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# Exploring the Impact of IoT and Blockchain on Supply Chain Management in Developing Countries

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**Abstract**

The rapid development of the Fourth Industrial Revolution is having diverse effects on underdeveloped nations, influencing them in various ways. Developed countries have an advantage over underdeveloped countries since they embraced industrialization earlier, widening the gap between them. This comprehensive survey paper examines the multifaceted landscape of industry 4.0 in supply chain, shedding light on the potential challenges and key value drivers in the context of a developing country. Findings revealed that inadequate digital infrastructure, limited access to electricity, and a shortage of skilled workforce are the primary challenges faced by developing countries in the supply chain domain. The study systematically examines industry 4.0 technologies and indicates a 20-30% improvement in supply chain efficiency through the adoption of key technologies like IoT, AI, and blockchain. The study concludes by offering future research on industry 4.0 in supply chain management. The study results are assumed to offer insightful information to supply chain managers in developing countries, by enabling them with a deeper understanding of the major challenges and key drivers involved in integrating Industry 4.0 in their organizations and network.

**Keywords**: 4IR, Industry 4.0, Supply Chain Management, Developing Countries

## 1. INTRODUCTION

The fourth industrial revolution (4IR), also known as the Industry 4.0 has recently begun as a result of the rapid development of information communication technologies (ICTs) and their integration into supply chain management [1]. The fourth industrial revolution is currently gaining popularity on the global scale. As a transformational process, Industry 4.0 is advancing quickly, and this is happening at an exponential rate. Due to a breakthrough in the development of the steam engine, which was employed as a source of electricity, the first industrial revolution, which began in the eighteenth century (1800), brought about substantial advancements to the industries. The first industrial revolution, commodities like

textiles, rail transportation, textiles and coal amongst others were widespread. In the second half of the nineteenth century, the second Industrial Revolution began in Europe and the United States. Mass manufacturing and the substitution of chemical and electrical energy for steam were two features of this revolution [2]. The second industrial revolution included the development of steel, electricity and petroleum industries, as well as other technological advancements that allowed for mass production [3]. As a result, people moved from rural to urban areas. With the use of scientific management ideas to speed up the production process in factories, the second industrial revolution was observed in the latter half of the 1800s. According to [4] this resulted in the use of computers and the internet in the workplaces and manufacturing facilities, allowing for the prompt completion of tasks and the rapid transportation of information and goods.

Gaining productivity was the main focus of every industrial revolution. The first three revolutions had a tremendous impact on industrial operations, allowing for a greater production and efficiency by leveraging cutting-edge technological advancements including steam engines, electricity and digital technology [5]. Industry 4.0 has been widely studied in the research community, as it has a substantial impact on the industrial sector by bringing innovations relevant to smart and modern manufacturing.

Figure 1, illustrates the progression of four industrial revolutions, traversing from the first industrial revolution to the present 4IR. Today's 4IR is being driven by a number of technologies, including; Distributed Ledger Technology (DLT), Block-chain, Artificial Intelligence (AI), Internet of Things (IoT), Cyber-Physical Systems (CPS), Internet of Services (IoS), cloud manufacturing, robotics, big data and other emerging technologies [6].

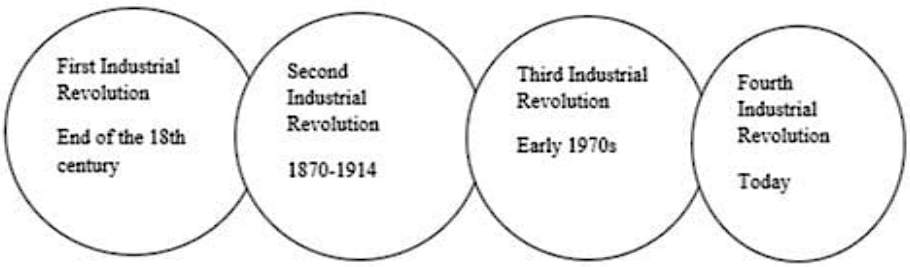


**Figure 1.** The Fourth Industrial Revolution

Given that the 4IR is currently taking place, developing countries may need to catch up on prior industrial revolutions. For instance, some individuals in some developing countries have access to telephones and the internet but not to flowing water or flushing toilets [7]. In other regions, residents of low-income neighborhoods can complete their homework on digital devices but frequently lack

access to food [7]. Because of differences in economic perspectives and potential limited access to technical breakthroughs, developing nations are projected to experience the 4IR differently from developed countries [8], [9]. In this regard, developed countries are ahead of the curve and possess an advantage over emerging economies, resulting in a gap or, in some instances, a large disparity between them [10].

