



Review

Assessment of Digitalized Logistics for Implementation in Low-Income Countries

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Abstract: Integration of digitalization and automation with logistics systems promotes effective and efficient flow of goods, information, and services, contributing to economic development. The level of implementation of digitalization and automation in low-income countries is still low, however. The aim of this study is to establish which digitalized logistics practices could best be adopted by firms in low-income countries. A systematic literature review was used to identify state-of-the-art digitalization and automation technologies in logistics chains. Criteria for adopting digitalized logistics practices were also identified in the literature review. An expert survey was conducted to identify criteria weights using analytical hierarchy process (AHP). Economic benefit, infrastructure, and affordability were the criteria that were given the highest weights by the experts. Case studies that applied state-of-the-art technologies such as internet of things (IoT), radio frequency identification (RFID), blockchain, big data analytics (BDA), and sensors mainly for traceability, production operation, and warehouse and inventory management were considered as recommended practices. Identification of suitable practices considering the local conditions in low-income countries could help logistics professionals and policymakers adopt enabling technologies in logistics chains.

Keywords: logistics; digitalization; technologies; low-income countries



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1. Introduction

Logistics has been identified as one of the core pillars of economic development [1]. It involves the process of planning, implementing, and controlling effective and efficient forward and reverse flow of goods, information, finances, and services from production to consumption, and vice versa, in a way that satisfies customers and complies with environmental requirements [2] (Figure 1). Some of the basic logistics processes include transportation, warehousing, procurement, and inventory management [3]. Logistics is crucial for any economy [4], as it affects the productivity of organizations [5]. Organizations benefit from a properly managed logistics system, since it results in improved mobility of their goods [6]. An effective logistics management system aids firms in gaining competitive advantage through value enhancement and cost reduction [7]. In recent years, digitalization and automation have been introduced in logistics chains to create a logistics system that is interconnected, intelligent, integrated, and automated [8]. These technologies are vital to logistics, as they enable proper and sound management of complex logistics environments [9]. They also contribute to sustainability by reducing logistics costs and lowering environmental impacts [10]. Additionally, digitalization and automation in logistics decrease the rate of error occurrence and improve the level of quality [11]. These technologies are also applied for reverse logistics. In recent years, the flow of products being returned to manufacturers has increased immensely. This increase has led to the application of digital technologies in reverse logistics, to track products and parts that are being returned [12].

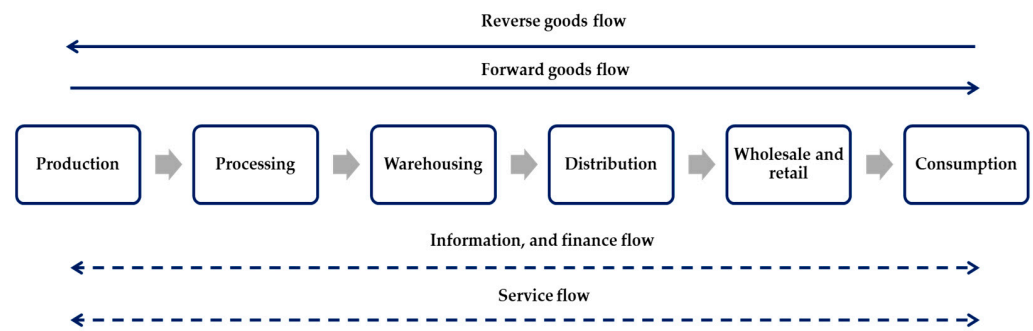


Figure 1. Basic steps in the logistics process.

The internet of things (IoT) and other enabling technologies, such as radio frequency identification (RFID) and smart sensors, enable real-time monitoring of the whole supply chain [13]. These technologies are used in vehicle fleet management and for monitoring the condition of goods being transported [14]. Technologies such as blockchain enable information sharing among stakeholders and help in mitigating common challenges in logistics, such as loss of documentation and unknown source of products [15]. Blockchain, as an alternative to a trusted third-party database, also creates mutual trust among stakeholders by recording transactions that are impossible to tamper with. Cloud computing (CC) is used for computation in a pay-as-you-go method, reducing within-premises expenses such as software, hardware, and maintenance [16]. Big data analytics (BDA) adds value in logistics by analyzing the data generated by IoT devices [17] and making meaningful interpretations and predictions. Special types of robots known as autonomous guided vehicles (AGVs) are implemented in warehouse and inventory management for material handling [18], reducing the need for operating personnel [19].

Previous studies have shed light on many new digital technologies, their characteristics, and their applicability. Some also provide analyses of adoption of emerging technologies for logistics and supply chain management. Horvath and Szabo [20] conducted a qualitative study to determine the barriers encountered by both small- and large-scale companies when adopting digital technologies. Using analytical hierarchy process (AHP), Luthra and Mangla [21] identified and ranked the key challenges in implementing digital technologies. Singh and Bhanot [22] used the decision-making trial and evaluation laboratory (DEMATEL) technique to analyze the barriers to implementing IoT. Sriram and Vinodh [23] examined the factors that small and medium-sized enterprises (SMEs) need to consider when adopting digital technologies and prioritized them using a multicriteria decision-making (MCDM) framework. According to Bellman and Paul [24], recommended practices are identified to determine actions that need to be taken to reach a desired outcome. The identification of digitalized logistics practices is vital to improve the performance of the logistics chain. It aids stakeholders in deciding which technologies to implement in their logistics chain and can facilitate the transferability of knowledge and experience from one region to another. However, research on digitalized practices in logistics for application in low-income countries is still lacking.

Low-income countries are associated with poor logistics performance, as their supply chains are unreliable [1]. Their logistics systems are characterized by long lead times [25], lack of adequate infrastructure, and higher logistics costs [26]. Therefore, there is a need to develop solutions that can improve these systems. Although there has been an exponential rise in the accessibility of enabling technologies in recent years, uptake of these technologies in low-income countries is still in its infancy. Thus, the objective of the present study was to assess digitalized logistics on a global level and identify digitalized logistics practices suitable for implementation in low-income countries to improve the performance of their logistics systems. Specifically, the study addressed the following important research questions:

1. What are the state-of-the-art technologies in logistics in relation to the application of digitalization and automation?
2. What are the criteria for the application of digitalization and automation practices in logistics?
3. Which digitalized logistics practices could best be implemented in low-income countries?

2. Materials and Methods

To answer the above research questions, a systematic literature review (SLR) was used. The state-of-the-art logistics technologies in logistics, as well as criteria for adopting digitalized logistics practices, were identified from the SLR. An expert survey was conducted to identify criteria weights using the analytical hierarchy process (AHP). Case study papers that were obtained from the SLR were evaluated using the criteria to obtain recommended logistics practices. The detailed description of the approach is depicted in Figure 2.

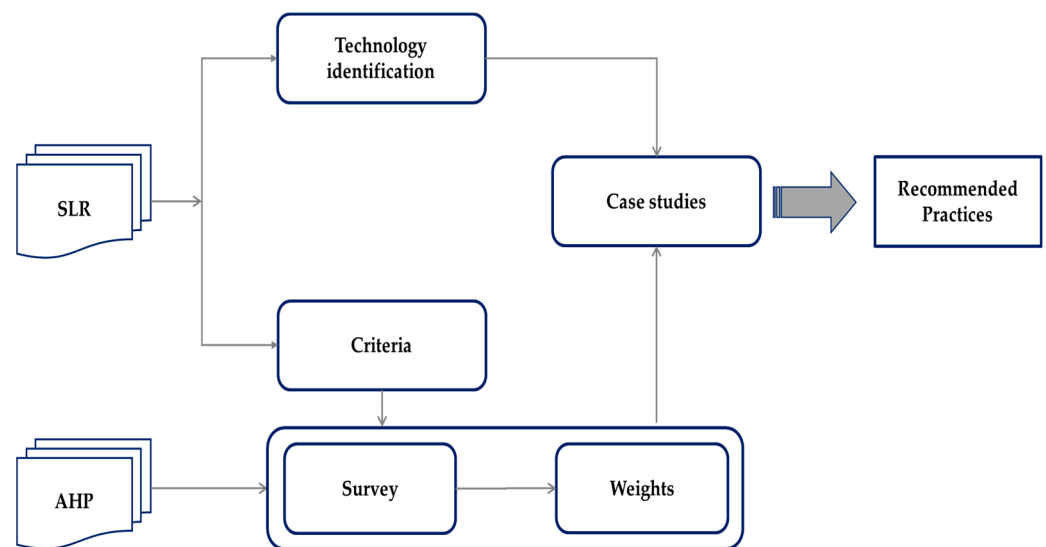


Figure 2. Methodology followed in this research.

2.1. Systematic Literature Review (SLR)

Comprehensive reviews of the literature on digitalization and automation technologies have been conducted recently by Abdirad and Krishnan [27], Lagorio et al. [28], and Chauhan and Singh [29]. These reviews discuss emerging digital technologies and their role in logistics and supply chain management. Attaran [30] conducted a literature review to study the impact of digital technologies on the performance of supply chains. Ghadge et al. [31] and Queiroz et al. [32], on the other hand, reviewed the literature to identify the challenges, opportunities, and barriers in implementing digital technologies in supply chains. Dhamija et al. [33], Fatorachian and Kazemi [34], and Oztemel and Gursev [35] carried out literature reviews on the application of digital technologies in the manufacturing sector, where the technologies were applied to create an automated system and ensure operational efficiency.

Some reviews have concentrated on specific technologies. Reviews by Addo-Tenkorang and Helo [36] and Chehbi-Gamoura et al. [37] provided insights into the application of BDA in supply chain management. Wang et al. [38] reviewed the literature on blockchain and its influence on supply chain practices and policies. Adamson et al. [16] conducted a review on current trends and developments of CC in the manufacturing sector. Other papers have reviewed the application of technologies in various sectors. For example, Lezoche et al. [39] reviewed technologies in the food supply chain, while Mueller et al. [40] identified and discussed the different technologies used for digitalization in the wood supply chain.

As our focus is on low-income countries in the present study, a systematic literature review (SLR) was considered necessary for our specific context. The review aimed to:

- Acquire comprehensive knowledge of state-of-the-art logistics technologies.
- Identify the criteria that low-income countries need to consider when adopting digital technologies in their logistics environment.
- Select suitable case study papers for identification and recommendation of digitalized logistics practices.

The literature review guidelines developed by Avni et al. [41] were applied. The review comprised two phases: a literature search and literature analysis (see Figure 3).

