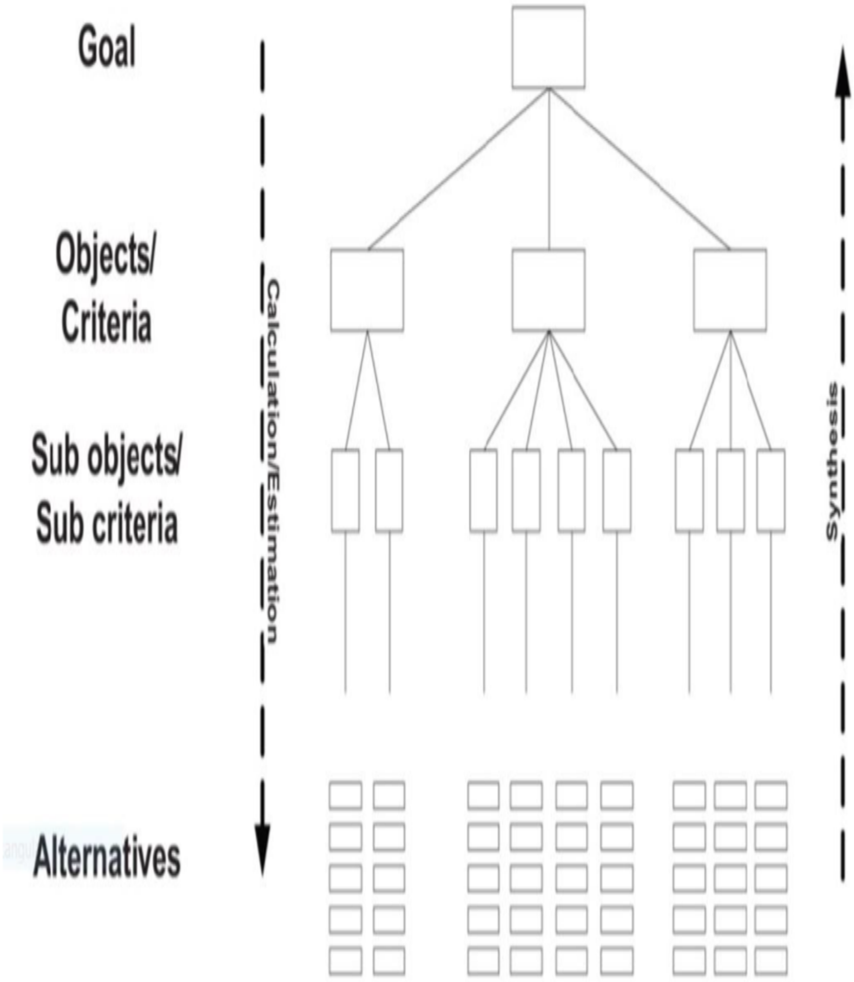

Figure 2: AHP hierarchy Source (Tsinidou et al., 2010).

Step 3: Build up the pairwise comparative matrices among criteria and factors.

The pairwise comparisons were rendered by Saaty's scale for both criteria and their factors, relying on the opinion of the experts (Saaty, 1990). The parameters of each stage were compared pairwise to decide the relative weights of all criteria and their factors. As Saaty recommended, a pairwise comparison matrix must have been established. Saaty proposed a subjective ranking scale of 1 to 9 focused on psychological evaluations in which one means similarly essential and 9 signifies tremendous importance (Saaty, 1990).

Table 4: preference scale for pairwise comparison.

Preference Level	Numeric value
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strong preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

It is important that the criteria are weighted based on proper judgment, where, in this case, the justification can either be factual or logical. The decision-makers should have enough information concerning the criteria and options to estimate the numerical weights in a matrix. If there are conflicts of opinion, then differing numerical ratings allocated to weight are averaged using the geometric mean (Equation 1). When the estimates differ substantially, each event can be computed separately, and the totality of the result with the least fluctuations is used (Saaty & Kearns, 1985).

$$\left(\prod_{i=1}^{n} x_i\right)^{\frac{1}{n}} = \sqrt[n]{x_1 x_2 \dots x_n} \quad (1)$$

A matrix is an arrangement of numbers in horizontal rows and vertical columns. The individual items in a matrix are called its elements. Matrices can be applied to solve systems of linear equations, coordinate transformations in geometry, and iteratively draw graphs. Pairwise comparison is comparing elements in pairs to determine which element is preferred. When comparing two decision makers, assign a numerical value from a relative importance scale to any pair representing the element. The matrix form is preferred for pairwise comparisons because it provides a simple and established framework for testing. Adaptation, information acquisition through comparison, and sentiment analysis of the importance of general judgments (Saaty & Kearns, 1985).