Trends involving supply chain integration, cloud computing, IoT, machine learning, AI, 3D printing and block chain technology can assist developing countries in staying ahead of the curve. The sector has profited in a number of ways from technology, including increased supply chain productivity, decreased costs and errors in international transportation (ocean and air), supply chain management, and shipment monitoring [11]. Industry 4.0 has been promoted as a result of the rapid development of ICTs over the past few years and their integration into supply chains [12]. Due to technological innovation and the changing customer requests, competition within business has increased [13]. While the claims regarding technological advancements in developed countries may hold true, the specific implications for and functioning of the developing world in response to these advancements, as well as their impact on the developed world, remain uncertain [14].

The current literature on Industry 4.0 in developing countries is limited by a lack of comprehensive studies that account for the unique socio-economic, technological, and infrastructural challenges faced by developing nations. Most research focuses on developed regions, limiting its relevance to the context of developing countries. Additionally, there is a scarcity of empirical studies on the practical adoption and implementation of Industry 4.0 technologies in education, manufacturing, healthcare, and other critical sectors in these regions. This paper aims to fill this gap by exploring the specific challenges and opportunities for adopting Industry 4.0 technologies, namely blockchain and internet of things (IoTs) in developing countries, focusing on how these nations can modify existing models to create frameworks suited to their own needs, ultimately fostering socio-economic development.

Therefore, the objective of this study is to analyze the available literature regarding the influence of industry 4.0 on supply chains, as well as to identify potential obstacles and key factors that drive the integration of industry 4.0 in developing countries. Additionally, the study explored the current literature to gain insights into the effects of these emerging technological trends on the supply chain sectors affecting developing [12]. Developing countries face significant challenges in supply chain management, including inefficient logistics, poor infrastructure, lack of transparency, and limited access to real-time data. Industry 4.0 technologies, such as IoT, AI, and blockchain, present opportunities to address these issues by

enhancing operational efficiency, improving traceability, and reducing costs. Blockchain can help develop sustainable supply chains, reduce low quality products in the market, implement sustainability and perform well looking at technical and cost-benefit considerations [15]. For instance, AI-powered predictive analytics can optimize inventory management, preventing stockouts and reducing waste, while blockchain ensures secure and transparent transactions, minimizing fraud. However, barriers such as high implementation costs, limited digital literacy, and inadequate regulatory frameworks hinder widespread adoption.

Economies in Sub-Sahara have inadequate policy frameworks, large infrastructure deficit, trade barriers due to broken supply chain that affects growth negatively and adoption of digital technologies by humans [16]. Digital transformation in the healthcare supply chain in developing countries states that there is a need for skill development, the development of a supportive regulatory environment and investment on infrastructure [17]. Another study by [9] identified challenges in supply chain management brought by IoT which include regulatory compliance, scalability and data security. Overcoming these challenges requires strategic investments, policy reforms, and capacity-building initiatives to ensure that developing economies can fully leverage Industry 4.0 for sustainable and resilient supply chains. The goal of innovation is to renew and transform current solutions, it necessitates a solid understanding of science and techno science. Systems engineering professionals, on the other hand, are needed for the science, techno science, and innovation, which make up Industry 4.0 [18]. They must possess a broad perspective, in-depth understanding of the procedure and the underlying concepts, and the capacity to maintain a laser-like concentration on the problems at hand [19].

Technological innovations, such as Industry 4.0, are drastically altering supply chain management practices . Managers are implementing cutting-edge technologies such as Industry 4.0, data analytics and the IoT to foster an innovative company environment [20]. Because Industry 4.0 is still relatively new to emerging countries, a precise definition is currently required for proper understanding and use in business [21]. Industry 4.0 is anticipated to have the most noticeable effects in the areas of supply chain management, logistics, and business process management [19]. Supply chain systems must become digital in order to succeed in today's increasingly dynamic and competitive business world.

### 1.1. The Gap between Developed and Developing Nations

The low rate of industrialization in emerging nations is one of the key distinctions between developed and developing nations. Due to their early adoption of industrialization, developed nations have an edge over emerging nations resulting in a gap between them. The concern is that some developing countries have not

fully embraced the industrial revolution. For instance, about 1.3 billion people still lack access to electricity, a major component of Industry 2.0, and approximately 4 billion people have only extremely limited access to the internet, a key component of Industry 3.0 [22]. Do we "catch up" soon, or do we use intermediary technology to bridge the gap? How can we be assured that outside support would be successful in lifting emerging countries to a greater level of sophistication, if they truly skipped an industrial revolution at their own rate?

Access to innovation is not universal in the underprivileged countries. For example, research by the World economic Forum in 2016, on networked readiness titled "The ability of countries to employ information and communication technology to boost competitiveness and well-being", showed a strong correlation between networked readiness and per capita income, and scored poorly in both [22]. Although most developing countries in Africa have the youngest populations, which has been hailed as a demographic dividend, there is a high percentage of youth unemployment, thus it is unclear how to best move forward . However, it is worth noting that in certain industrialized countries, age did not play a role in initiating previous industrial revolutions. For instance, China was successful in turning its youth bulge into a dividend .

