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Implementation of digital technologies in logistics systems of low-income countries

An assessment based on case studies in Ethiopia

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Abstract

Digital technologies have significant potential in enhancing logistics performance. However, the adoption of digital technologies is limited in low-income countries. Therefore, it is important to investigate their potential impact on logistics performance and how they can be introduced. Using Ethiopia as a case study, this thesis evaluated the possibilities of adopting digital technologies in logistics systems in low-income countries and analysed factors influencing their adoption.

An assessment of current practices in digital technologies adoption in logistics identified transport and warehouse performance indicators (PIs) relevant to low-income countries. In a logistics audit, the performance of the Ethiopian coffee and dairy supply chains was evaluated in terms of digital technologies implementation. A technology acceptance model (TAM) was then used to estimate stakeholder acceptance of digital technologies. Finally, a framework for digital technology adoption was developed.

Security and order lead time were identified as important PIs in low-income countries. Further analysis revealed limited adoption of digital technologies in the coffee and dairy supply chains, although the coffee supply chain performed better in terms of digital technology implementation. Optimisation of facilities, routes and resources in the dairy supply chain led to reduced distance and travel time. Stakeholder perceptions of digital technologies and factors such as infrastructure, finance, technology access, human resources and supportive policies contributed to successful adoption. A framework for digital technology adoption using two approaches, gradual digitalisation and end-to-end digitalisation, was developed. These findings can assist policy-makers and practitioners in assessing the current adoption level and in identifying challenges to advance implementation of digital technologies in low-income countries.

Keywords: logistics, supply chain, transportation, low-income countries, digital technologies

Införande av digital teknik i logistiksystem

En analys baserad på fallstudier i Etiopien

Abstract

Digital teknik har stor potential att förbättra logistikprestanda. Användningen av digital teknik är dock begränsad i låginkomstländer. Det är därför mycket viktigt att undersöka vilka effekter de kan medföra på logistikprestanda och hur de kan introduceras. Med Etiopien som fallstudie har detta arbete utvärderat studie möjligheterna att använda digital teknik i logistiksystem i låginkomstländer och analyserat faktorer som påverkar dess användning.

En analys av nuvarande praxis för införande av digital teknik i logistik identifierade nyckeltal för logistikprestanda inom transport och lagerhantering (PI) som är relevanta för låginkomstländer. I en logistikanalys utvärderades prestanda för etiopiska försörjningskedjor för kaffe- och mejeriprodukter med avseende på införandet av digital teknik. En teknikacceptansmodell (TAM) användes sedan för att värdera intressenternas acceptans för digital teknik. Slutligen utvecklades ett ramverk för införande av digital teknik.

Säkerhet och ledtider identifierades som viktiga indikatorer i låginkomstländer. Vidare visade på begränsad användning av digital teknik i försörjningskedjorna för kaffe och mejeriprodukter, även om kaffe presterade bättre med avseende på implementering av digital teknik. Optimering av anläggningar, rutter och resurser i mejeriförsörjningskedjan ledde till minskad sträcka och restid. Intressenternas uppfattningar om digital teknik och faktorer som infrastruktur, ekonomi, tillgång till teknologi, mänskliga resurser och stödjande policy bidrog till framgångsrikt införande. Ett ramverk för införande av digital teknik med två ansatser, gradvis digitalisering och genomgripande digitalisering, utvecklades. Dessa resultat kan hjälpa beslutsfattare och utförare att bedöma den nuvarande nivån av implementering och att identifiera utmaningar för vidare införande av digital teknik i låginkomstländer.

Nyckelord: logistik, försörjningskedja, transport, låginkomstländer, digital teknik

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Tadesse, M.D., Gebresenbet, G., Tavasszy, L. & Ljungberg, D. (2021). Assessment of digitalized logistics for implementation in low-income countries. Future Transportation 1, 227-247.

II. Tadesse, M.D., Kine, H.Z., Gebresenbet, G., Tavasszy, L. & Ljungberg, D. (2022). Performance indicators in low-income countries: The case of the import-export chain in Ethiopia. Sustainability 14 (19).

III. Tadesse, M.D., Gebresenbet, G., Tavasszy, L. & Ljungberg, D. (2024). Digital traceability capabilities: The case of the Ethiopian coffee supply chain. International Journal of Logistics Management (submitted).

IV. Jote, F.A., Tadesse, M.D., Gebresenbet, G., Tavasszy, L. & Ljungberg, D. (2024). Assessing the logistics of the dairy supply chain in low-income countries: A case study in Ethiopia. Research in Transportation Business and Management (submitted).