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When two sets of criteria or options are compared, one is placed in the horizontal row section and the other in the vertical column section of the matrix to form a square matrix. This square matrix has an equal number of rows, columns, and other valuable features, such as eigenvectors and eigenvalues. These later indicate the importance of factors that the problem solver should focus on.

Matrices have a reciprocal property (equation 2); if activity i has assigned one of the previous numbers compared to activity j, then j has a reciprocal—value when compared to ı (Saaty & Kearns, 1985).

$$a_{ij} = \frac{1}{a_{ij}} \neq 0 \tag{2}$$

Hence, giving the matrix form:

$$\begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \tag{3}$$

The main diagonal line will always be one because criterion n is always of equal importance relative to criterion n, thus giving a numerical rank of 1.

It is also worth noting that the matrix has n (Equation 4) number of weight judgments, where n is the number of criteria in each matrix because reciprocal values are assigned automatically (Saaty & Kearns, 1985).

$$Number\ of\ comparisons = \frac{n(n-1)}{2} \quad (4)$$

In the second level of the hierarchy, criteria are compared pairwise by assessing their relative importance. Each comparison involves evaluating the criterion in the column on the left against the criterion in the row on top. This process is repeated for all elements in the matrix, where the relationship between weights (w_i) and judgments (a_ij) is expressed as (Saaty & Kearns, 1985):

$$a_{ij} = w_i/w_j \quad (5)$$

And :
$$\begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \quad (6)$$

The second level Excel table presents the pairwise comparisons of the criteria.

Table 5: The comparison of weights in the second level of hierarchy (Saaty & Kearns, 1985).

Objective	Criteria 1	Criteria 2	Criteria 3	…	Criteria n
Criteria 1	-	-	-		-
Criteria 2	-	-	-		-
Criteria 3	-	-	-		-
…					
Criteria n	-	-	-		-
Total **Σ**					

After pairwise comparison exercises at the second criterion level, the following process would occur: a similar exercise at the third level of the alternative. However, this study identifies the aspiration level and assigns importance weights only for the criteria without considering alternatives. The second-level comparisons are recorded in a pairwise comparison matrix, and the sum of the columns for each matrix is calculated using the formula (Equation7):

$$\Sigma_{i=1}^{n} = a_{ij} \tag{7}$$

Thomas L. Saaty has presented four techniques to find the eigenvectors and their priority vectors. These are approximation techniques that offer solutions. The most effective and most precise is the use of computerized AHP software.

Row Sum Method: Sum all the quantities in each row and then sum up the totals of each row sum. Some areas are normalized by dividing each row sum by the total sum, deriving the priority vector.

Reciprocal Method: Are the row and column normal? That is, calculate the sum of each column and take the reciprocal of these sums for normalization across the row.

Column Normalization Method: For each element in a column, take its value and divide it by the overall sum of the respective column. Finally, sum up these values of the corresponding row and divide by the number of values existing in that row to get the priority vector.

Geometric Mean Method: Multiply all the elements in a row and take the nn-th root (where n is the number of elements in the row) to calculate the eigenvector. Normalize these eigenvectors by dividing each by the total sum of all eigenvectors to derive the priority vector.

All of them give slightly different results, the accuracy of which gradually increases with the complexity of the method, with the highest geometric mean (method 4). For additional computations, method four will be employed, as stated above. This method calculates the eigenvectors by multiplying all the elements in a row and taking the n^{th} root, representing the total number of elements in the row (Saaty & Kearns, 1985).

$$Row\ n \rightarrow \sqrt[n]{\frac{w_n}{w_1} * \frac{w_n}{w_2} * \frac{w_n}{w_3} * \cdots \frac{w_n}{w_n}} = Eigenvector\ a, b, c, \cdots, n \tag{8}$$

The weights in each row are, in turn, multiplied to get the n^{th}root for the eigenvector for that row. After performing the eigenvectors calculations of *a, b, c,* $\dots n$ for all the rows in the matrix, an aggregation of all such resultant eigenvectors gives the total eigenvector sum as shown below in Equation 6 (Saaty & Kearns, 1985).

$$a + b + c + \cdots n = Total \tag{9}$$

The priority vector $x_1, x_2, x_3, \dots, x_n$ (Equation 10) is determined by normalizing the eigenvector obtained for each respective row (Saaty & Kearns, 1985).

$$\frac{n}{Total} = Vector\ of\ priority\ x \tag{10}$$

However, these values do not sum up to one; the eigenvector is normalized to obtain the priority vector. By ranking these results, it is possible to determine the order of importance of the criteria in question. The weights of the eigenvectors contain a tangible value in AHP because they provide a picture of each of the criteria's contributions toward the objective. For instance, an eigenvector value of 0.05 means the contribution is four times smaller than the eigenvector value of 0.2 (Saaty & Kearns, 1985).