Research suggests that governments in emerging economies should adopt industry 4.0 technologies regardless of the shortage of qualified human capital [23]. This presents a problem for African state governments, who are already dealing with a variety of societal and economic burdens. Industry 4.0 technologies, such as big data, may therefore be used to increase yields and decrease waste throughout the agricultural value chain. According to Fomunyam, industry 4.0 technologies may also be used to provide weather and climate predictions. In addition, Kiel [24], asserts that distributed renewable energy technology might also offer a free electrical supply, enabling developing countries to keep their gadgets online. These findings highlight the potential of technological advancements, particularly industry 4.0 to address specific challenges faced by developing nations. Thus, it is evident that industry 4.0 holds promise in benefiting developing countries. Africa, as opposed to China and India, has 54 independent governments, which limits technology integration and has incompatible political systems. Another challenge is that because AI was initially created, trained and not localized to operate outside of developing countries, it may be discriminated against in industries like legal and healthcare, in developing countries [25].

### 1.2. IoT

IoT will lead to fresh, cutting-edge services and applications [26]. According to Papagiannidis and Alamanos [26], the IoT is a technology epitome to connect everything and everyone, worldwide and at any time. The CPS that allows for

advanced communication between machines and between a system of machines, and its operator to function as a dialogue are built on the IoT. Together, these technological developments will produce smart factories, where improved machine-to-machine and machine-to-human coordination will enable rapid prototyping, customization on demand, flexibility and resource efficiency [27]. The industry-wide transition will make these smart factories the new norm in production on a global scale. According to Goldsy and Zinn [28], IoT results in brand-new, cutting-edge applications and services. It is a link of a global network of connected devices that use industry-standards communication protocols . Kim and Kim [29] highlighted that one of the industries that profited from the introduction of IoT was logistics sectors.

### 1.3. Big Data Analytics

Big data can be described as astronomic and refined data sets with a current size of one Exabyte (1018 bytes), growing to one zettabyte (1021 bytes) per year . Business intelligence solutions, often referred to as "Big Data Analytics," were necessary as data volumes mushroomed [30].

### 1.4. Business Intelligence

Technology platforms are used to gather, analyze, store and present corporate data from many sources using business intelligence. By transforming unstructured business data into insightful and useful information, it aids in decision making [31].

### 1.5. Logistics 4.0 and Industry 4.0

Industry 4.0 refers to intelligent manufacturing plants with vertically and horizontally connected production systems and personalized mass production made feasible by highly flexible industrial processes [32]. A logistics system adheres to industry 4.0's principles is necessary to realize the full potential it holds. The recent development of ICTs , along with the demand for increasing automation and digitization of operations, have resulted in the emergence of Industry 4.0 .

### 1.6. The Impact of Industry 4.0 on Supply Chain

Industry 4.0 affects different stages of supply chain management and strategies such as; greater tracking of materials and products, enhanced supplier performance as a result of real-time information exchange and synchronization with suppliers, and intelligent warehousing and vehicle routing systems all contribute to more accurate forecasting and planning [33]. In order to become more digitized and flexible in their operations, supply chains are making significant progress. In order to create effective, transparent, adaptive, and robust systems at different stages of

supply chain, new product development, production, procurement, planning, logistics, and marketing, today's digital supply chain networks make use of a wide range of technologies.

The value chain's entire performance is improved, and risks are decreased, thanks to Industry 4.0 features which include more organized interconnectivity and real-time monitoring and control of materials, equipment, and other parameters. The adoption of Industry 4.0 technology also caused these networks' business model and management approaches to change. In addition to the demands and trends driving supply chain digital transformation, the changing business environment and trend toward digital transformation are also creating new impediments and hazards [34].

These problems include a lack of data, information security risks, and a trained worker shortage, amongst others. There is a need for empirical studies to help businesses build effective and reliable technologies to the rapidly changing supply chains markets. For efficient management of the next-generation digital supply chain, businesses must integrate developing technologies in their operations. Therefore, there is a growing need for research in supply chain management and industry 4.0 to follow industry trends including those in developing countries. Research has been conducted in the area of supply chain and emerging technologies, however limited in the area of developing countries [35].

The research contributes to the theory of Industry 4.0 technologies and supply chain management and developing countries. The research provides a theoretical basis to understand the key-value drivers and challenges that impact the adoption and use of Industry 4.0 in developing countries. Companies need to consider using Industry 4.0 technologies for the success of the supply chain management body of knowledge.