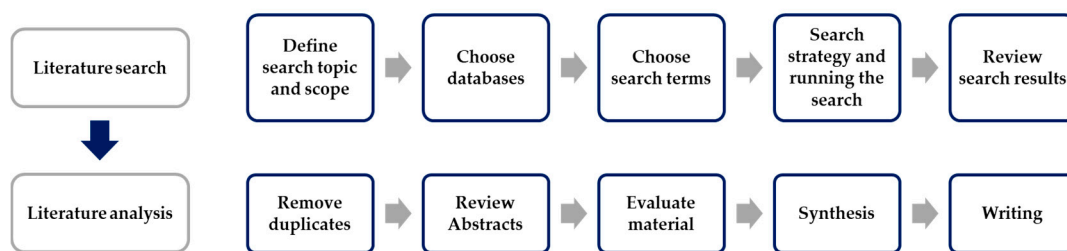


Figure 3. Steps followed in the systematic literature review (SLR).

In the first phase of the SLR, the search topics and scope for the review were defined. The databases Web of Science Core Collection and Scopus were chosen as search resources. For the search strategy, keywords that would maximize the number of search hits where enabling technologies, such as digitalization, internet of things, digitization, and industry 4.0, were evaluated in a logistics or supply chain context were chosen. The search string used was: “digitalization OR internet of things OR digitization OR industry 4.0” AND “logistics OR supply chain” AND “performance OR evaluation”. Although the aim of the review was to identify digitalized logistics practices for low-income countries, keywords like “low-income” or “developing country” were not included in the search string, in order to maximize the number of hits obtained. The search was restricted to peer-reviewed papers written in English and published from the year 2000 to 2020. The search was carried out in two phases. The first search was made in April 2020, and the second was made in February 2021. The second search aimed to include new papers published from April 2020 onwards. The results were then organized and further analyzed using EndNote X9 [42].

In the second phase of the SLR, literature analysis, duplicate papers were removed. Inclusion/exclusion criteria were established for evaluating the abstracts of the remaining papers. The criteria for inclusion/exclusion were: (a) inclusion of only peer-reviewed papers, (b) inclusion of only papers published in English, (c) inclusion of papers published from the year 2000 to 2020, and (d) exclusion of papers that were not within the scope of logistics or did not have clear technology application in logistics.

2.2. Criteria Selection

Logistics technologies are vital for organizations to gain a competitive advantage. A study by Yu and Hsiao [43] revealed a high technological gap in the logistics operation of low-income countries. Hence, the present study sought to identify the criteria that organizations in low-income countries need to consider when implementing digital technologies in their logistics chains. During the review process, articles that discussed the opportunities and challenges of digital technologies were identified by evaluating articles from the SLR. This was used to formulate selection criteria for firms to adopt digitalized logistics practices.

2.3. Weight Assessment

Analytical hierarchy process (AHP) was used to assess the weight of each criterion. AHP is a type of MCDM framework that is appropriate for assigning quantitative values

to qualitative attributes [44]. It requires a hierarchical structure and pairwise comparisons [45] that later help in assigning weights to each alternative. The method helps decision-makers in handling complex information and converts subjective assessments of relative importance into weights [46]. Although AHP is criticized for having issues related to inconsistency [47], the method is still perceived as effective for dealing with complex problems [48].

AHP has diverse applications in the field of logistics. For instance, [49] used AHP to select the most appropriate logistics center location, while Lam et al. [50] used it to categorize potential risk factors in warehouse order fulfillment. Shaik and Abdul-Kader [51] applied the AHP method to measure the performance of transportation in reverse logistics. Chang et al. [52] applied fuzzy AHP to select risk mitigation strategies for shipping companies to reduce operational risk impacts. Luthra and Mangla [21] identified the challenges of digital technologies in the manufacturing sector and ranked the challenges using the AHP method. The method has also been used by several authors, including Ecer [53], Gürcan et al. [54], and Peng [55], to select logistics service providers.

According to Saaty [45], the AHP method involves the construction of pairwise comparisons with alternatives. If there are n alternatives, then there will be $n(n - 1)/2$ comparisons. The alternatives are compared against each other by experts, using an importance scale with values ranging from 1 to 9 (see Table 1). Following Khan and Samadder [56], the weights (w_i) of each alternative are computed by (a) calculating the sum of values in each column of matrix A, (b) dividing each element in the matrix by its column total to obtain normalized values, and (c) obtaining w_i by taking the average of the elements in each row of the normalized matrix. Finally, the consistency ratio (CR) is calculated using Equations (1) and (2) [57]:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

where CI is the consistency index, λ_{max} is the principal eigenvalue, n is the total number of alternatives, and RI is the random consistency index. The average RI values can be obtained from Table 2. For the weights obtained to be valid, CR should be less than 10%. If the CR is greater than 10%, the weights should be revised by assigning new values to meet the requirement. The experts should then be contacted again to check if they agree with the newly assigned values [58].

Since the AHP method is not affected by small sample size [59], in the present case, 30 experts were contacted to perform the pairwise comparisons via a web survey. The experts were from academia and industry with relevant experience in the logistics sector. These experts were chosen using a purposive sampling technique [60], which is a deliberate nonrandom sampling technique where participants are chosen based on the qualities they possess. The responses from the experts were then analyzed using an AHP template developed by Goepel [61].

Table 1. Importance scale for making pairwise comparisons in the analytical hierarchy process (AHP) method [45].

Importance Scale	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between adjacent judgments
Reciprocals	If activity i has one of the above values when compared against activity j , then activity j has a reciprocal value when compared to i

Table 2. Average random consistency index (RI) values [45].

<i>n</i>	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

2.4. Evaluation of Digitalized Logistics Practices

To assess the applicability of the identified digitalized logistics practices for developing countries, case studies of implementations in logistics sectors, identified in the SLR, were taken as starting point. The propensity for adoption of technologies in each case was evaluated using the selection criteria. The case studies were examined in order to check which criteria they have considered either by mentioning the criteria and providing a description or by conducting an analysis for the criteria. Next, the degree of applicability (DOA) of each case study was computed by taking the weighted sum of the criteria fulfilled by that case study (Equation (3)):

$$DOA = \sum_{i=1}^n a_i w_i \tag{3}$$

where *n* is the number of criteria, *a_i* is the application factor with values of either 1 or 0 (1 if the criterion is considered in the case study being evaluated; 0 otherwise), and *w_i* is the weight given to each criterion. Case studies with the highest DOA values were taken as recommended practices and are presented in Section 3 of this paper.

3. Results

3.1. Systematic Literature Review (SLR)

The first literature search resulted in the retrieval of 736 papers. From this total, 213 duplicates and 255 papers not meeting the inclusion/exclusion criteria were removed. This resulted in 268 papers for further analysis. The second phase of the literature search, conducted in February 2021, resulted in the retrieval of 134 new papers. Hence, 402 papers were analyzed in total.

3.1.1. Trends in Publication

Although the literature search included papers starting from 2000, relevant publications only started from 2007. The number of publications showed a significant increase from 2015 onwards (Figure 4). This increase shows that the application of digital technologies in logistics has attracted more research in recent years as more logistics chains have adopted, or are in the process of adopting, these technologies.

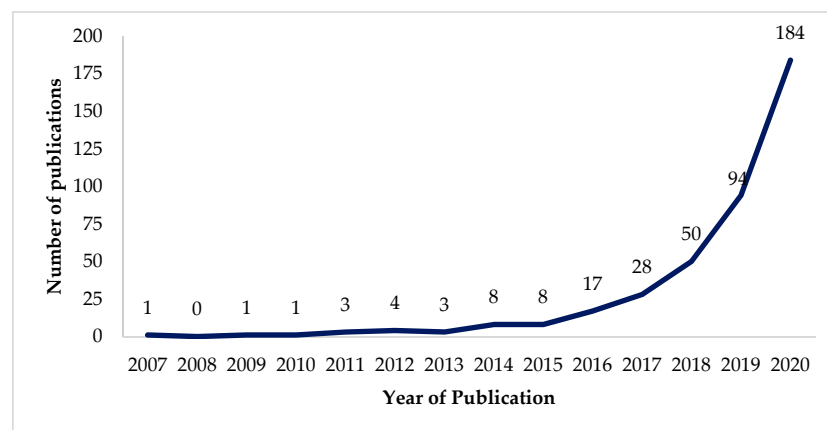


Figure 4. Trend in publication of papers related to logistics technologies in recent decades.

3.1.2. Publication by Region and Economic Category

The region from which the articles originated was examined in order to gain insights into the regions with the most research on logistics technologies. A region was assigned to each paper based on the authors’ affiliation. Each country of origin was also categorized by its economic class, using the classification of World Bank [62].

The SLR showed that 59% of the papers were from high-income countries (e.g., Germany, USA, UK), 29% were from upper-middle-income countries (e.g., Brazil, China, Turkey), and 12% were from lower-middle-income countries (e.g., Egypt, India, Pakistan). Within high-income countries, the largest number of papers was from Europe (157 publications). Asia had the highest number of publications from upper-middle-income countries (94 publications). Asia also had the largest share of papers from lower-middle-income countries (42 publications) (Table 3).

Table 3. Distribution of the 402 papers reviewed based on region of origin and economic category of country of origin.

Economic Category	Region	Number of Publications	Total	Percentage
Lower middle income	Asia	42	48	12
	Africa	6		
Upper middle income	Asia	94	119	29
	Europe	13		
	Latin America	9		
	Africa	3		
High income	Europe	156	236	59
	North America	37		
	Asia	32		
	Oceania	10		

3.1.3. Types of Scientific Paper

The categorization by type of scientific paper resulted in six categories. Since some papers follow multiple research approaches, they might fall into more than one category. Accordingly, 139 papers focused on developing models, 80 papers were review papers, and 71 papers were case study papers. Studies that developed frameworks, surveys, and conceptual papers were also identified from the SLR (Figure 5).

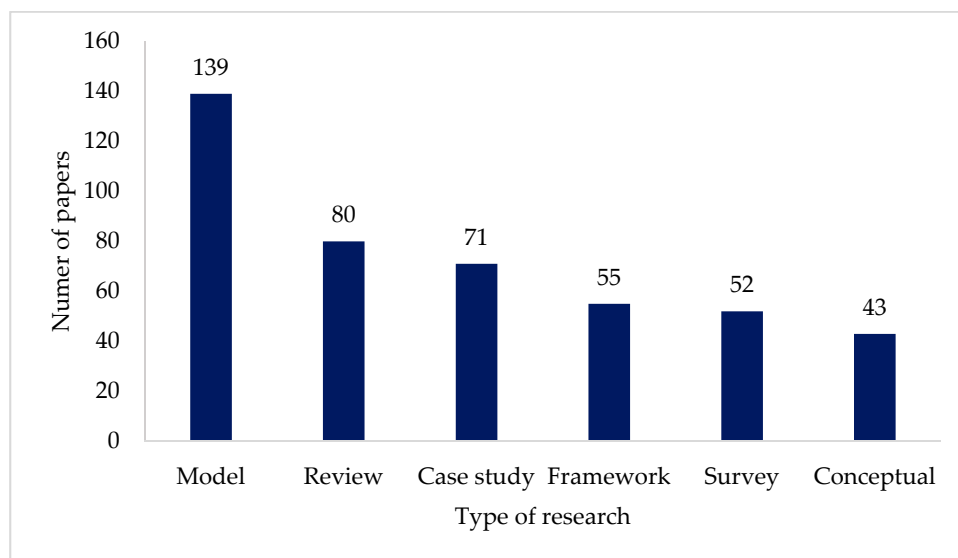


Figure 5. Distribution of articles based on the type of research.