At this stage, numbers $x_1, x_2, x_3, \dots, x_n$ are equal to $w_1, w_2, w_3, \dots, w_n$ correspondingly. These eigenvectors approximate the values, not the exact ones, which makes the calculations easier. However, at this point, the particular matrix information is often inaccurate, and a consistency check must be run to raise the credibility level (Saaty & Kearns, 1985).

Step 4**:** Determine the consistency ratio.

The first step in the pairwise comparison involves evaluating whether the decision-makers weight estimations are consistent. The above consistency assessment uses the maximum eigenvalue(λ_{max}) (Saaty & Kearns, 1985). which is calculated from the adjusted matrix (A′') using the formula:

$$A'w' = \lambda_{max}\, w'A' = (a_{ij}) \tag{11}$$

The calculated λ_{max} is then used to determine what is known as the Consistency Index or CI 'where n is the number of elements in the matrix.'' The CI shows how much each of the judgments departs from the others. The RI fixed scale is a function of the size of the matrix. Indeed, the given value characterizes an average random index for matrices of a given size, obtained based on a sample of 100 random matrices. When we reach the matrix size, the RI value also increases from the matrix size (Saaty & Kearns, 1985).

$$CI = \frac{(\lambda_{max} - n)}{n-1} \quad (12)$$

The final step of evaluating consistency is determining the consistency ratio from the division of the consistency index by the random index. This ratio simply measures how much of the transitivity rule has been violated across the documents. If the identified preferred choices are perfectly aligned, the deviation is expected to be equal to zero. However, as the consistency ratio increases, the possibility of increased inconsistency in the evaluations increases (Saaty & Kearns, 1985).
The consistency ratio is computed using the formula:

$$CR = \frac{CI}{RI} < 0{,}1 \sim 10\% \quad (13)$$

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Figure 3: RI values for n items being compared.

The CR measures the degree to which the transitivity rule has been breached. When there is an ideal consistency of the preferences, the CR is equal to 0.1. When inconsistency is low, the CR rises. In general, the consistency of a matrix is, by and large, determined by checking the CR, and by trend, the CR should be less than 10%. (Saaty & Kearns, 1985).
Step 5**:** Evaluate local and global weight (Saaty, 1990).

After creating pairwise comparisons, the comparative matrices of the decision are received by the opinion of the experts, and the consistency ratio is checked. Under this section, factors of a specific level are contrasted in the immediate upper level concerning a similar criterion. The resulting weights from the elements can usually be known as local weights (Saaty, 1990) (Nimawat & Gidwani, 2021). This last step of AHP assists in forming a logical and sequential hierarchy to rank Industry 4.0 technologies according to their impacts on the chosen criteria, favoring strategic decision-making.

2.6. For Validating Expert Judgments in AHP

To achieve the objective of increasing the reliability of the expert's judgment in the scenario considered as the AHP process and also considering the flexibility of the collective judgments and the possible discrepancies that may exist among the experts, the linear mixed model (LMM) approach is used. The aggregate approach suggested by Lin and Lu (2012) offers a clear structure for solving problems related to individual differences and random errors in pairwise comparison matrices. Thus, a judgment process must be valid because decisions based on data may contain inaccurate or inconsistent information, thus resulting in biased or wrong conclusions (S. Lin & Lu, 2012).

1. Construct Pairwise Comparison Matrices:

Each expert provides pairwise comparisons between criteria or alternatives. These comparisons are compiled into square matrices A_k for $k = 1, \cdots, r, where\ r$ is the number of experts. Each element, aijaij, represents the ratio of the relative importance of criterion i to j (S. Lin & Lu, 2012).

$$A_k = \begin{bmatrix} 1 & \cdots & a_{1nk} \\ \vdots & \ddots & \vdots \\ 1/a_{ink} & \cdots & 1 \end{bmatrix}$$

2. Transform Pairwise Comparisons Using Logarithms:

To analyze the data statistically, pairwise comparisons are transformed into a log-linear form (S. Lin & Lu, 2012).

$$y_{ijk} = \log(a_{ijk}) = u_i - u_j - \epsilon_{ijk}$$

y_{ijk}: Log-transformed relative importance of criterion i over j for expert k,

u_i, u_i: Logarithmic weights of criteria i and j,

ϵ_{ijk}: Random error term.

3. Fit the Linear Mixed Model:

Using statistical software, fit the linear mixed model (LMM) to estimate variance components (S. Lin & Lu, 2012):

σ^2_{expert}: This captures variability arising from differences in perspectives or knowledge among experts. It is calculated as the variance of the random effects associated with the experts. A high σ^2_{expert} suggests significant disagreement among experts, which may require further investigation or consensus-building (S. Lin & Lu, 2012.