V. Tadesse, M.D., Gebresenbet, G., Ljungberg, D. & Tavasszy, L. (2024). The technology acceptance model for digitalized logistics in low-income countries: The case of Ethiopia. Research in Transportation Business and Management (submitted).

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The contribution of Mahlet Demere Tadesse to the papers included in this thesis was as follows:

I. Planned the research, carried out the literature review, administered the expert survey and performed the analysis. Wrote the paper with contributions from the co-authors.

II. Planned the research, carried out the literature review, administered the expert survey and performed the analysis. Wrote the paper with contributions from the co-authors.

III. Planned the research and carried out data collection. Wrote the paper with contributions from the co-authors.

IV. Planned the research, carried out data collection and performed the analysis. Wrote the paper with contributions from the co-authors.

V. Planned the research, carried out data collection, performed the analysis and built the model. Wrote the paper with contributions from the co-authors.

List of tables

List of figures

Abbreviations

AHP	Analytical hierarchy process
AI	Artificial intelligence
AT	Attitude
AVE	Average variance extracted
BDA	Big data analytics
BI	Behavioural intention
CC	Cloud computing
CFA	Confirmatory factor analysis
CFI	Comparative fit index
CI	Consistency index
CLU	Coffee Liquoring Unit
CR	Consistency ratio
CSA	Central Statistical Agency
ECX	Ethiopian Commodity Exchange
FAO	Food and Agricultural Organization
FSIN	Food Security Information Network
GNI	Gross national income
GPS	Global positioning systems
HR	Human resource

ICT	Information and communication technology
IoT	Internet of things
KMO	Kaiser-Meyer-Olkin
PEU	Perceived ease of use
PI	Performance indicators
PU	Perceived usefulness
QR Codes	Quick response codes
RFID	Radio frequency identification
RI	Random index
RMSEA	Root mean square error of approximation
SEM	Structural equation modelling
SME	Small and medium sized enterprise
SMS	Short message service
SRMR	Standardised root mean square residual
TAM	Technology acceptance model
TLI	Tucker Lewis index
USD	United States dollars
VRP	Vehicle routing problem
WFP	World Food Program

1. Introduction

Low-income countries, defined by the World Bank as nations with gross national income (GNI) below 1085 USD (World Bank, 2021), have poorer logistics performance than middle and high-income countries (Arvis *et al.*, 2018; Çelebi, 2019). There are 26 countries worldwide classified as low-income countries, of which 22 are located in Sub-Saharan Africa (World Bank, 2021). The logistics system of countries in this income group is characterised by long lead times (Yang & Chang, 2019), lack of adequate infrastructure (Rabiya & Edward, 2016) and high operational costs (Rabiya & Edward, 2016). Their transportation industry suffers from high fuel consumption and maintenance costs, resulting from the use of aged trucks (Arvis *et al.*, 2010), poor road infrastructure, low truck availability and frequent traffic accidents caused by incompetent drivers (Tadesse *et al.*, 2022). Warehouses in these countries suffer from inadequate storage conditions, lack of skilled personnel and limited technology availability (Georgise & Mindaye, 2020; Tadesse *et al.*, 2022).

The agri-food sector in low-income countries is of vital importance in sustaining its inhabitants, but it is comparatively complex, especially for perishable items such as fresh fruits, vegetables and dairy products. This complexity arises from the involvement of multiple stakeholders throughout the supply chain and the necessity for increased care during transportation and storage (Guner & Utku, 2021). In addition, the sector experiences seasonal fluctuations in both demand and supply, further contributing to its complex nature.

In 2022, 258 million people worldwide faced acute food insecurity (FSIN & Global Network Against Food Crises, 2023), with low-income countries most significantly impacted (FAO & WFP, 2022). One of the contributors to food insecurity in low-income countries is food waste and losses along the agri-food supply chain (FAO, 2015). In Sub-Saharan Africa, 52% of fruit and vegetables and 25% of dairy products are lost (Nicastro & Carillo, 2021), due to inappropriate transport and storage facilities (Gebresenbet & Mpagalile, 2015). Therefore, an efficient logistics system is vital for ensuring food security in low-income countries.

Digital technologies have emerged as key enablers for enhancing logistics performance (Ekici *et al.*, 2019; World Bank, 2016), by reducing operational costs in supply chains (World Bank, 2016). Technologies such as blockchain, the Internet of Things (IoT), barcodes, quick response (QR) codes, cloud computing (CC), and global positioning system (GPS) have been used for optimising the performance of logistics at various stages of the supply chain. However, there is limited adoption of digital technologies in low-income countries, due to the cost of implementation and the economic limitations of supply chain stakeholders (Kittipanya-Ngam & Tan, 2020a).