3.1.4. Digital Technologies and Their Fields of Application

During the categorization of papers by technology type, it was observed that 38% did not focus on a specific technology, but on digitalization or automation in a general sense. The remaining papers were classified based on the technologies on which they focused. It should be noted here that some papers covered more than one type of technology. In terms of frequency of publication, it was found that IoT was the most published technology (Figure 6). IoT is a key technology to achieve digital transformation [63]. It facilitates the exchange of information between physical objects or “things” and optimizes the physical flow of goods [28]. Technologies such as RFID, blockchain, BDA, and sensors were also covered in the papers reviewed.

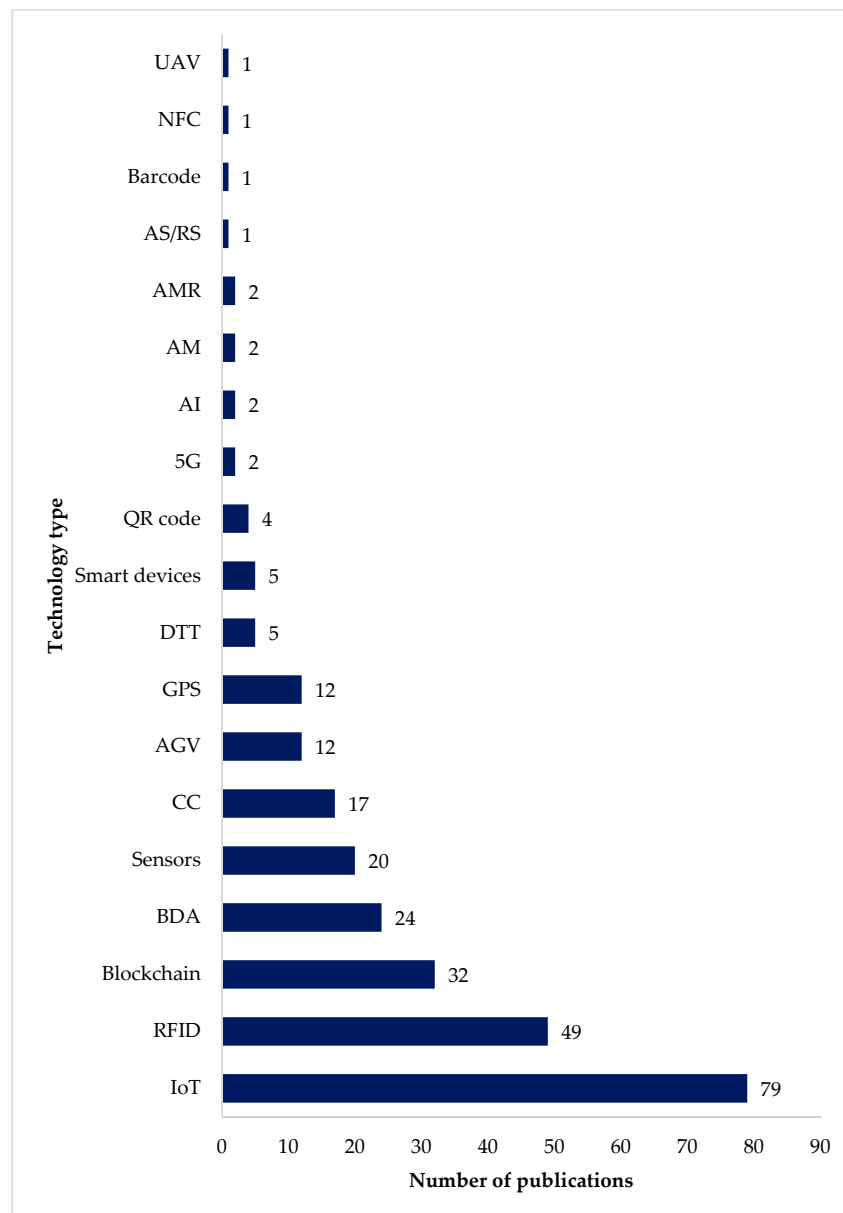


Figure 6. Distribution of the papers reviewed based on type of technology covered. IoT = internet of things; RFID = radio frequency identification; BDA = big data analytics; CC = cloud computing; AGV = autonomous guided vehicles; GPS = global positioning system; DTT = digital twin technology; QR code = quick response code; 5G = fifth-generation technology; AI = artificial intelligence; AM = additive manufacturing; AMR = autonomous mobile robots; AS/RS = automated storage and retrieval systems; NFC = near-field communication; UAV = unmanned autonomous vehicles.

In terms of applicability of the technologies, it was observed that 46% of the papers included in the SLR did not specify the application area of the technology, but studied the implementation of the technologies throughout the logistics chain. Among the remaining papers, it was found that the highest proportion studied the use of digital technologies for traceability and production operations. The results also showed that digital technologies were applied in warehouse and inventory management (Figure 7).

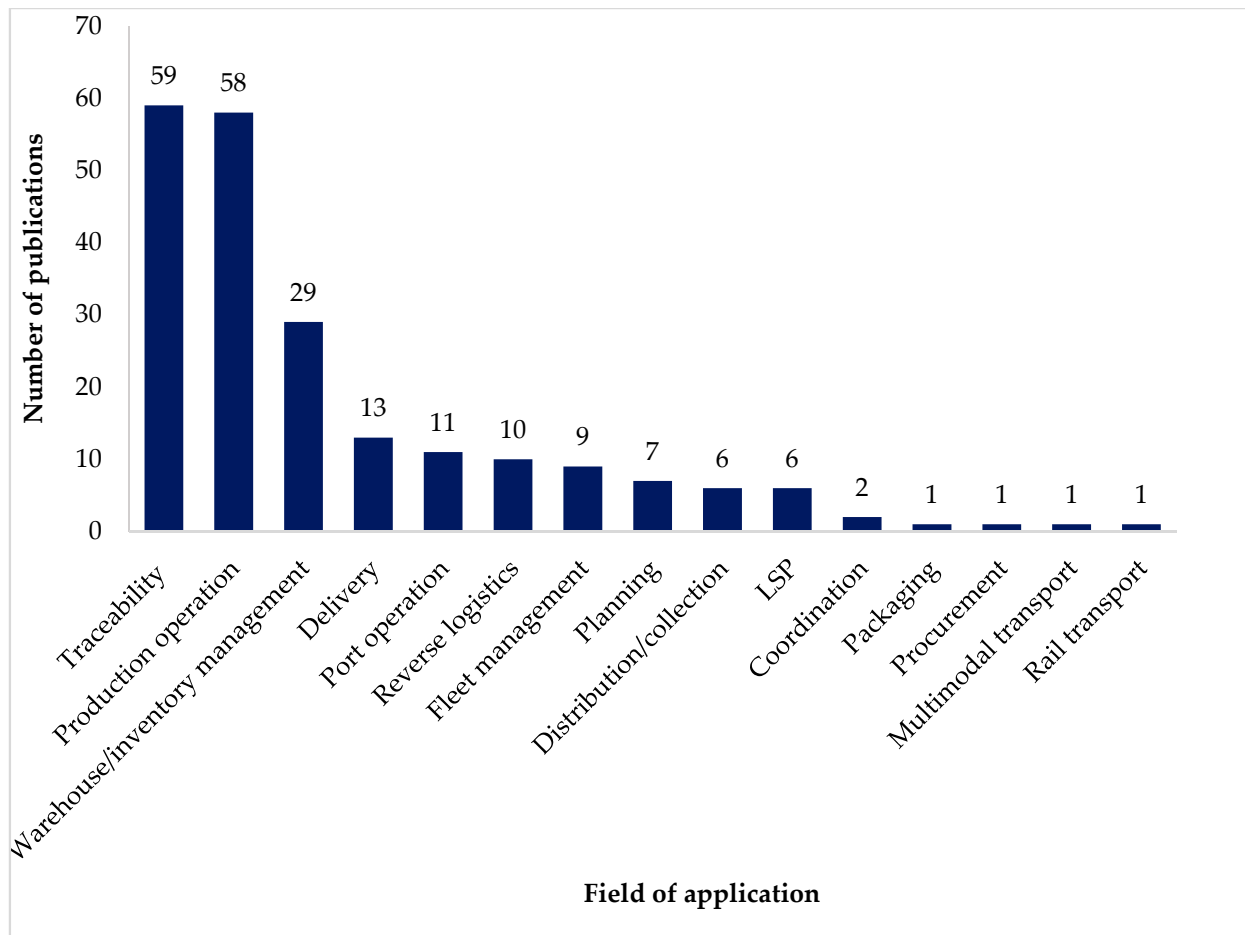


Figure 7. Distribution of the papers reviewed based on field of application. LSP = logistics service providers.

3.1.5. Applicability in Different Sectors

Although the majority of the papers reviewed (80%) did not specify the sector in which the digital technologies were applied, some examined applications in various sectors. It was observed from the review that several publications concerned the agri-food sector (Figure 8). Other sectors such as automotive, healthcare, and construction were also identified from the SLR.

Further analysis of the type of technology applied in the agri-food, automotive, and healthcare sectors revealed that IoT is the most common technology in all three sectors. IoT-enabling technologies, such as RFID and sensors, were also common in the agri-food sector (Figure 9).

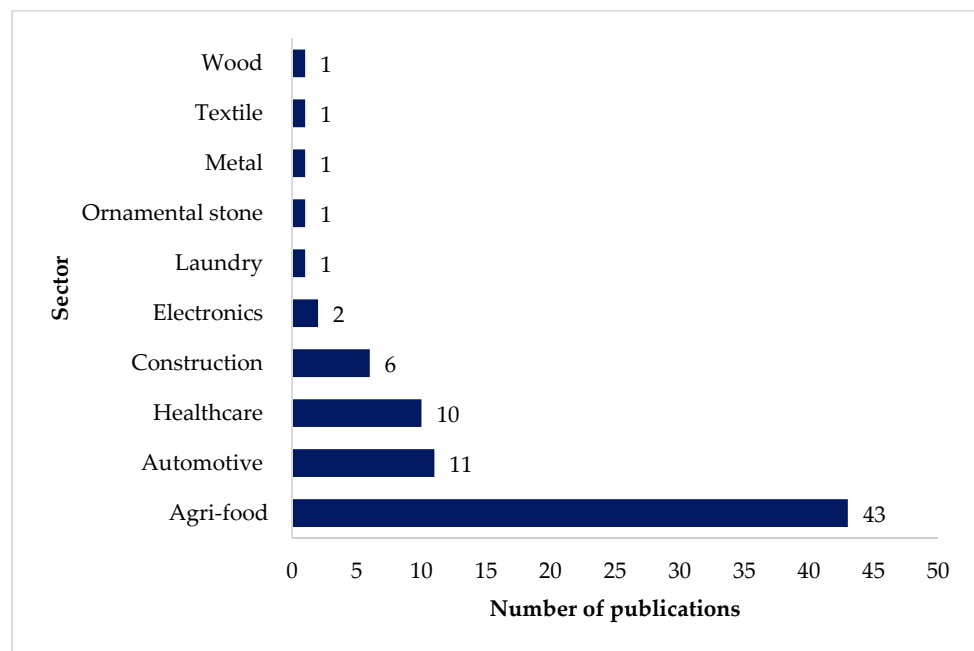


Figure 8. Distribution of the papers reviewed based on the sector(s) focused upon.