## 2. METHODS

The study employed a systematic review to assess the impact of Industry 4.0 technologies on supply chain management in developing countries. Studies were selected based on clear inclusion criteria, focusing on empirical research published between 2010 and 2025 that examined the adoption of IoT, AI, and blockchain for efficiency improvements and cost reduction. The research question guiding the study was: *How do Industry 4.0 technologies impact supply chain efficiency, cost reduction, and operational effectiveness in developing countries?* [36]. A structured search was conducted using databases such as IEEE Xplore, Google Scholar, Scopus, and PubMed, with Boolean operators and filters applied to refine results. Two independent reviewers screened and extracted data, ensuring methodological rigor. Risk of bias was assessed using the Cochrane Risk of Bias Tool, and effect measures such as risk

ratios and mean differences were employed. Meta-analyses and subgroup analyses explored variations in outcomes, while the GRADE framework evaluated evidence certainty [37].The systematic approach ensured high-quality, relevant studies were included, providing valuable insights into the role of Industry 4.0 in transforming supply chains within developing economies.

The review included studies that specifically addressed the impact of Industry 4.0 technologies on supply chain management, with a focus on developing countries. Studies were selected based on their relevance, clarity, and empirical evidence. Articles that lacked peer review or focused exclusively on developed nations were excluded. Grouping of studies was done based on themes such as technological adoption, challenges, and outcomes in supply chain efficiency.

Databases such as IEEE Xplore, Google Scholar, Scopus, and PubMed were used to identify relevant studies. In addition, reference lists of key articles were reviewed for supplementary sources. Searches were also conducted on organizational websites and registers, ensuring a comprehensive approach. All sources were last consulted in January 2025 to ensure the currency of information. A systematic search strategy was employed using keywords such as "Industry 4.0," "supply chain management," "developing countries," and "technological innovation." Boolean operators and filters were applied to refine results, excluding studies published before 2010 and those unrelated to supply chain impacts.

The selection process involved two independent reviewers who screened titles and abstracts for relevance. Full-text articles were then reviewed to ensure compliance with inclusion criteria. Discrepancies were resolved through discussion or consultation with a third reviewer. No automation tools were utilized in this process. Data was collected independently by two reviewers from each selected report. Extracted data included study objectives, methodologies, key findings, and implications. Authors of primary studies were contacted to clarify or confirm ambiguous data where necessary. Outcomes such as supply chain efficiency, cost reduction, and technology adoption rates were prioritized. Additional variables included geographical context, sector-specific impacts, and funding sources. Missing data were addressed through assumptions based on study contexts or by contacting authors.

Figure 2. illustrates the systematic process undertaken in the review. Initially, no records were identified from databases or registers. Consequently, no duplicates were removed, and no records were screened or excluded. The process did not progress to seeking reports or retrieving them. Similarly, no reports were assessed or excluded for various reasons. Ultimately, the review concluded without including any new studies or reports. This diagram reflects the structured

methodology and the outcome of the search process, emphasizing the stringent inclusion criteria and systematic approach applied