$\sigma^2_{residual}$: This represents inconsistencies within an individual expert's judgments, including rounding errors in the pairwise comparison scale. A high $\sigma^2_{residual}$ indicates the need for training or recalibration of the judgment processVariance due to rounding errors and intra-expert inconsistencies(S. Lin & Lu, 2012).

The total variance (σ^2_{total})is the sum of these components:

$$\sigma^2_{total} = \sigma^2_{expert} + \sigma^2_{residual}$$

Using this decomposition, we assessed whether the primary source of uncertainty was due to inter-expert disagreements or intra-expert inconsistencies.

4. Interpret Results and Validate Judgments (S. Lin & Lu, 2012):

   If σ^2_{expert} is high, investigate whether experts fully understand the criteria or whether sub-groups exist in the panel

   If $\sigma^2_{residual}$ is significant, train experts in pairwise comparison tasks to minimize inconsistencies.

5. onsistency Ratio (CR) Validation

CR was previously calculated to ensure judgments were consistent, with a threshold of $CR < 0{,}1$ indicating acceptable consistency (Saaty & Kearns, 1985). This ensures the reliability of the pairwise comparison matrices**.**

2.7. Calculation of Multi-Criteria Decision-Making, using Analytical Hierarchy Process

The criteria were then compared relative to the intensity of importance between the two elements, ranging from 1 to 9. Professionals were informed how to make these decisions and expected to produce this information using their professionalism. The aim was to identify which factors are most important in determining how Industry 4.0 solutions should be prioritized for e-commerce supply chains. The geometric matrix obtained from these comparisons, shown in table 6, represent the aggregate opinion of the experts and forms the basis of the criteria ranking.

Table 6: Pairwise comparison matrix.

Criteria	C1	C2	C3	C4	C5	C6
C1	1,0000	3,9642	2,9307	3,5027	5,0060	6,2073
C2	0,2523	1,0000	2,5001	2,8857	4,8444	4,4914
C3	0,3412	0,4000	1,0000	1,7728	2,9781	4,2260
C4	0,2855	0,3465	0,5641	1,0000	3,8142	4,0862
C5	0,1998	0,2064	0,3358	0,2622	1,0000	4,7752
C6	0,1611	0,2226	0,2366	0,2447	0,2094	1,0000
TOTAL	2,2398	6,1397	7,5673	9,6680	17,8521	24,7861

This step involved dividing each matrix element by the sum of its respective columns, yielding a normalized table that represents the relative weights of the criteria on a standardized scale, as shown in table 7.

Table 7: Normalized Data.

Criteria	C1	C2	C3	C4	C5	C6
C1	0,4465	0,6457	0,3873	0,3623	0,2804	0,2504
C2	0,1126	0,1629	0,3304	0,2985	0,2714	0,1812
C3	0,1523	0,0651	0,1321	0,1834	0,1668	0,1705
C4	0,1275	0,0564	0,0745	0,1034	0,2137	0,1649
C5	0,0892	0,0336	0,0444	0,0271	0,0560	0,1927
C6	0,0719	0,0363	0,0313	0,0253	0,0117	0,0403

TOTAL	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

The normalized table shows the importance of each criterion on the scale where all the criteria are standardized. The priority weights of the criteria, as presented in table 8, were determined by averaging the normalized values across each row. These weights are used to estimate the priority of factors that define the importance of Industry 4.0 solutions for e-commerce supply chains. Visual representation of priority is provided in figure 4, offering intutive understanding of their relative significance.

Table 8: Priority Weight Table

Criteria	Priority Weight
C1	0,3954
C2	0,2262
C3	0,1451
C4	0,1234
C5	0,0738
C6	0,0361
TOTAL	1,0000