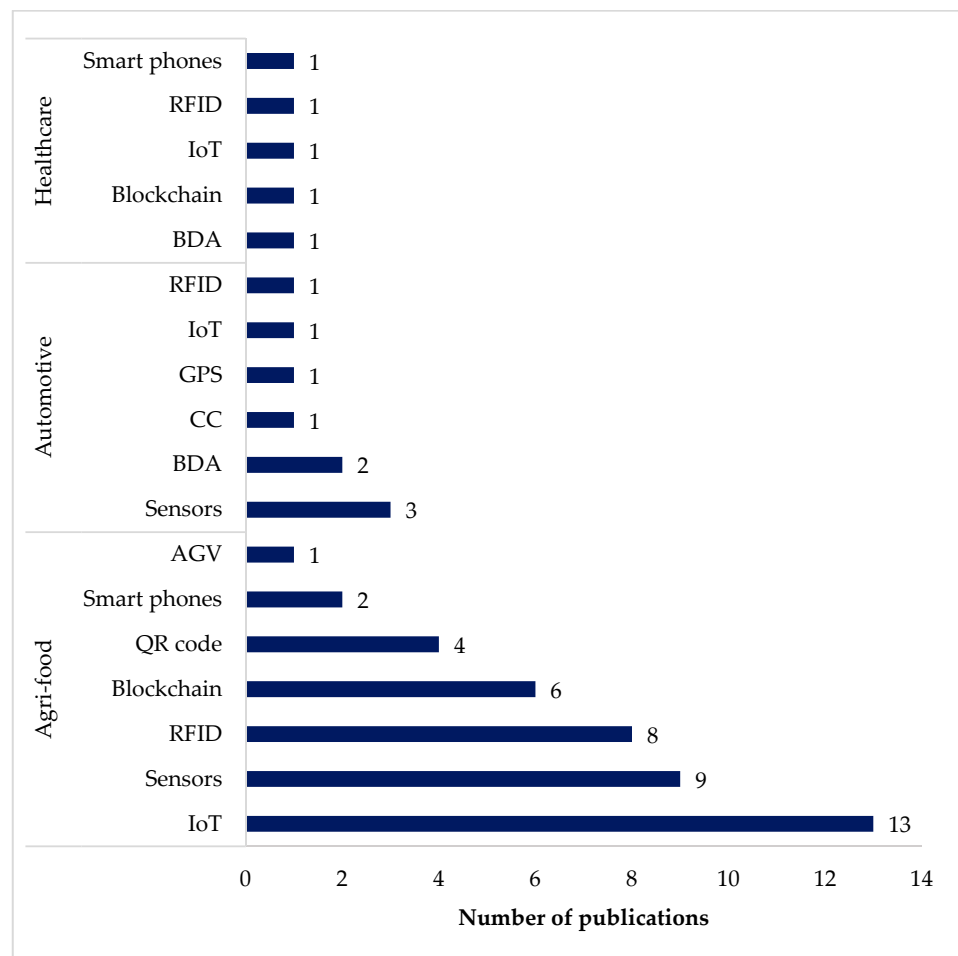


Figure 9. Type of technology applied in the three common sectors.

3.2. Criteria for Selection of Digitalized Logistics Practices

The introduction of digital technologies in logistics has changed how the system operates. These technologies offer numerous opportunities, including transparency, visibility, and productivity (Table 4). However, they are also associated with some challenges, including uncertainty, cost, and complexity [64] (Table 5).

Table 4. Opportunities for digitalization in the logistics chain.

Opportunities	References
Transparency and visibility	Nawaz and Thowfeek [65], Zafarzadeh et al. [66], Kshetri [67]
Productivity	Ooi et al. [68], Kshetri [67]
Competitive advantage	Yang [69]
Reduced emissions and fuel consumption	Hopkins and Hawking [70], Mastos et al. [71]
Reduced lead times	Da Silva and Gil [72]
Reduced car accidents	Hopkins and Hawking [70]

Table 5. Challenges to digitalization in the logistics chain.

Challenges	References
Cybersecurity	Pandey et al. [73], Hsu and Yeh [74], Singh and Bhanot [22], Li [75], Kshetri [67]
Legal issues	Yang et al. [76], Kshetri [67], Luthra and Mangla [21], Ghadge et al. [31], Queiroz et al. [32]
Skilled personnel	Hsu and Yeh [74], Singh and Bhanot [22], Chong et al. [77], Arora and Rathi [78], Horvath and Szabo [20], Kurpjuweit et al. [79], Mahroof [80], Ghadge et al. [31], Queiroz et al. [32]
Energy consumption	Singh and Bhanot [22]
Investment cost	Singh and Bhanot [22], Tu [13], Horvath and Szabo [20], Zafarzadeh et al. [66], Kshetri [67]
Big data management	Zafarzadeh et al. [66]
Government support	Tu [13], Ghadge et al. [31]
Internet connectivity	Sriram and Vinodh [23]
Technology access	Mathauer and Hofmann [81]

Opportunities and challenges mentioned in Tables 4 and 5 that fall into similar categories were merged together to form eight criteria that low-income countries need to consider for the selection of digitalized logistics practices. The criteria were:

- i.* Economic benefits: This criterion refers to the financial gains that result from the adoption of digital technologies. The use of digital technologies results in an improvement in the performance of the logistics system. It facilitates better resource utilization and improved asset management [66]. Improved performance can also result in cost savings due to operational efficiency and reduced lead times.
- ii.* Infrastructure: This criterion refers to both physical and organizational infrastructures that are required for the operation of digital technologies. Infrastructure that can handle the big data from IoT-enabled devices should be presented [74].
- iii.* Affordability: Financial constraints are one of the major drivers for technology implementation [31]. In the present context, affordability refers to the economic ability of users to purchase digital technologies.
- iv.* Accessibility: This criterion refers to the availability of the technologies for purchase by stakeholders in low-income countries.

- v. Policy: Legal issues, government support, policy measures [31], and associated regulatory constraints [82] can inhibit the adoption of digital technologies in logistics. Hence, this criterion refers to all policy measures that are required for the adoption and implementation of digital technologies.
- vi. Human resource: There is a need for IT experts to run, control, and manage the digitalized system [74]. This criterion refers to the need for these experts.
- vii. Social benefits: This criterion refers to the social gains associated with the use of digital technologies. The benefits include reduced traffic accidents, capacity building, knowledge sharing, and improved working environment.
- viii. Environmental benefits: This criterion refers to the environmental gains that result from the adoption of digital technologies. One of the environmental benefits of the application of digital technologies in logistics chains is reduced emissions as a result of optimized and efficient systems [70].

3.3. Weighting of Practices for Implementation in Low-Income Countries

In order to identify digital logistics technologies for implementation in low-income countries, weights for each criterion were assessed using the AHP method. This enabled in identifying which criteria are relatively important for low-income countries. Additionally, the criteria and weights were also used to evaluate the case studies.

3.3.1. Weight Assessment

The online survey resulted in 14 responses from the 30 experts contacted. The experts that responded to the survey included both academicians and practitioners. They were either from low-income countries or had experience working with stakeholders from low-income countries in the logistics sector. Table 6 shows the resulting weights calculated using the AHP method. Calculation of CR produced a value of 1.316%, which is within the acceptable limit. Hence, the matrix was consistent and the calculated weights were accepted.

Table 6. Weights assigned to the eight criteria using analytical hierarchy process (AHP).

Attribute	Weight	Percentage
Economic benefit	0.189	18.9
Infrastructure	0.154	15.4
Affordability	0.141	14.1
Accessibility	0.137	13.7
Policy	0.129	12.9
Human resource	0.115	11.5
Social benefit	0.087	8.7
Environmental benefit	0.048	4.8

The weights obtained using the AHP method showed that economic benefits are of highest significance for low-income countries, with a weight of 0.189 (Table 6). This is because the economic benefits gained by an organization, in terms of reduced cost, improved performance, and better efficiency, are some of the main drivers for implementing new technologies. The presence of infrastructure affects the level of digitalization in low-income countries [83]. Thus, the experts gave infrastructure the second-highest ranking, with a weight of 0.153. Social benefits and environmental benefits were given the lowest weights, 0.087 and 0.048, respectively (Table 6).

3.3.2. Criteria for Selection of Digitalized Logistics Practices Identified from Case Studies

Out of the 71 case studies (Figure 5), 42 were case studies of implementations of technologies in logistics sectors. Thus, these case studies were analyzed further. When evaluating these case studies, it was found that 82.6% of the papers used digital technologies to gain economic benefits, while 39.1% of the papers focused on environmental and social

benefits. Only 4.3% of the papers focused on policy. These findings differed from the results obtained in the expert survey, where the respondents gave more weight to economic benefit (18.9%), infrastructure (15.4%), and affordability (14.1%) (Figure 10). This shows that experts from low-income countries mainly focused on the adoption of digital technologies in logistics along with the necessary infrastructure for adoption. In contrast, middle- and high-income countries focused on building sustainable digitalized logistics solutions.