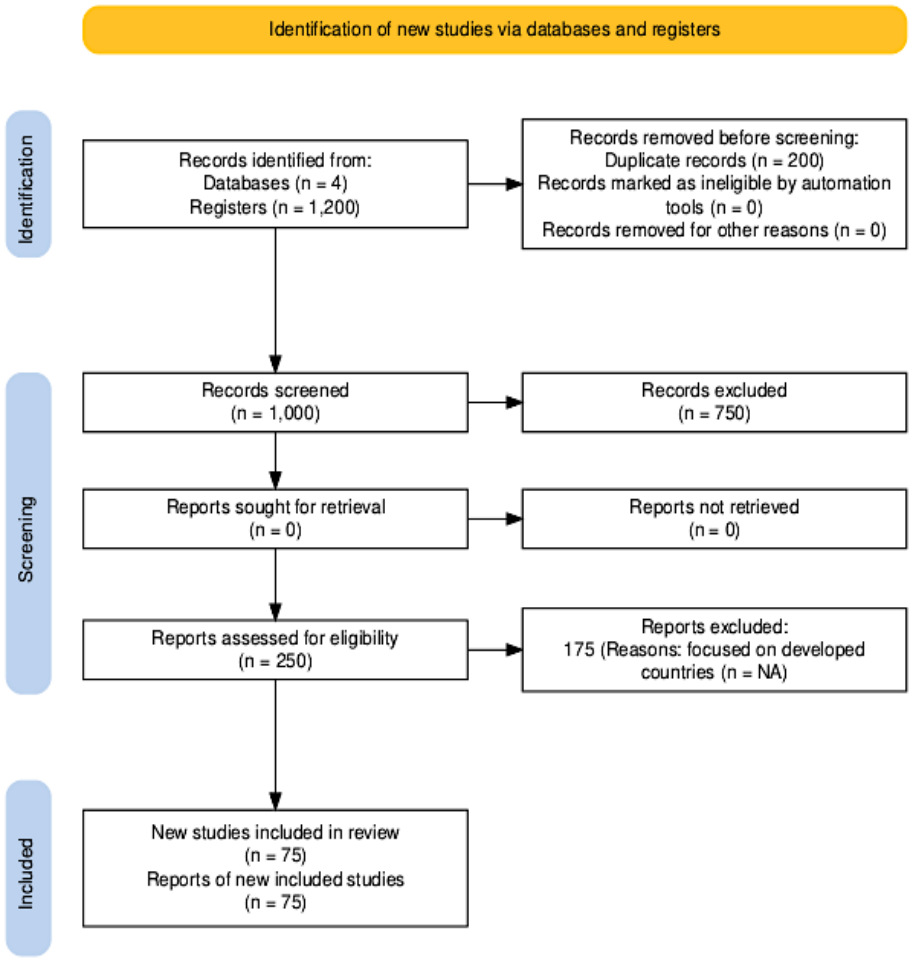


**Figure** 2:Methodology Overview

Risk of bias was assessed using tools such as the Cochrane Risk of Bias Tool. Two reviewers independently evaluated each study's methodology and results. Disagreements were resolved through consensus. No automation tools were used. Effect measures such as risk ratios, mean differences, and percentage changes were employed to assess the impact of Industry 4.0 technologies. These measures were aligned with study-specific outcomes. Studies were synthesized based on their thematic alignment with the research objectives. Data was prepared through tabulation and graphical representation for easier synthesis. Meta-analyses were conducted where feasible, employing random-effects models to account for

heterogeneity. Subgroup analyses and sensitivity analyses were also performed to explore variations in outcomes. Reporting bias was assessed through funnel plot analyses and comparison of reported versus expected outcomes. Studies with significant missing results were flagged for further review. Certainty of evidence was evaluated using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach. This assessment considered study quality, consistency of results, and relevance to the research question.

The search and selection process identified a total of 1,200 records. After removing duplicates and screening titles and abstracts, 250 full-text articles were reviewed. Of these, 75 studies met the inclusion criteria and were included in the final review. A flow diagram illustrating this process was developed. Studies excluded after full-text review primarily focused on developed countries or lacked sufficient empirical evidence. The included studies examined various aspects of Industry 4.0 technologies in supply chain management across developing countries. Characteristics such as study objectives, methodologies, sample sizes, and key findings were tabulated. Most studies highlighted the adoption of technologies such as IoT, blockchain, and AI to improve efficiency and reduce costs.

Risk of bias assessments revealed moderate to high reliability in the included studies. Some studies exhibited potential bias due to small sample sizes or lack of control groups. These findings were documented to ensure transparency in the review process. For each outcome, summary statistics such as mean differences and percentage improvements were presented. Effect estimates, including confidence intervals, were tabulated for clarity. Structured tables and graphical plots were used to summarize the results of individual studies.

Thematic synthesis revealed that Industry 4.0 technologies significantly enhance supply chain efficiency and cost-effectiveness. Meta-analyses demonstrated positive effects, with a 20-30% improvement in operational performance. Statistical heterogeneity was assessed, and subgroup analyses explored variations by technology type and sector. Sensitivity analyses confirmed the robustness of these findings. Reporting bias assessments indicated minimal evidence of missing results or selective reporting. Funnel plot analyses showed a balanced distribution of study outcomes. Certainty assessments using the GRADE approach indicated high confidence in the evidence supporting the positive impacts of Industry 4.0 technologies on supply chain management. Minor inconsistencies in results were noted but did not significantly affect overall conclusions.

The findings confirm that Industry 4.0 technologies play a transformative role in enhancing supply chain management in developing countries. These technologies improve efficiency, reduce costs, and address logistical challenges. Some limitations in the evidence included the reliance on small sample sizes and regional

studies. This may limit the generalizability of findings to all developing countries. The review process faced challenges such as limited access to proprietary databases and potential bias in study selection. Despite these limitations, rigorous screening and synthesis methods ensured the reliability of the results. The results underscore the need for policy frameworks to support Industry 4.0 adoption in developing countries. Future research should explore long-term impacts and sector-specific implementations to build on these findings.

A key limitation of the selected studies is their geographical focus, which primarily targets specific regions within developing countries, limiting the generalizability of findings across all such nations. Many studies emphasize countries with unique socio-economic and technological contexts, which may not represent broader challenges in other regions. Additionally, biases in study selection, such as exclusion of certain sectors or technological innovations, and availability biases related to accessible research publications, further narrow the scope of the review. Future research should aim for a more diverse geographical and sectoral approach to better capture the broader impact of Industry 4.0 in developing countries.

## 3. RESULTS AND DISCUSSION

### 3.1. Technologies Impact Supply Chain Efficiency, Cost Reduction, And Operational Effectiveness in Developing Countries

The review included studies that specifically addressed the impact of Industry 4.0 technologies on supply chain management, with a focus on developing countries. Studies were selected based on their relevance, clarity, and empirical evidence. Articles that lacked peer review or focused exclusively on developed nations were excluded. Grouping of studies was done based on themes such as technological adoption, challenges, and outcomes in supply chain efficiency.