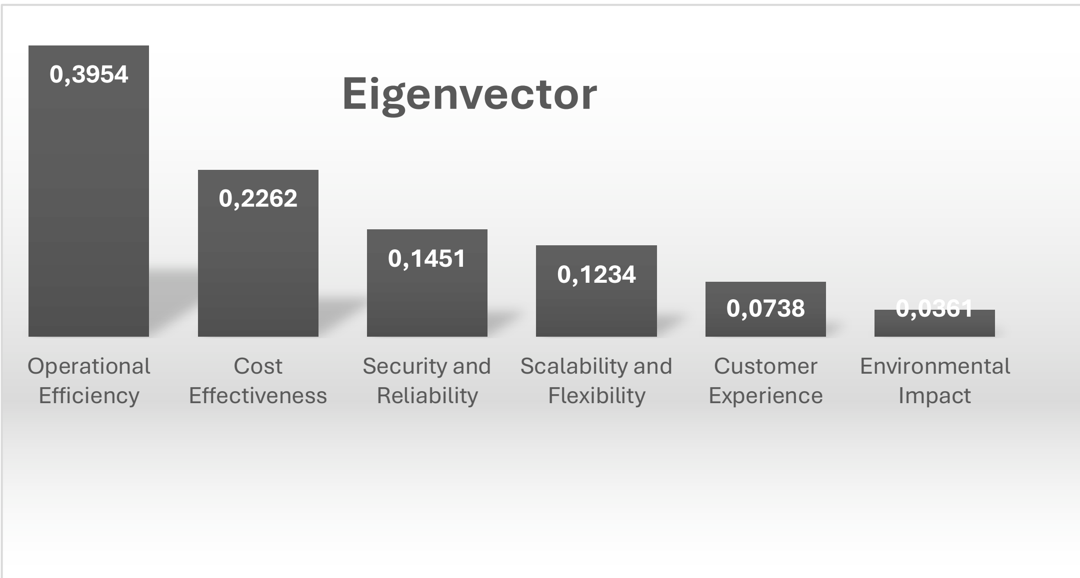

Figure 4: Priority Weights of Criteria.

The priority weights of the criteria were obtained from the values of the pairwise comparison matrix, and the Weighted Sum Vector for each criterion was obtained by summing the products of the pairwise comparison matrix and the priority weights. This step also makes the judgments consistent and arrives at the principal eigenvalue (λ_max), which helps arrive at the CI. The results provide information on the extent to which the criteria relate to the overall priorities of the weights.

C1. Operational Efficiency

1·0.3954+3.9642·0.2262+2.9307·0.1451+3.5027·0.1234+5.0060·0.0738+6.2073·0.0361=2.7432

C2. Cost Effectiveness

0.2523·0.3954+1·0.2262+2.5001·0.1451+2.8857·0.1234+4.8444·0.0738+4.4914·0.0361=1.5646

C3. Security and Reliability

0.3412·0.3954+0.4000·0.2262+1·0.1451+1.7728·0.1234+2.9781·0.0738+4.2260·0.0361=0.9618

C4. Scalability and Flexibility

0.2855·0.3954+0.3465·0.2262+0.5641·0.1451+1·0.1234+3.8142·0.0738+4.0862·0.0361=0.8258

C5. Customer Experience

0.1998·0.3954+0.2064·0.2262+0.3358·0.1451+0.2622·0.1234+1·0.0738+4.7752·0.0361=0.4531

C6. Environmental Impact

0.1611·0.3954+0.2226·0.2262+0.2366·0.1451+0.2447·0.1234+0.2094·0.0738+1·0.0361=0.2302

To find λ_{max}, you divide the Weighted Sum Vector of each criterion by its corresponding Priority Weight and then calculate the average of these values. The results are presented in table 9, which illustrates the λ_{max} values for each criterion and their average average.

Table 9: λ_max Table

Criteria	λ_{max}
Operational Efficiency	6,9373
Cost Effectiveness	6,9184
Security and Reliability	6,6306
Scalability and Flexibility	6,6918
Customer Experience	6,1378
Environmental Impact	6,3689
Average	**6,6141**

The Consistency Index (CI) is used to measure the degree of consistency in the judgments made during the pairwise comparison process. From the previous calculation:

- λ_{max}= 6,6141
- $n = 6$ (the number of criteria).

Substitute these values into the formula:

$$CI = \frac{6{,}6141 - 6}{6 - 1} = 0{,}1228$$

The Consistency Ratio (CR) is calculated to assess the acceptability of inconsistency in the pairwise comparisons. Using the formula :

Where:

- $CI = 0{,}1228$
- $RI = 1.24$ (Random Index for $n = 6$).

Substitute the values:

$$CR = \frac{0{,}1228}{1.24} = 0{,}0991 < 0{,}1$$

The Consistency Ratio (CR) determines the extent of transitivity in pairwise comparisons. It is preferred that the CR should be less than 0.1 (Saaty & Kearns, 1985

CHAPTER 3: FINDINGS

3.1. Findings

Consequently, the present study evaluated the results based on the observations. Usually, it is necessary to consider the results in terms of objectivity, which is relevant to the data type and research methods. Implementing AHP analysis allows for displaying the quantitative ranking of the criteria and options explored in this work.