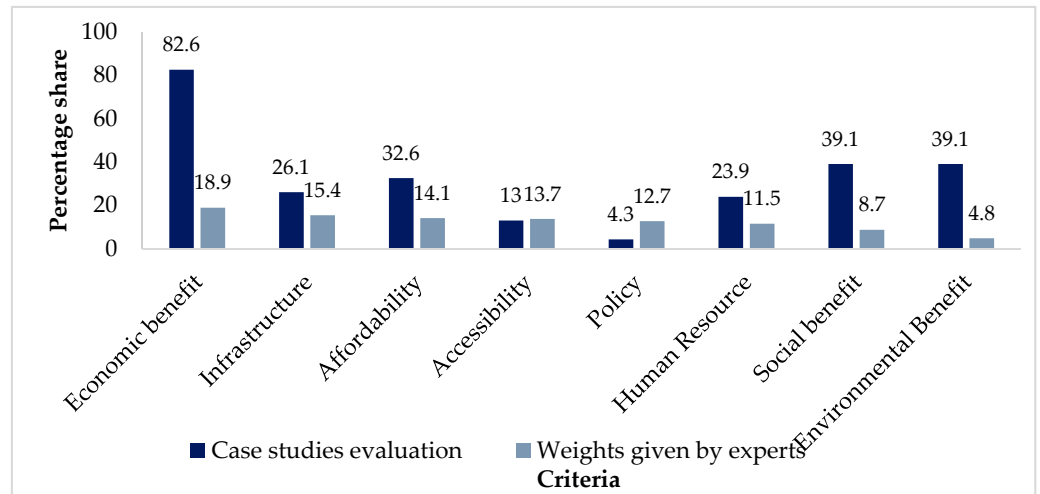


Figure 10. Total number of case studies considering each of the eight criteria.

The distribution of DOA scores showed that 72% of the case studies that were evaluated had a DOA between 0.2 and 0.4. Only 2% of case studies had a DOA between 0.6 and 0.8. Similarly, 2% of case studies had a DOA between 0.8 and 1 (Figure 11).

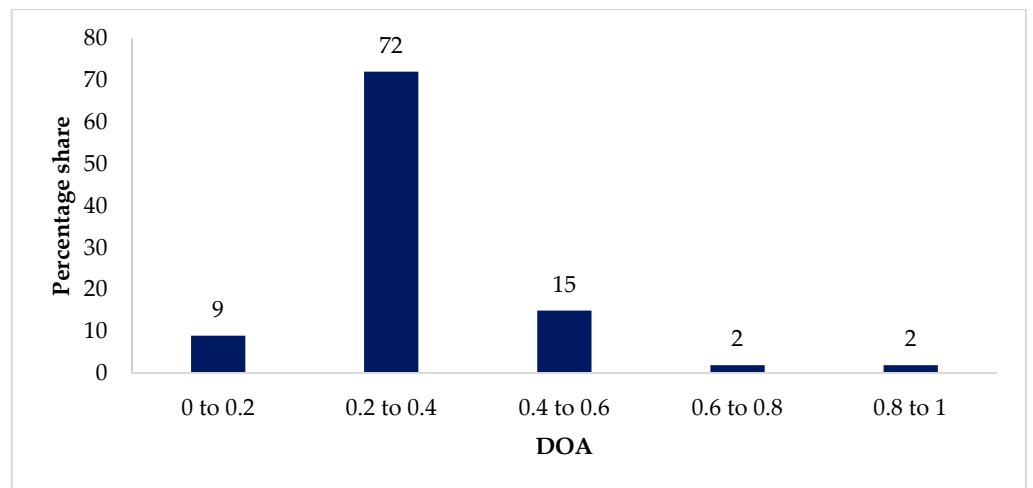


Figure 11. Percentage distribution of degree of applicability (DOA).

Recommended digitalized logistics practices were identified by evaluating case study papers using the eight criteria. Case study papers that fulfill three or more criteria are listed in Table 7. The distribution of the technologies and their applicability for the case studies that fulfill three or more criteria were also analyzed (Table 8). The analysis showed that IoT has been applied by the most case study papers, followed by RFID, CC, and BDA. A case study conducted by Ghobakhloo and Fathi [84] was given the highest ranking, with a DOA value of 0.823. That paper examined the use of CC and IoT for digitalizing production operations. According to the authors, digitalization of production processes should ensure social, economic, and environmental sustainability in order to overcome the challenges

that arise from digitalization. The case study also revealed that some stakeholders are not willing to adopt digital technologies, as the financial costs for adoption are high to change the existing structure into a new digital system. A case study by Kshetri [67], who used blockchain to digitalize the whole logistics chain, had a DOA value of 0.619. The author examined how blockchain can help in increasing transparency and accountability in the supply chain. The author also emphasized the use of IoT-enabling technologies in blockchain to enhance traceability. A case study by Chen et al. [85] that applied barcodes, RFID, and CC had a DOA value of 0.595. The feedback the authors received from their case company revealed that the technologies improved the traceability of products by reducing the rate at which products went missing. The technologies also reduced the inventory processing times. Thus, the integrated use of CC with other enabling technologies such as RFID or barcodes can reduce lead times for companies. A case study by Bag et al. [86], where IoT, BDA, and RFID were applied for digitalizing production processes, had a DOA value of 0.568. They found in their study that digital technologies in logistics could enhance production processes by reducing the supply and demand uncertainties in both forward and reverse logistics. This can reduce wastages in the supply chain, thereby creating a lean system.

The implementation of digital technologies enables meeting key supply chain objectives such as cost, quality, speed, dependability, risk reduction, sustainability, and flexibility [67]. The technologies also enable the creation of a lean system with little or no waste. Although this is the case, the case studies revealed that several factors inhibit the adoption of digital technologies. The readiness and willingness of firms to adopt these technologies to their logistics systems, as well as the resistance of workers for fear of loss of their jobs, are some of the factors that affect the adoption process [84]. Thus, stakeholders along the supply chain of low-income countries should be willing to adopt digital technologies to achieve interoperability. Firms from low-income countries should also develop implementation strategies that can enable them to prioritize which technologies to adopt, as well as which part of the supply chain to digitalize.

Table 7. Case studies focusing on adoption of digital technologies.

Author	Technology	Application	Ec	In	Aff	Acc	Po	HR	So	En	DOA
Ghobakhloo and Fathi [84]	CC, IoT	Production operation	*	*	*	*	-	*	*	-	0.823
Kshetri [67]	Blockchain	Logistics as a whole	*	*	*	-	-	-	*	*	0.619
Chen et al. [85]	RFID, barcode, CC	Traceability	-	*	*	*	-	*	-	*	0.595
Bag et al. [86]	IoT, RFID, BDA	Production operation	*	-	-	-	*	*	*	*	0.568
Alfian et al. [87]	Smartphones	Traceability	-	*	*	*	-	-	*	-	0.519
Ferretti and Schiavone [88]	IoT	Port operation	*	*	*	-	-	-	-	-	0.484
Jaeger and Mishra [89]	RFID, QR	Traceability	*	-	*	-	*	-	-	-	0.459
Shao et al. [90]	IoT	Fleet management	*	*	-	-	-	*	-	-	0.458
Wang et al. [91]	IoT	Warehouse and inventory management	*	-	*	-	-	*	-	-	0.445
Yadav et al. [92]	IoT	Coordination	*	-	-	-	-	*	*	-	0.391
Wang et al. [93]	IoT	Warehouse and inventory management	*	-	*	-	-	-	-	*	0.378
Tsang et al. [94]	IoT	Traceability	-	*	-	-	-	*	*	-	0.356
Garrido-Hidalgo et al. [12]	CC, sensors	Reverse logistics	-	*	*	-	-	-	-	*	0.343
Felsberger et al. [95]	IoT	Logistics as a whole	*	-	-	-	-	-	*	*	0.324
Gorecki et al. [96]	IoT	Production operation	*	-	-	-	-	-	*	*	0.324
Hopkins and Hawking [70]	BDA, GPS, sensors	Fleet management	*	-	-	-	-	-	*	*	0.324
Mastos et al. [71]	IoT	Reverse logistics	*	-	-	-	-	-	*	*	0.324
Parry et al. [97]	IoT	Reverse logistics	*	-	-	-	-	-	*	*	0.324
Vincent Liu et al. [98]	GPS, RFID	Fleet management	*	-	-	-	-	-	*	*	0.324
Zhao et al. [99]	IoT	Fleet management	*	-	-	-	-	-	*	*	0.324
Zerbino et al. [100]	BDA	Port operation	*	-	-	-	-	-	*	*	0.324

*: Criterion considered; -: criterion not considered. Ec = economic benefit; In = infrastructure; Aff = affordability; Acc = accessibility; Po = policy; HR = human resource; So = social benefit; En = environmental benefit; DOA = degree of applicability.

Table 8. Recommended digitalized logistics practices and their applicability.

Application	Barcode	BDA	Blockchain	CC	GPS	IoT	QR Code	RFID	Sensors	Smartphones
Coordination		*				*				
Fleet management					**	**		*	*	
Port operation		*				*				
Production operation		*		*		***		*		
Reverse logistics				*		***			*	
Traceability	*			*		*	*	**		*
Warehouse/inventory management						**				
Logistics as a whole			*			*				

*: 1 case study paper; **: 2 case study papers; ***: 3 case study papers.

4. Discussion

A systematic literature review was conducted on publications examining the application of digitalization and automation technologies in logistics, in order to identify state-of-the-art technologies. Analysis showed that 59% of the papers were from high-income countries, 29% were from upper-middle-income countries, 12% were from lower-middle-income countries, and there were no publications from low-income countries (Table 3). A study by Moldabekova et al. [101] revealed that low-income countries had the lowest progress in terms of technological innovation. Thus, the under-representation of studies from low-income countries in the present study could be attributed to infancy in the application of digital technologies. A common theme of publications from lower-middle-income countries was the study of the possibility of adopting digital technologies in their logistics chains by surveying companies that have already adopted the technologies. In contrast, common themes of publications from high-income countries were the optimization of the existing digitalized system, the simulation of the performance of digitalized systems under various conditions, and the search for sustainable digital solutions. As some of the challenges faced by lower-middle-income countries and low-income countries are similar, the lessons learned from the former could expedite the adoption process for the latter.

The weights given by the experts for accessibility, policy, HR, social benefit, and environmental benefits were lower compared to economic benefit, infrastructure, and affordability (Table 6). This, however, does not mean that firms in low-income countries should disregard the criteria with lower weights. When firms in low-income countries adopt digital technologies, if their focus is just on economic benefit, infrastructure, and affordability, they risk providing short-term solutions. This will create problems during the adoption process, as there would not be skilled labor to run the technologies and the existing government policies might not facilitate the adoption processes. Rather, firms in low-income countries should also make long-term plans to develop sustainable digital solutions. Policy-related measures should be developed by government officials to aid the adoption process. As human resources are important for running and operating these technologies, it is important that necessary capacity-building training be provided by creating linkages among firms, academics, and professionals.

The evaluation of published case studies using the criteria revealed that studies in middle- and high-income countries prioritized economic, social, and environmental benefits (Figure 10). Together, the studies of middle- and high-income countries primarily focus on the broad contribution of digital technologies to sustainability. This is in line with the World Economic Forum [102], which emphasizes the economic, social, and environmental gains from adopting digital technologies.