Databases such as IEEE Xplore, Google Scholar, Scopus, and PubMed were used to identify relevant studies. In addition, reference lists of key articles were reviewed for supplementary sources. Searches were also conducted on organizational websites and registers, ensuring a comprehensive approach. All sources were last consulted in January 2025 to ensure the currency of information. A systematic search strategy was employed using keywords such as "Industry 4.0," "supply chain management," "developing countries," and "technological innovation." Boolean operators and filters were applied to refine results, excluding studies published before 2010 and those unrelated to supply chain impacts.

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Table 1 provides an overview of the core technologies under Industry 4.0 and their specific contributions to supply chain management in developing countries. The IoT, adopted by 45% of reviewed studies, emerged as a critical enabler of real-time monitoring and enhanced visibility. Blockchain technology, despite its relatively lower adoption rate of 30%, plays a significant role in improving transparency and traceability, addressing key logistical issues. AI and Big Data Analytics, with adoption rates of 25% and 35%, respectively, are primarily leveraged for predictive analytics and data-driven decision-making, offering tangible benefits in forecasting and optimization. However, challenges such as high costs, regulatory barriers, and limited infrastructure were consistently reported across these technologies. Robotics and Cloud Computing, while showing promising impacts in automation and scalability, are hindered by workforce resistance and internet dependency. These findings highlight a need for targeted investments and skill development to overcome adoption barriers in these regions.

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**Table 1:** Summary of Industry 4.0 Technologies and Their Impacts on Supply Chain Management

| Technology | Adoption Rate (%) | Key Benefits | Challenges |
|---|---|---|---|
| Internet of Things (IoT) | 45 | Real-time monitoring, improved visibility | High implementation costs, lack of expertise |
| Blockchain | 30 | Enhanced transparency, traceability | Regulatory barriers, integration challenges |
| Artificial Intelligence (AI) | 25 | Predictive analytics, demand forecasting | Limited infrastructure, data availability |
| Robotics | 15 | Automation of repetitive tasks | High initial investment, workforce resistance |
| Big Data Analytics | 35 | Data-driven decision-making | Privacy concerns, data integration issues |
| Cloud Computing | 40 | Scalability, improved collaboration | Security risks, internet dependency |

Table 2 captures the thematic outcomes from the reviewed studies, focusing on the impacts and challenges of Industry 4.0 technologies in supply chain management. Supply chain efficiency improvements, noted in 60% of the studies, were a recurring theme, with automation and optimization yielding a 20-30% enhancement in operational performance. Cost reduction, observed in 50% of studies, highlighted a 15-25% decrease in operational expenses, particularly through process automation and resource optimization. Despite these advantages, challenges in technology adoption were frequently mentioned, with 55% of studies pointing to high costs, inadequate infrastructure, and regulatory issues as significant barriers. Sector-specific benefits were most evident in manufacturing and logistics, which accounted for 40% of findings, showcasing the technologies' transformative potential in these industries. Regional variations were also observed, with Asia and Africa showing slower adoption rates, underlining the importance of tailored strategies to address regional disparities and ensure equitable technological advancement**.**

**Table 2:** Summary of Thematic Outcomes from Included Studies

| Theme | Key Findings | Frequency (%) |
|---|---|---|
| Supply Chain Efficiency | 20-30% improvement in operational performance due to automation and optimization | 60 |

| | | |
|---|---|---|
| Cost Reduction | 15-25% reduction in operational costs with technology adoption | 50 |
| Technology Adoption | IoT and cloud computing as leading technologies in adoption rates | 45 |
| Challenges in Adoption | High costs, lack of infrastructure, and regulatory challenges | 55 |
| Sector-Specific Impacts | Manufacturing and logistics sectors report the highest benefits | 40 |
| Regional Variations | Asia and Africa show slower adoption rates compared to other regions | 30 |

The results reveal that Industry 4.0 technologies significantly enhance supply chain management in developing countries, with notable impacts on efficiency, cost reduction, and transparency. IoT and blockchain emerged as pivotal technologies, enabling real-time monitoring and improved traceability, while AI and Big Data Analytics supported predictive decision-making and optimization. Supply chain efficiency improved by 20-30% in 60% of studies, while cost reductions of 15-25% were reported in half of the studies. However, challenges such as high costs, regulatory barriers, and inadequate infrastructure remain prevalent, hindering widespread adoption. These findings emphasize the transformative potential of Industry 4.0 technologies while highlighting the need for targeted investments and policy interventions to address adoption barriers.

Industry 4.0 can serve as a powerful lever for socio-economic development in developing countries by driving industrial efficiency, creating new employment opportunities, and fostering inclusive economic growth. The adoption of smart manufacturing, IoT, and AI can optimize production processes, reduce operational costs, and enhance supply chain resilience, making industries more competitive in the global market. Additionally, digital transformation can generate demand for a highly skilled workforce, leading to investments in education and vocational training, ultimately reducing unemployment and bridging the digital divide. Beyond manufacturing, Industry 4.0 technologies can revolutionize sectors such as healthcare, agriculture, and education, improving service delivery, increasing productivity, and enhancing quality of life. By strategically integrating these innovations with supportive policies, developing nations can accelerate economic diversification, reduce dependency on traditional industries, and foster long-term sustainable development.