The relative importance of each factor affecting e-commerce smart supply chains was determined by assigning weights to each criterion through pairwise comparisons. It was found that Operational Efficiency with a priority weight of 39,54% is the most significant criterion. In contrast, Environmental Impact, with a priority weight of 3,61%, was moved to the last position as it presented the least level of importance. Such patterns of the importance of the evaluated criteria are valuable to practicing managers seeking to advance the capabilities and orientations of e-commerce smart supply chains, keeping Industry 4.0 technologies in mind across various aspects of smart supply chain development.

Table 10: AHP criteria, ranking and priority weights.

Criteria	**Priority Weight**	**Priority Weight(%)**	Rank
Operational Efficiency	0,3954	39,54	1
Cost Effectiveness	0,2262	22,62	2
Security and Reliability	0,1451	14,51	3
Scalability and Flexibility	0,1234	12,34	4
Customer Experience	0,0738	7,38	5
Environmental Impact	0,0361	3,61	6

C1:Operational Efficiency (39.54%)

Operational Efficiency emerged as the most critical criterion, accounting for 39.54% of the total weight. Consistent with the literature, technologies such as IoT and Cyber-Physical Systems (CPS) play a pivotal role in enhancing operational performance by enabling real-time decision-making, inventory tracking, and predictive maintenance (Anozie et al., 2024) (Gong, 2023). These advancements improve supply chain transparency, reduce response times, and support process optimization. For instance, Amazon leverages IoT devices like GPS trackers and sensors to monitor supply chain stages and make proactive decisions, ensuring regulatory compliance and operational excellence (Udeh et al., 2024). It affirms the extant research that stresses the application of Industry 4.0 solutions to enhance productivity, robustness, and competitiveness.

C2: Cost Effectiveness (22.62%)

Cost Effectiveness ranked second, with a weight of 22.62%, underscoring its importance in e-commerce supply chains. Big Data and Cyber-Physical Systems (CPS) play pivotal roles in reducing costs related to inventory management, logistics, and energy consumption. Big Data optimizes delivery routes and resource allocation using advanced algorithms, cutting transportation times and operational costs (Y. Zhang, 2024). CPS enhances cost efficiency by streamlining operations and increasing supply chain transparency, allowing businesses to adapt quickly to market changes (Gong, 2023).

Examples from industry leaders, such as DHL, highlight the practical applications of these technologies. By leveraging Big Data platforms, DHL optimizes routing, improves resource use, and implements cost-control measures (Shuo et al., 2024). Similarly, IoT-enabled CPS supports real-time monitoring and predictive maintenance, reducing waste and operational inefficiencies (Anozie et al., 2024). These findings and the reviewed studies point to cost reduction as a significant incentive for smart supply chain solutions.

C3: Security and Reliability (14.51%)

Security and Reliability were ranked third, with a weight of 14.51%. Blockchain technology significantly enhances transaction confidentiality, data credibility, and trust within e-commerce supply chains. Its distributed, transparent, and secure nature allows businesses to ensure traceability and prevent fraud, as evidenced by Walmart's blockchain-based food supply chain, which enhances customer trust and minimizes fraudulent practices (S. V. S. Kumar et al., 2024).

Integrating blockchain with cloud computing further strengthens data security, transparency, and collaboration by addressing challenges such as data authenticity and compatibility (Nwariaku et al., 2024). This technology supports supply chain optimization through real-time tracking, smart contracts, and digital identities, facilitating informed decision-making and enhancing operational efficiency (Oriekhoe et al., 2024). Another interesting aspect of these outcomes is that they are consistent with concerns expressed in the literature about using Industry 4.0 technologies to enhance supply chain security, reliability, and performance.

C4: Scalability and Flexibility (12.34%)

Ranked fourth, Scalability and Flexibility received a weight of 12.34%. The literature highlights the need for adaptable supply chain frameworks to meet evolving customer demands (Amajuoyi et al., 2024). CPS and cloud computing provide scalable solutions that enable resource redeployment and monitoring during high-demand periods, such as Alibaba's operations during Singles' Day (S. Chen et al., 2024). AS these findings show the significance of scalability for current supply chain networks, as discussed in the literature.

C5: Customer Experience (7.38%)

Customer Experience was ranked fifth, with a weight of 7.38%. As noted in the literature, technologies like Big Data and blockchain enhance customer satisfaction by improving tracking, accountability, and delivery accuracy (Amosu et al., 2024) . Although customer experience remains a core focus for e-commerce businesses, innovations such as Amazon's use of deep learning and graph convolutional networks further demonstrate how Industry 4.0 technologies indirectly support this factor (Shen et al., 2023). These technologies also support other strategic interests by improving customer intent identification and the prediction in generalized probability calculations.