Technologies such as IoT, RFID, blockchain, BDA, and sensors have been widely applied in middle- and high-income countries for production operations, traceability, port operation, and fleet management (Table 8). These technologies can potentially reduce the incidence of defects and increase production flexibility [95]. Since technological innovation and readiness are important promoters of logistics efficiency [101], their implementation in low-income countries can reduce lead time [72] and lower coordination and management costs [103]. Supply chains in low-income countries function poorly due to a lack of

traceability [104]. Thus, technologies such as IoT can be implemented in their supply chains to improve the connectivity of goods, facilitate visibility, and achieve a high level of efficiency and effectiveness [8,64]. By implementing IoT-enabling technologies, such as RFID and sensors, organizations can obtain the stock status of their company, maximize efficiency at minimal cost, save time, provide better control, and improve accuracy for inventory management [105]. The adoption of these technologies can also inhibit the spread of counterfeit products, which is a problem in a number of sectors, including the healthcare supply chain, in low-income countries [104]. Organizations in low-income countries can also use BDA and GPS technologies for fleet management to reduce car accidents and emissions caused by trucks [70].

Although digital technologies have applicability in numerous sectors, the SLR revealed that one of the most strongly influenced sectors was the agri-food supply chain (Figure 8). This may be because other sectors such as the automotive and electronics sectors are already integrated compared to the agri-food sector. Thus, new enabling technologies in the agri-food sector can potentially improve how the sector operates and integrate stakeholders, which was not possible before. Since perishable foods have the highest food loss rate [106], logistics processes should be optimized to ensure food security [107]. In low-income countries, postharvest food losses mainly occur due to inappropriate storage environments and transportation problems [108]. This creates an imbalance between demand and supply, as most of the food produced spoils before it reaches consumers. To mitigate food losses in low-income countries, digital technologies can be implemented in the logistics chain [87]. Continuous tracking of the storage and transportation environment is crucial to preserve the freshness of food [107]. Hence, an IoT platform can be used to enable end-to-end traceability [89]. The use of IoT-enabling technologies, such as RFID, can improve the revenue of the supply chain by reducing logistics costs and product losses [109]. Sensors that gather data on temperature, humidity, and location can be used to monitor the condition of goods, while BDA can be used to analyze the information sent from the sensors [87]. Blockchain can be used in the agri-food sector to ensure traceability and reduce the occurrence of foodborne outbreaks. Blockchain can also be used by consumers to track the origin of the food that they have purchased [67]. Since one of the barriers to the adoption of technologies is network availability [92], governmental intervention by building necessary infrastructures may be required to facilitate the process of adoption in low-income countries. The government can also improve network reachability, since internet connection is fundamental for operation [85]. This will hinder stakeholders along the supply chain from reverting to traditional methods to carry out their logistics activities.

In order to advance the level of digitalization, strategies that aid the process of implementation need to be identified [85]. Ghobakhloo and Fathi [84] concluded that smaller businesses could start by digitizing certain core operations in their chains. Accordingly, organizations from low-income countries can identify areas of their supply chains that need prioritization for digital transformation in circumstances where affordability is an issue. Alternatively, low-income countries can use low-cost digital solutions. For instance, smartphones are readily available and can be used for real-time monitoring and traceability in the supply chain [87]. Barcodes and QR codes can also be used for traceability, due to their low cost [110]. However, barcodes and QR codes can only read objects that are within the line of sight of the reader [110,111]. Therefore, RFID has become the leading technology for automatic identification [112]. Organizations in low-income countries also need access to the required cloud services and infrastructures for the technologies to operate well. To experience the full capability of digital solutions, other stakeholders along the supply chain should also be willing to adopt these technologies. Robust and sustainable technology solutions could enable the improvement of their logistics system and increase their competitiveness in the global market.

In summary, the recommended practices identified in this paper provide numerous opportunities for organizations in low-income countries to meet the logistics objectives of improving performance and reducing cost. The application of these technologies in

low-income countries could increase their competitiveness in national and global markets, leading to economic development. To ease the process of implementation, digitalization should be seen as an ongoing process instead of a discrete one. Technologies that are currently accessible can be introduced in certain parts of the supply chain and then be gradually developed over time. However, implementing digitalization has negative social implications, such as cybersecurity risks and unemployment of low-skilled workers [113]. Lack of skilled resources and resistance from workers [114] are some of the challenges low-income countries are expected to face during implementation. Hence, workforce training may help in alleviating issues related to job security [84].

5. Conclusions

Digitalization technologies improve the performance of logistics chains by reducing logistics costs, lowering lead times, and contributing to sustainability. The SLR conducted in this study showed that there was no literature on this topic from low-income countries and most papers were from high-income countries. Technologies such as IoT, RFID, blockchain, and BDA have received the most attention in recent years. Although the application of these technologies has been reported across numerous sectors, the SLR showed that the agri-food sector has seen the most research on the application of digital technologies.

The expert survey indicated that low-income countries weigh economic benefit, infrastructure, and affordability as the most important factors for the adoption of digital technologies. Recommended digitalized logistics practices included implementation of technologies such as IoT, RFID, CC, BDA, and blockchain, mainly for production operations, traceability, port operations, and fleet management. Thus, the practices identified in this study could be adopted in low-income countries taking into consideration local conditions, particularly relating to existing infrastructure.

The limitations of this study are that the SLR only included peer-reviewed papers. The case studies that were used to identify digitalized logistics practices were also peer-reviewed papers obtained from the SLR. Hence, further research where nonacademic papers are reviewed is recommended. Additionally, detailed case studies are required to map the existing conditions in low-income countries, primarily concerning the readiness of organizations to implement digitalization and automation in their logistics chains.

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References

1. Arvis, J.-F.; Saslavsk, D.; Ojala, L.; Shepherd, B.; Busch, C.; Raj, A.; Naula, T. *Connecting to Compete 2016: Trade Logistics in the Global Economy—The Logistics Performance Index and Its Indicators*; World Bank: Washington, DC, USA, 2016.
2. CSCMP. Supply Chain Management Terms and Glossary. Available online: https://cscmp.org/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx (accessed on 24 April 2021).
3. Gebresenbet, G.; Mpagalile, J. *Firm-Level Logistics Systems for the Agrifood Sector in Sub-Saharan Africa—Report Based on Appraisals in Cameroon, Ghana, Uganda and the United Republic of Tanzania*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2015.
4. Saidi, S.; Mani, V.; Meftteh, H.; Shahbaz, M.; Akhtar, P. Dynamic linkages between transport, logistics, foreign direct Investment, and economic growth: Empirical evidence from developing countries. *Transp. Res. Policy Pract.* **2020**, *141*, 277–293. [CrossRef]
5. Abdur Razzaque, M. Challenges to logistics development: The case of a Third World country—Bangladesh. *Int. J. Phys. Distrib. Logist. Manag.* **1997**, *27*, 18–38. [CrossRef]
6. Abbasi, M.; Nilsson, F. Developing environmentally sustainable logistics. *Transp. Res. Transp. Environ.* **2016**, *46*, 273–283. [CrossRef]

7. Brewer, A.M.; Button, K.J.; Hensher, D.A. Handbook of Logistics and Supply-Chain Management. In *Handbooks in Transport 2*; Pergamon: Amsterdam, The Netherlands, 2001.
8. Abdel-Basset, M.; Manogaran, G.; Mohamed, M. Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems. *Future Gener. Comput. Syst.* **2018**, *86*, 614–628. [[CrossRef](#)]
9. Mondragon, A.E.; Mondragon, C.E.; Coronado, E.S. Managing the food supply chain in the age of digitalisation: A conceptual approach in the fisheries sector. *Prod. Plan. Control.* **2020**, *32*, 242–255. [[CrossRef](#)]
10. Taniguchi, E.; Thompson, R.G. *Logistics Systems for Sustainable Cities: Proceedings of the 3rd International Conference on City Logistics (Madeira, Portugal, 25–27 June, 2003)*; Elsevier: Amsterdam, The Netherlands, 2004.
11. Murauer, N.; Pflanz, N. A full shift field study to evaluate user-and process-oriented aspects of smart glasses in automotive order picking processes. *Interact. Des. Archit.* **2018**, *38*, 64–82.
12. Garrido-Hidalgo, C.; Olivares, T.; Javier Ramirez, F.; Roda-Sanchez, L. An end-to-end Internet of Things solution for Reverse Supply Chain Management in Industry 4.0. *Comput. Ind.* **2019**, *112*, 103127. [[CrossRef](#)]
13. Tu, M. An exploratory study of Internet of Things (IoT) adoption intention in logistics and supply chain management: A mixed research approach. *Int. J. Logist. Manag.* **2018**, *29*, 131–151. [[CrossRef](#)]
14. Gebresenbet, G.; Bosona, T.; Olsson, S.-O.; Garcia, D. Smart System for the Optimization of Logistics Performance of the Pruning Biomass Value Chain. *Appl. Sci.* **2018**, *8*, 1162. [[CrossRef](#)]
15. Tijan, E.; Aksentijević, S.; Ivanić, K.; Jardas, M. Blockchain Technology Implementation in Logistics. *Sustainability* **2019**, *11*, 1185. [[CrossRef](#)]
16. Adamson, G.; Wang, L.; Holm, M.; Moore, P. Cloud manufacturing—a critical review of recent development and future trends. *Int. J. Comput. Integr. Manuf.* **2017**, *30*, 347–380. [[CrossRef](#)]
17. Keivanpour, S.; Kadi, D.A. Perspectives for application of the internet of things and big data analytics on end of life aircraft treatment. *Int. J. Sustain. Aviat.* **2018**, *4*, 202–220. [[CrossRef](#)]
18. Bechtsis, D.; Tsolakis, N.; Vlachos, D.; Iakovou, E. Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles. *J. Clean. Prod.* **2017**, *142*, 3970–3984. [[CrossRef](#)]
19. Stareček, A.; Bachár, M.; Horňáková, N.; Cagaňová, D.; Makyšová, H. Trends in automatic logistics systems and logistic market in Slovakia. *Acta Logist.* **2018**, *5*, 7–14. [[CrossRef](#)]
20. Horvath, D.; Szabo, R.Z. Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technol. Forecast. Soc. Chang.* **2019**, *146*, 119–132. [[CrossRef](#)]
21. Luthra, S.; Mangla, S.K. Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process Saf. Env. Prot.* **2018**, *117*, 168–179. [[CrossRef](#)]
22. Singh, R.; Bhanot, N. An integrated DEMATEL-MMDE-ISM based approach for analysing the barriers of IoT implementation in the manufacturing industry. *Int. J. Prod. Res.* **2019**, *58*, 2454–2476. [[CrossRef](#)]
23. Sriram, R.M.; Vinodh, S. Analysis of readiness factors for Industry 4.0 implementation in SMEs using COPRAS. *Int. J. Qual. Reliab. Manag.* **2020**, *38*, 1178–1192. [[CrossRef](#)]
24. Bellman, C.; Paul, C. Best Practices for IoT Security: What Does That Even Mean? *Computer Science Cryptography and Security. arXiv* **2020**, arXiv:2004.12179.
25. Yang, C.-C.; Chang, Y.-K. Crucial factors influencing international logistics operations for African landlocked countries—A case study of Burkina Faso. *Marit. Policy Manag.* **2019**, *46*, 939–956. [[CrossRef](#)]
26. Rabiya, H.; Edward, K. Analysis of transport logistics challenges affecting freight forwarding operations in Malawi. *Afr. J. Bus. Manag.* **2016**, *10*, 607–614. [[CrossRef](#)]
27. Abdirad, M.; Krishnan, K. Industry 4.0 in Logistics and Supply Chain Management: A Systematic Literature Review. *Eng. Manag. J.* **2020**, 1–15. [[CrossRef](#)]
28. Lagorio, A.; Zenezini, G.; Mangano, G.; Pinto, R. A systematic literature review of innovative technologies adopted in logistics management. *Int. J. Logist. Res. Appl.* **2020**, 1–24. [[CrossRef](#)]
29. Chauhan, C.; Singh, A. A review of Industry 4.0 in supply chain management studies. *J. Manuf. Technol. Manag.* **2019**, *31*, 863–886. [[CrossRef](#)]
30. Attaran, M. Digital technology enablers and their implications for supply chain management. *Supply Chain Forum: Int. J.* **2020**, *21*, 158–172. [[CrossRef](#)]
31. Ghadge, A.; Er Kara, M.; Moradlou, H.; Goswami, M. The impact of Industry 4.0 implementation on supply chains. *J. Manuf. Technol. Manag.* **2020**, *31*, 669–686. [[CrossRef](#)]
32. Queiroz, M.M.; Pereira, S.C.F.; Telles, R.; Machado, M.C. Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities. *Benchmarking Int. J.* **2019**, *28*, 1761–1782. [[CrossRef](#)]
33. Dhamija, P.; Bedi, M.; Gupta, M.L. Industry 4.0 and Supply Chain Management: A Methodological Review. *Int. J. of Bus. Anal.* **2020**, *7*, 1–23. [[CrossRef](#)]
34. Fatorachian, H.; Kazemi, H. A critical investigation of Industry 4.0 in manufacturing: Theoretical operationalisation framework. *Prod. Plan. Control* **2018**, *29*, 633–644. [[CrossRef](#)]
35. Oztemel, E.; Gursev, S. Literature review of Industry 4.0 and related technologies. *J. Intell. Manuf.* **2020**, *31*, 127–182. [[CrossRef](#)]
36. Addo-Tenkorang, R.; Helo, P.T. Big data applications in operations/supply-chain management: A literature review. *Comput. Ind. Eng.* **2016**, *101*, 528–543. [[CrossRef](#)]