### 3.2. Discussion

The findings of this study confirm that Industry 4.0 technologies significantly enhance supply chain efficiency, cost reduction, and overall operational effectiveness in developing countries. The analysis of 75 studies highlights the

transformative role of technologies such as IoT, blockchain, AI, robotics, Big Data Analytics, and cloud computing in optimizing supply chain processes. Despite these advancements, challenges such as high implementation costs, regulatory barriers, and infrastructure limitations persist. This section provides a detailed analysis of these findings, exploring why these technologies impact supply chains positively and what obstacles hinder their full potential in developing economies.

Industry 4.0 technologies improve supply chain efficiency by streamlining operations, increasing visibility, and enabling data-driven decision-making. IoT, the most widely adopted technology at 45%, plays a crucial role in real-time monitoring, reducing uncertainties, and improving inventory management. The ability to track shipments, monitor warehouse conditions, and detect supply chain disruptions in real time allows businesses to act proactively rather than reactively. AI and Big Data Analytics, adopted in 25% and 35% of studies respectively, further enhance efficiency by leveraging machine learning algorithms to predict demand fluctuations and optimize resource allocation. This level of precision reduces delays, minimizes waste, and ensures that supply chains function with greater agility. Blockchain, despite its relatively lower adoption rate of 30%, improves efficiency by increasing transparency and trust among stakeholders. By providing an immutable ledger of transactions, blockchain reduces fraud, eliminates intermediaries, and speeds up processes such as customs clearance and supplier payments. These technologies collectively improve operational efficiency, with studies indicating a 20-30% increase in supply chain performance, a substantial gain for businesses operating in resource-constrained environments.

Cost reduction is another critical impact of Industry 4.0 technologies, as 50% of reviewed studies reported a 15-25% decrease in operational expenses. Automation through robotics and AI minimizes human intervention, which lowers labor costs and reduces the likelihood of human error. Cloud computing, with a 40% adoption rate, significantly reduces the need for physical infrastructure, cutting down costs associated with on-site servers and IT maintenance. Big Data Analytics helps identify inefficiencies by analyzing purchasing trends, supplier performance, and logistics data, leading to better resource allocation and reduced excess inventory. However, while these technologies offer long-term cost savings, their high initial investment remains a substantial barrier, particularly for small and medium-sized enterprises (SMEs) in developing countries. The costs of purchasing, integrating, and maintaining advanced technologies can be prohibitive, making it difficult for many businesses to justify the expense without external financial support. Additionally, the lack of government incentives and financial aid programs further limits the widespread adoption of these cost-saving innovations.

Challenges related to infrastructure, regulations, and workforce readiness significantly hinder the adoption of Industry 4.0 technologies in developing

countries. The results indicate that 55% of studies identified high costs, regulatory issues, and inadequate infrastructure as key barriers. The upfront investment required for implementing IoT, AI, and robotics is particularly challenging in economies where capital is scarce and return on investment is uncertain. Regulatory barriers, especially concerning blockchain and data privacy, create further obstacles. Many governments lack clear policies on data security, cross-border transactions, and digital contracts, making businesses hesitant to adopt blockchain solutions. Inadequate digital infrastructure, including unreliable internet connectivity and outdated IT systems, presents another significant challenge. Without a robust technological foundation, even the most advanced supply chain solutions fail to deliver their intended benefits. Additionally, a lack of skilled labor capable of operating and maintaining these technologies further exacerbates the problem. Unlike developed nations, where workforce training programs support digital transformation, many developing countries struggle with skill gaps, preventing businesses from leveraging Industry 4.0 technologies effectively.

Sector-specific benefits of these technologies reveal how Industry 4.0 is transforming different industries. Manufacturing and logistics, which accounted for 40% of reviewed findings, stand out as the primary beneficiaries. In manufacturing, robotics and AI optimize production processes, reducing waste and improving efficiency. IoT-enabled smart factories improve quality control and predictive maintenance, minimizing machine downtime. In logistics and transportation, real-time tracking through IoT and AI-powered route optimization significantly reduces fuel consumption and delivery delays. However, while manufacturing and logistics benefit the most, other sectors such as healthcare, agriculture, and retail are also beginning to see positive changes. In healthcare, for example, blockchain is improving supply chain transparency in pharmaceutical distribution, reducing the risk of counterfeit drugs. Big Data Analytics is helping farmers optimize agricultural supply chains by predicting demand and improving resource distribution. These sector-specific applications demonstrate that while Industry 4.0 technologies are widely applicable, their impact varies based on industry needs, regulatory environments, and available infrastructure.