C6: Environmental Impact (3.61%)

Environmental Impact ranked last, with a weight of 3.61%, reflecting a current focus on other strategic goals despite its importance for sustainability (A. Gupta et al., 2022). Big Data and blockchain technologies improve supply chain efficiency by reducing waste, emissions, and energy use through predictive maintenance, real-time transport planning, and enhanced transparency (Anozie et al., 2024) (Zrigui et al., 2023). Cloud computing complements these efforts by optimizing resource utilization, promoting green energy, and supporting sustainable delivery systems (Andrei et al., 2024). Such advancements highlight industry 4.0 technologies that contribute to achieving environmental goals solely through mediation.

What emerged was the resultant relationship between these criteria, which contributes toward the development of an e-commerce smart supply chain. Again, Volume/Transactional and Functional Importance prioritize the traits where Operational Efficiency and Cost Effectiveness fully unleash their potential, stressing the need for real-time data. Next comes security, scalability, and customer experience, which show how they interact with strategic business goals regarding balancing and realization. Even though environmental impact has a relatively low level of importance, it is still significant in achieving sustainability objectives.

This match between the findings and the literature shows that Industry 4.0 technologies play a significant role in the evolution of the e-commerce supply chain. These insights will benefit practicing managers as they identify which investments and initiatives to promote that will advance their supply chain systematically.

CONCLUSION

Conclusion

This research employed the Analytical Hierarchy Process (AHP) to evaluate and prioritize the impacts of Industry 4.0 technologies on e-commerce smart supply chains. The results revealed that operational efficiency and cost-effectiveness, with priority weights of 39.54% and 22.62%, respectively, are the most critical factors influencing supply chain performance. Therefore, These findings demonstrate the importance of these criteria in enhancing decision-making and resource optimization, which are indispensable for achieving competitiveness and sustainability in the rapidly evolving e-commerce sector. Operational efficiency enables firms to adapt swiftly to changing customer demands, while cost-effectiveness ensures resource utilization remains efficient, reducing expenses and bolstering profitability. This affirms the current research that has observed these factors as fundamental drivers of performance, flexibility, and resilience in supply chain management.

In contrast, environmental impact ranked lowest, with a weight of 3.61%, reflecting the current prioritization of operational and financial objectives over sustainability in e-commerce supply chains. Nonetheless, as the push towards sustainability increases internationally because of legal regulations and consumers' awareness, environmental factors should find more importance. Advanced technologies like IoT for energy optimization and blockchain for carbon tracking offer solutions that balance short-term operational needs with long-term sustainability goals, positioning firms to address future challenges effectively.

Integrating Industry 4.0 technologies—IoT, Big Data, Cloud Computing, Blockchain, Machine Learning, and Cyber-Physical Systems—has profoundly transformed e-commerce supply chains. IoT facilitates real-time tracking and inventory management, Big Data enhances demand forecasting and resource allocation, and Cloud Computing supports seamless integration and scalability. Blockchain ensures secure and transparent transactions, while Machine Learning improves predictive analytics and decision-making. Cyber-physical systems unify the physical and digital realms, creating agile and adaptive supply chain networks. By leveraging these technologies, businesses can address key scalability, efficiency, and transparency challenges, ensuring their supply chains remain competitive in dynamic market conditions.

This study systematically assesses the benefits and challenges associated with Industry 4.0 technologies, offering valuable insights for e-commerce firms to optimize their supply chain strategies. By prioritizing these advancements, organizations can strengthen their operational capabilities and prepare for a sustainable future in a technology-driven marketplace.

Implications

The implication of the findings of this research is significant to both the academic and industrial community. In the case of e-commerce businesses, focusing on efficiency and cost can help to direct the technology acquisition and organizational processes, thus helping to thrive in a dynamically changing environment. The Internet of Things and Machine learning technologies of Industry 4.0 enable the firm to enhance decision-making and optimize resource consumption efficiently. Moreover, the study reveals that IoT and Machine Learning should be used to improve decision-making and resource optimization in the context of Industry 4.0.

The study also shows the importance of managing the environment in supply chain management. Although assigned a lower level of importance in this research, sustainability is becoming more important in long-term planning. Applying advanced technologies like Blockchain and Big Data can improve transparency and reduce waste, bring operations in line with international sustainability standards, and gain the trust of environmentally friendly consumers.

To scholars, this research adds to the existing literature on Industry 4.0 and smart supply chains, especially in the e-commerce environment. The methodological approach employed in this study—AHP for decision-making—can be used as a reference for other studies that plan to evaluate the complex effects of emerging technologies. This research provides the basis for further studies of how Industry 4.0 technologies are related and how their combined effect on various supply chain objectives, such as efficiency, scalability, and sustainability, can be examined. By systematically comparing and sorting these impacts, the study provides a clear hierarchy that can be expanded to investigate other factors, including cultural, economic, and regional differences in technology use. For instance, it has been established that cultural beliefs about the use of technology can significantly affect implementation outcomes, especially in areas where traditional business culture dominates. Furthermore, economic variables like infrastructure and investment capability can define the rate and level of Industry 4.0. The availability of skilled labor and technology resources within the region also influences the possibility of implementing advanced supply chain technologies. By including these dimensions, future work can offer a richer view of the context in which technology adoption occurs. Subsequent research can expand on this framework to offer more refined approaches toward enhancing the global supply chain and innovation in an e-commerce environment.