37. Chehbi-Gamoura, S.; Derrouiche, R.; Damand, D.; Barth, M. Insights from Big Data Analytics in supply chain management: An all-inclusive literature review using the SCOR model. *Prod. Plan. Control.* **2020**, *31*, 355–382. [[CrossRef](#)]
38. Wang, Y.; Han, J.H.; Beynon-Davies, P. Understanding blockchain technology for future supply chains: A systematic literature review and research agenda. *Supply Chain Manag. Int. J.* **2019**, *24*, 62–84. [[CrossRef](#)]
39. Lezoche, M.; Panetto, H.; Kacprzyk, J.; Hernandez, J.E.; Alemany Diaz, M.M.E. Agri-food 4.0: A survey of the Supply Chains and Technologies for the Future Agriculture. *Comput. Ind.* **2020**, *117*, 1–15. [[CrossRef](#)]
40. Mueller, F.; Jaeger, D.; Hanewinkel, M. Digitization in wood supply—A review on how Industry 4.0 will change the forest value chain. *Comput. Electron. Agric.* **2019**, *162*, 206–218. [[CrossRef](#)]
41. Avni, A.; Burley, P.; Casey, P.; Cherney, J.; Christiansen, L.; Daly, J.S.; Rita, E.; David, J.; Greg, L.; Andrew, M. Literature Searches and Literature Reviews for Transportation Research Projects. In *How to Search, Where to Search, and How to Put It All Together: Current Practices*; Transportation Research Board: Washington, DC, USA, 2015.
42. The EndNote Team. *EndNote X9*; Clarivate: Philadelphia, PA, USA, 2013.
43. Yu, M.-M.; Hsiao, B. Measuring the technology gap and logistics performance of individual countries by using a meta-DEA-AR model. *Marit. Policy Manag.* **2016**, *43*, 98–120. [[CrossRef](#)]
44. Gerd Sri, N.; Kocaoglu, D.F. Applying the Analytic Hierarchy Process (AHP) to build a strategic framework for technology roadmapping. *Math. Comput. Model.* **2007**, *46*, 1071–1080. [[CrossRef](#)]
45. Saaty, R.W. The Analytic Hierarchy Process—What is it and how is it used. *Math. Model.* **1987**, *9*, 161–176. [[CrossRef](#)]
46. Hanaoka, S.; Kunadhamraks, P. Multiple criteria and fuzzy based evaluation of logistics performance for intermodal transportation. *J. Adv. Transp.* **2009**, *43*, 123–153. [[CrossRef](#)]
47. Rezaei, J. Best-worst multi-criteria decision-making method. *Omega* **2015**, *53*, 49–57. [[CrossRef](#)]
48. Harputlugil, T.; Prins, M.; Gultekin, A.T.; Topcu, Y.I. Conceptual Framework for Potential Implementations of Multi Criteria Decision Making (MCDM) Methods for Design Quality Assessment. In *Proceedings of the International Conference on Management and Innovation for a Sustainable Built Environment*, Amsterdam, The Netherlands, 19–23 June 2011.
49. Kayikci, Y. A conceptual model for intermodal freight logistics centre location decisions. *Procedia Soc. Behav. Sci.* **2010**, *2*, 6297–6311. [[CrossRef](#)]
50. Lam, H.Y.; Choy, K.L.; Ho, G.T.S.; Cheng, S.W.Y.; Lee, C.K.M. A knowledge-based logistics operations planning system for mitigating risk in warehouse order fulfillment. *Int. J. Prod. Econ.* **2015**, *170*, 763–779. [[CrossRef](#)]
51. Shaik, M.N.; Abdul-Kader, W. Transportation in reverse logistics enterprise: A comprehensive performance measurement methodology. *Prod. Plan. Control* **2013**, *24*, 495–510. [[CrossRef](#)]
52. Chang, C.-H.; Xu, J.; Dong, J.; Yang, Z. Selection of effective risk mitigation strategies in container shipping operations. *Marit. Bus. Rev.* **2019**, *4*, 413–431. [[CrossRef](#)]
53. Ecer, F. Third-party logistics (3PLs) provider selection via Fuzzy AHP and EDAS integrated model. *Technol. Econ. Dev. Econ.* **2017**, *24*, 615–634. [[CrossRef](#)]
54. Gürçan, Ö.F.; Yazıcı, İ.; Beyca, Ö.F.; Arslan, Ç.Y.; Eldemir, F. Third Party Logistics (3PL) Provider Selection with AHP Application. *Procedia Soc. Behav. Sci.* **2016**, *235*, 226–234. [[CrossRef](#)]
55. Peng, J. Selection of Logistics Outsourcing Service Suppliers Based on AHP. *Energy Procedia* **2012**, *17*, 595–601. [[CrossRef](#)]
56. Khan, D.; Samadder, S.R. A simplified multi-criteria evaluation model for landfill site tanking and selection based on AHP and GIS. *J. Env. Eng. Landsc. Manag.* **2015**, *23*, 267–278. [[CrossRef](#)]
57. Chang, P.-Y.; Lin, H.-Y. Manufacturing plant location selection in logistics network using Analytic Hierarchy Process. *J. Ind. Eng. Manag.* **2015**, *8*, 1547–1575. [[CrossRef](#)]
58. Saaty, T.L. How to make a decision: The Analytic Hierarchy Process. *Eur. J. Oper. Res.* **2009**, *48*, 9–26. [[CrossRef](#)]
59. Sambasivan, M.; Fei, N.Y. Evaluation of critical success factors of implementation of ISO 14001 using analytic hierarchy process (AHP): A case study from Malaysia. *J. Clean. Prod.* **2008**, *16*, 1424–1433. [[CrossRef](#)]
60. Etikan, I. Comparison of Convenience Sampling and Purposive Sampling. *Am. J. Appl. Stat.* **2016**, *5*, 1. [[CrossRef](#)]
61. Goepel, K.D. Implementing the Analytic Hierarchy Process as a Standard Method for Multi-criteria Decision Making. In *Proceedings of the International Symposium on the Analytic Hierarchy Process*, Kuala Lumpur, Malaysia, 23–26 June 2013.
62. World Bank. *World Bank List of Economies*; World Bank: Washington: DC, USA, 2020.
63. Mostafa, N.; Hamdy, W.; Alawady, H. Impacts of internet of things on supply chains: A framework for warehousing. *Soc. Sci.* **2019**, *8*, 84. [[CrossRef](#)]
64. Aryal, A.; Liao, Y.; Nattuthurai, P.; Li, B. The emerging big data analytics and IoT in supply chain management: A systematic review. *Supply Chain Manag. Int. J.* **2018**, *25*, 141–156. [[CrossRef](#)]
65. Nawaz, S.S.; Thowfeek, M.H. Blockchain technology adoption by chain professionals. *Int. J. Psychosoc. Rehabil.* **2020**, *24*, 121–137. [[CrossRef](#)]
66. Zafarzadeh, M.; Wiktorsson, M.; Hauge, J.B.; Jeong, Y. Data-Driven Production Logistics—An Industrial Case Study on Potential and Challenges. *Smart Sustain. Manuf. Syst.* **2019**, *3*, 53–78. [[CrossRef](#)]
67. Kshetri, N. 1 Blockchain’s roles in meeting key supply chain management objectives. *Int. J. Inf. Manag.* **2018**, *39*, 80–89. [[CrossRef](#)]
68. Ooi, K.-B.; Lee, V.-H.; Tan, G.W.-H.; Hew, T.-S.; Hew, J.-J. Cloud computing in manufacturing: The next industrial revolution in Malaysia? *Expert Syst. Appl.* **2018**, *93*, 376–394. [[CrossRef](#)]