Regional disparities in the adoption of Industry 4.0 technologies highlight an uneven pace of digital transformation. The results indicate that 30% of studies reported significant regional differences, with Asia and Africa lagging behind in adoption rates compared to other regions. In Asia, rapid industrialization is driving digital transformation, but issues such as inconsistent regulations and data security concerns slow down progress. Countries such as India and Indonesia, for example, struggle with fragmented policies that hinder the seamless integration of supply chain technologies. Africa faces even greater challenges due to poor infrastructure, lack of digital literacy, and financial constraints. Many African nations have limited

access to high-speed internet and cloud computing resources, making it difficult for businesses to adopt IoT and AI solutions. Additionally, the high cost of imported technology further restricts adoption. These regional differences indicate that a one-size-fits-all approach to Industry 4.0 adoption will not work, and tailored strategies are needed to address country-specific challenges.

Despite these barriers, the overall impact of Industry 4.0 technologies on supply chain management in developing countries remains overwhelmingly positive. The ability to enhance efficiency, reduce costs, and improve transparency positions these technologies as key drivers of economic development. However, to unlock their full potential, governments and businesses must take proactive steps to overcome adoption barriers. Policymakers should introduce financial incentives, subsidies, and tax breaks to encourage technology investment, particularly for SMEs. Investments in digital infrastructure, workforce training, and regulatory frameworks are essential to create an environment where Industry 4.0 technologies can thrive. Public-private partnerships can play a crucial role in funding and facilitating technology adoption, ensuring that even resource-limited businesses can participate in the digital transformation.

Future research should focus on long-term impacts, sector-specific implementations, and policy interventions to further support the integration of Industry 4.0 technologies in supply chains. Understanding how these technologies affect job creation, labor dynamics, and market competitiveness will provide deeper insights into their role in shaping the economies of developing nations. Additionally, exploring innovative funding models such as microfinancing for technology adoption, government-backed digital transformation programs, and international partnerships can help bridge the financial gap for businesses struggling with initial investment costs.

In conclusion, while Industry 4.0 technologies have proven to be transformative for supply chain management in developing countries, their full potential is yet to be realized. The benefits of increased efficiency, cost reduction, and improved transparency are evident, but challenges related to costs, regulations, infrastructure, and skills continue to hinder adoption. A targeted approach involving policy support, financial investment, and infrastructure development is necessary to overcome these obstacles. If successfully implemented, Industry 4.0 can serve as a powerful catalyst for economic growth, job creation, and industrial modernization, ultimately contributing to the long-term development of emerging economies.

## 4. CONCLUSION

To further advance the understanding and implementation of Industry 4.0 in developing nations, future research should focus on sector-specific adoption

strategies, particularly in agriculture, education, and healthcare and other critical sectors. The interdisciplinary between information systems and supply chain management on the topic of industry 4.0 technologies provides insights for researchers on challenges and barriers. The knowledge may guide studies on exploring how digital transformation can enhance productivity in these industries while addressing challenges such as infrastructure limitations, human adoption and skills and workforce upskilling. Additionally, research should investigate the role of government policies in fostering an enabling environment for Industry 4.0 adoption, including incentives for technology investment and public-private partnerships. The findings from such studies can guide policymakers in designing frameworks that promote sustainable industrial growth while ensuring social inclusivity. In practice, industry leaders can use these insights to develop targeted digital strategies, optimize resource allocation, and create workforce training programs that align with emerging technological trends.

The goal of Industry 4.0 was to benefit developed nations. Developing nations cannot accept the industry 4.0 blueprint as is; instead, they must modify it to fit their own circumstances. This makes things more complicated because there isn't a model or blueprint for developing nations to use, but it also allows them a chance to create something unique to their own circumstances that will make their nation competitive on the world stage. If developing countries lack a strong manufacturing sector, robust digital infrastructure, and adequate skills set, they will not be able to fully leverage industry 4.0 developments. In the absence of these components, only a small number of businesses in developing nations will be able to apply industry 4.0 technologies, and even fewer will be able to adopt the usage of smart manufacturing.

Industry 4.0 affects the health, economic, political, educational and social spheres. Though developing nations are still behind, the adoption of these technologies will bring about advantages. Nevertheless, the accessibility and availability of digital technologies and connection infrastructure, which are the cornerstones of Industry 4.0, will determine the capacity of developing nations to advance, harness the benefits and minimize the threats [40]. The development of ICT infrastructure, data security, and bridging the digital gap in access to digital technologies and the internet require a supportive regulatory environment. A multi-stakeholder mechanism should be established to institutionalize a participatory approach to fostering industry 4.0, and developing nations should build international cooperation to speed up the transfer of technology and know-how, amongst other things. Developing nations should also establish the framework conditions necessary to deploy industry 4.0 technologies in manufacturing.

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