Limitations and Future Research

However, this study has its limitations. The small number of experts involved in the study may limit how much the results can be generalized. Despite the presence of participants from different countries, it is possible to increase the number of experts in future studies and involve more participants from different industries and countries. Further, the study mainly aims to categorize the Industry 4.0 technologies based on their impact; understanding the practical implementation and integration of these technologies and their relationship in different e-commerce environments would be more valuable.

Future studies should also look at applying sustainability measures and the impact of Industry 4.0 technologies on the supply chain over the long term. Case studies and longitudinal studies are recommended further to understand these technologies' impact on sustainability over time. Furthermore, there is a potential to apply numerical modeling, for instance, system dynamics or life-cycle analysis, to study the interrelations between environmental, economic, and operational performance. It may also advance the knowledge of these long-term effects and provide solutions for global supply chain improvements by investigating collaborative structures that integrate the opinions of professionals with data simulation. Studying the complex interconnections between productivity, costs, and environmental performance may reveal best practices to achieve business success and sustainability in e-commerce environments.

In conclusion, this research forms the first stage in systematically categorizing the effects of Industry 4.0 technologies on e-commerce smart supply chains. It offers decision-makers much-needed information and creates a foundation for further research on improving the supply chain in a rapidly growing digital world and becoming more connected

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APPENDIX 1: QUESTIONNAIRE

Prioritizing Industry 4.0's Influence on E-commerce's Smart Supply Chain

Dear Expert,

Thank you for participating in this survey. For the statement below, please compare the relative SEVERITY with respect to: This study aims to prioritize the influence of industry 4.0 technologies on e-commerce smart supply chains using the Analytic Hierarchy Process (AHP). Your expertise and insights will help us better understand the impact of industry 4.0 technologies on e-commerce smart supply chains. How to complete the survey:

Paired Comparisons: You are asked to compare two benchmarks or two technologies at the same time. Comparisons help us understand which factor or technology is more important. You will use a scale from 1 to 9:

- 1= The two are equally important
- 3= One is moderately more important than the other
- 5= one is strongly more important than the other
- 7= One is very strongly more important than the other
- 9= One is extremely more important than the other
- Intensities of 2, 4, 6, and 8 Can be used to express intermediate values.

Section 1: General Information

1. Name.:

2. Country:

3. Years of experience:

4. Area of expertise (select all apply):

Internet of Things

Big Data

Cloud Computing

Machine Learning

Blockchain

Cyber-Physical System

Section 2:Pairwise Comparison

List of criteria:

A. Operational Efficiency: criteria related to improving the overall efficiency of supply chain operations.

B. Cost Effectiveness: criteria for reducing operational costs and achieving long-term cost savings.

C. Security and Reliability: criteria for ensuring data security and delivering consistent and reliable supply chain operations.

D. Scalability and Flexibility: criteria related to the technologies, ability to scale up or down in response to demand, and adapt to various operational contexts and changing requirements.

E. Customer Experience: criteria that are related to improving customer satisfaction.

F. Environmental impact: criteria related to the technology's contribution to sustainability.

Operational Efficiency	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost Effectiveness
Operational Efficiency	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Security and Reliability
Operational Efficiency	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Scalability and Flexibility
Operational Efficiency	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer Experience
Operational Efficiency	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental Impact
Cost Effectiveness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Security and Reliability
Cost Effectiveness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scalability and Flexibility
Cost Effectiveness	9	8	7	6	6	4	3	2	1	2	3	4	5	6	7	8	9	Customer Experience
Cost Effectiveness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental impact
Security and Reliability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Scalability and Flexibility
Security and Reliability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer Experience
Security and Reliability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental impact
Scalability and Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Customer Experience

Thank you for completing this questionnaire .

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

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Degree	Major	University	Year
Undergraduate Degree	Economic Sciences – Business	Azad University (South Tehran Branch)	2015-2020
Master Degree	Master of Business Administration	Atilim University	2022-2025

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Workplace	Position	Year
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Raya Tejarat Day Company	Office Manager	2018-2019
Gaomat Information Company	Office Manager	2016-2018

Foreign Languages: Persian, English, Turkish

Publications:

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