69. Yang, C.-S. Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *131*, 108–117. [[CrossRef](#)]
70. Hopkins, J.; Hawking, P. Big Data Analytics and IoT in logistics: A case study. *Int. J. Logist. Manag.* **2018**, *29*, 575–591. [[CrossRef](#)]
71. Mastos, T.D.; Nizamis, A.; Vafeiadis, T.; Alexopoulos, N.; Ntinias, C.; Gkortzis, D.; Papadopoulos, A.; Ioannidis, D.; Tzovaras, D. Industry 4.0 sustainable supply chains: An application of an IoT enabled scrap metal management solution. *J. Clean. Prod.* **2020**, *269*, 122377. [[CrossRef](#)]
72. Da Silva, A.; Gil, M.M. Industrial processes optimization in digital marketplace context: A case study in ornamental stone sector. *Results Eng.* **2020**, *7*, 100152. [[CrossRef](#)]
73. Pandey, S.; Singh, R.K.; Gunasekaran, A.; Kaushik, A. Cyber security risks in globalized supply chains: Conceptual framework. *J. Glob. Oper. Strat. Sourc.* **2020**, *13*, 103–128. [[CrossRef](#)]
74. Hsu, C.-W.; Yeh, C.-C. Understanding the factors affecting the adoption of the Internet of Things. *Technol. Anal. Strat. Manag.* **2017**, *29*, 1089–1102. [[CrossRef](#)]
75. Li, Z. A method on dynamic management of internet of things based on cloud computing architecture. *Int. J. Simul. Syst. Sci. Technol.* **2016**, *17*, 17.1–17.6. [[CrossRef](#)]
76. Yang, T.; Fu, C.; Liu, X.; Pei, J.; Liu, L.; Pardalos, P.M. Closed-loop supply chain inventory management with recovery information of reusable containers. *J. Comb. Optim.* **2018**, *35*, 266–292. [[CrossRef](#)]
77. Chong, A.Y.-L.; Liu, M.J.; Luo, J.; Keng-Boon, O. Predicting RFID adoption in healthcare supply chain from the perspectives of users. *Int. J. Prod. Econ.* **2015**, *159*, 66–75. [[CrossRef](#)]
78. Arora, A.K.; Rathi, P. Determinants for the Adoption of Digitalization by Manufacturing SMEs in India: An Empirical Study. *Prabandhan Indian J. Manag.* **2019**, *12*, 7–21. [[CrossRef](#)]
79. Kurpjuweit, S.; Schmidt, C.G.; Klockner, M.; Wagner, S.M. Blockchain in Additive Manufacturing and its Impact on Supply Chains. *J. Bus. Logist.* **2019**, *42*, 46–70. [[CrossRef](#)]
80. Mahroof, K. A human-centric perspective exploring the readiness towards smart warehousing: The case of a large retail distribution warehouse. *Int. J. Inf. Manag.* **2019**, *45*, 176–190. [[CrossRef](#)]
81. Mathauer, M.; Hofmann, E. Technology adoption by logistics service providers. *Int. J. Phys. Distrib. Logist. Manag.* **2019**, *49*, 416–434. [[CrossRef](#)]
82. Land, A.; Buus, A.; Platt, A. Data analytics in rail transportation: Applications and effects for sustainability. *Ieee Eng. Manag. Rev.* **2019**, *48*, 85–91. [[CrossRef](#)]
83. Billon, M.; Lera-Lopez, F.; Marco, R. Differences in digitalization levels: A multivariate analysis studying the global digital divide. *Rev. World Econ.* **2010**, *146*, 39–73. [[CrossRef](#)]
84. Ghobakhloo, M.; Fathi, M. Corporate survival in Industry 4.0 era: The enabling role of lean-digitized manufacturing. *J. Manuf. Technol. Manag.* **2020**, *31*, 1–30. [[CrossRef](#)]
85. Chen, S.-L.; Chen, Y.-Y.; Hsu, C. A New Approach to Integrate Internet-of-Things and Software-as-a-Service Model for Logistic Systems: A Case Study. *Sensors* **2014**, *14*, 6144–6164. [[CrossRef](#)] [[PubMed](#)]
86. Bag, S.; Yadav, G.; Wood, L.C.; Dhamija, P.; Joshi, S. Industry 4.0 and the circular economy: Resource melioration in logistics. *Resour. Policy* **2020**, *68*, 101776. [[CrossRef](#)]
87. Alfian, G.; Syafrudin, M.; Rhee, J. Real-Time Monitoring System Using Smartphone-Based Sensors and NoSQL Database for Perishable Supply Chain. *Sustainability* **2017**, *9*, 2073. [[CrossRef](#)]
88. Ferretti, M.; Schiavone, F. Internet of Things and business processes redesign in seaports: The case of Hamburg. *Bus. Process. Manag.* **2016**, *22*, 271–284. [[CrossRef](#)]
89. Jaeger, B.; Mishra, A. IoT Platform for Seafood Farmers and Consumers. *Sensors* **2020**, *20*, 4230. [[CrossRef](#)] [[PubMed](#)]
90. Shao, S.; Xu, G.; Li, M. The design of an IoT-based route optimization system: A smart product-service system (SPSS) approach. *Adv. Eng. Inform.* **2019**, *42*, 1–9. [[CrossRef](#)]
91. Wang, M.; Altaf, M.S.; Al-Hussein, M.; Ma, Y. Framework for an IoT-based shop floor material management system for panelized homebuilding. *Int. J. Constr. Manag.* **2020**, *20*, 130–145. [[CrossRef](#)]
92. Yadav, S.; Luthra, S.; Garg, D. Internet of things (IoT) based coordination system in Agri-food supply chain: Development of an efficient framework using DEMATEL-ISM. *Oper. Manag. Res.* **2020**, 1–27. [[CrossRef](#)]
93. Wang, W.; Zhang, Y.; Zhong, R.Y. A proactive material handling method for CPS enabled shop-floor. *Robot. Comput. Manuf.* **2020**, *61*, 61. [[CrossRef](#)]
94. Tsang, Y.P.; Choy, K.L.; Wu, C.H.; Ho, G.T.S.; Lam, H.Y.; Koo, P.S. An IoT-based cargo monitoring system for enhancing operational effectiveness under a cold chain environment. *Int. J. Eng. Bus. Manag.* **2017**, *9*, 1–13. [[CrossRef](#)]
95. Felsberger, A.; Qaiser, F.H.; Choudhary, A.; Reiner, G. The impact of Industry 4.0 on the reconciliation of dynamic capabilities: Evidence from the European manufacturing industries. *Prod. Plan. Control.* **2020**, 1–24. [[CrossRef](#)]
96. Gorecki, S.; Possik, J.; Zacharewicz, G.; Ducq, Y.; Perry, N. A multicomponent distributed framework for smart production system modeling and simulation. *Sustainability* **2020**, *12*, 6969. [[CrossRef](#)]
97. Parry, G.C.; Brax, S.A.; Maull, R.S.; Ng, I.C.L. Operationalising IoT for reverse supply: The development of use-visibility measures. *Supply Chain Manag. Int. J.* **2016**, *21*, 228–244. [[CrossRef](#)]
98. Liu, S.; Zhang, Y.; Liu, Y.; Wang, L.; Wang, X.V. An ‘Internet of Things’ enabled dynamic optimization method for smart vehicles and logistics tasks. *J. Clean. Prod.* **2019**, *215*, 806–820. [[CrossRef](#)]

99. Zhao, Z.; Zhang, M.; Xu, G.; Zhang, D.; Huang, G.Q. Logistics sustainability practices: An IoT-enabled smart indoor parking system for industrial hazardous chemical vehicles. *Int. J. Prod. Res.* **2020**, *58*, 7490–7506. [[CrossRef](#)]
100. Zerbino, P.; Aloini, D.; Dulmin, R.; Mininno, V. Towards Analytics-Enabled Efficiency Improvements in Maritime Transportation: A Case Study in a Mediterranean Port. *Sustainability* **2019**, *11*, 4473. [[CrossRef](#)]
101. Moldabekova, A.; Philipp, R.; Satybaldin, A.A.; Prause, G. Technological Readiness and Innovation as Drivers for Logistics 4.0. *J. Asian Financ. Eco-Nomics Bus.* **2021**, *8*, 145–156. [[CrossRef](#)]
102. World Economic Forum. *World Economic Forum White Paper. Digital Transformation of Industries: Logistics Industry*; World Economic Forum: Geneva, Switzerland, 2016.
103. Di Vaio, A.; Varriale, L. Digitalization in the sea-land supply chain: Experiences from Italy in rethinking the port operations within inter-organizational relationships. *Prod. Plan. Control* **2020**, *31*, 220–232. [[CrossRef](#)]
104. Pisa, M.; McCurdy, D. *Improving Global Health Supply Chains through Traceability*; Center for Global Development: Washington, DC, USA, 2019.
105. Arif, J.; Azzouz, K.; Mouzouna, Y.; Jawab, F. Design on improvement of traceability process in the outsourcing of logistics' activities using the internet of things (IoT) applications. *Int. J. Adv. Sci. Technol.* **2020**, *29*, 1093–1108.
106. Ju, M.; Osako, M.; Harashina, S. Food loss rate in food supply chain using material flow analysis. *Waste Manag.* **2017**, *61*, 443–454. [[CrossRef](#)]
107. Van der Vorst, J.G.; Snels, J. *Developments and Needs for Sustainable Agro-Logistics in Developing Countries*; World Bank: Washington, DC, USA, 2014.
108. Bhat, R.; Jöudu, I. Emerging issues and challenges in agri-food supply chain. In *Sustainable Food Supply Chains: Planning, Design, and Control through Interdisciplinary Methodologies*; Elsevier: Bologna, Italy, 2019.
109. Yan, R. Optimization approach for increasing revenue of perishable product supply chain with the Internet of Things. *Ind. Manag. Data Syst.* **2017**, *117*, 729–741. [[CrossRef](#)]
110. Fernandez-Carames, T.M.; Blanco-Novoa, O.; Froiz-Miguez, I.; Fraga-Lamas, P. Towards an Autonomous Industry 4.0 Warehouse: A UAV and Blockchain-Based System for Inventory and Traceability Applications in Big Data-Driven Supply Chain Management. *Sensors* **2019**, *19*, 2394. [[CrossRef](#)] [[PubMed](#)]
111. Katayama, M.; Nakada, H.; Hayashi, H.; Shimizu, M. Survey of RFID and Its Application to International Ocean/Air Container Tracking. *Ieice Trans. Commun.* **2012**, *E95B*, 773–793. [[CrossRef](#)]
112. Lopez, T.S.; Ranasinghe, D.C.; Harrison, M.; McFarlane, D. Adding sense to the Internet of Things An architecture framework for Smart Objective systems. *Pers. Ubiquitous Comput.* **2012**, *16*, 291–308. [[CrossRef](#)]
113. Ghobakhloo, M. The future of manufacturing industry: A strategic roadmap toward Industry 4.0. *J. Manuf. Technol. Manag.* **2018**, *29*, 910–936. [[CrossRef](#)]
114. Cichosz, M.; Wallenburg, C.M.; Knemeyer, A.M. Digital transformation at logistics service providers: Barriers, success factors and leading practices. *Int. J. Logist. Manag.* **2020**, *31*, 209–238. [[CrossRef](#)]