Previous studies have explored implementation of digital technologies across various sectors. For instance, Bettín-Díaz *et al.* (2018) studied adoption of blockchain in the food supply chain taking Columbia as a case study, while Mondragon *et al.* (2020) developed a digitalisation framework tailored for the fishery sector. Other studies have investigated digital technology adoption potential in rural communities in developing countries (Abdulai *et al.*, 2023; Deichmann *et al.*, 2016), the challenges associated with digitalisation in developing countries such as Pakistan (Jamil, 2021), the impact of digitalisation on logistics performance (Moldabekova *et al.*, 2021), and the drivers of digitalisation in the manufacturing sector (Yang *et al.*, 2021). Given the significant potential of digital technologies in improving logistics performance, it is vital to investigate their adoption possibilities and subsequent effects on logistics performance in low-income countries. It is also crucial to assess the factors influencing technology adoption in these regions, to ensure effective implementation and enable future improvements in logistics performance.

Against this background, this thesis addressed several gaps in knowledge concerning performance in the transportation and warehousing sector, adoption of digital technology for logistics in the agri-food sector in low-income countries, and the behavioural intention of stakeholders to adopt these technologies in low-income countries. Chapter 2 introduces the aims of the work and the research questions addressed.

2. Aim and Structure

2.1 Aim

The overall aim of this thesis was to assess the possibility for implementation of digital technologies to improve logistics performance in low-income countries. Specific objectives of the work were to:

- Assess current practices in digital logistics that could improve logistics performance in low-income countries (Paper I).
- Identify performance indicators (PIs) suitable for characterising logistics operations in low-income countries (Paper II).
- Evaluate logistics performance in low-income countries in relation to the implementation of digital technologies (Papers III and IV).
- Model acceptance of digital technologies by stakeholders in low-income countries (Papers V).

In order to assess the possibility for integrating digital technologies into the logistics operations of low-income countries, it is crucial to first understand the current status of digital technology adoption in these countries. Thus, the following research question (RQ) was addressed in this thesis:

- RQ1: How are low-income countries performing concerning the adoption of digital technologies in their logistics operations? (Papers II, III and IV)

Adoption and implementation of digital technologies are influenced by a range of factors. While there are common drivers for technology adoption across all countries, there are specific challenges that are unique to low-income countries. To identify these challenges, the following research question was addressed in this thesis:

- RQ2: What are the factors influencing technology adoption in low-income countries? (Paper I and Paper V)

2.2 Scope and study limitations

The scope of this thesis was to explore the possibility for adopting digital technologies in the logistics system of low-income countries, with specific focus on the agri-food sector. This is illustrated in Figure 1 as the intersection of three conceptual circles representing the focus of this thesis.

To exemplify the current implementation level of digital technologies and their possibility for adoption, the coffee and dairy supply chains were examined in case studies conducted on diverse stakeholders in these supply chains in the context of Ethiopia. Logistics processes, including product handling, transportation and storage, were investigated from production to export for the coffee supply chain and from production to domestic consumption for the dairy supply chain. Limitations and scope of the studies are described in more detail within the respective papers.

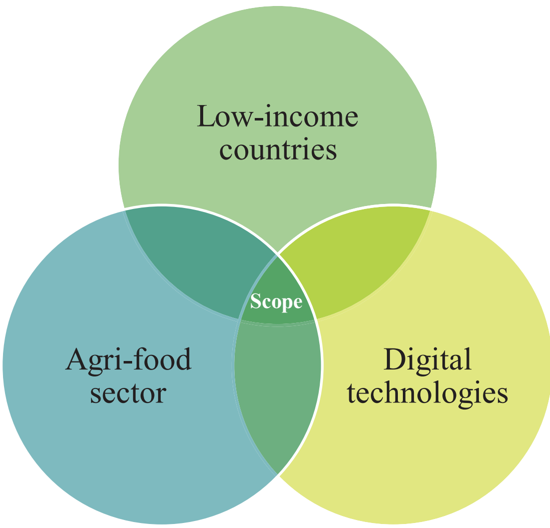


Figure 1. Scope of the work in this thesis

2.3 Thesis structure

The work described in Papers I-V aimed to improve understanding of digital technology adoption and its impact on logistics in low-income countries. Together, these studies provided insights into the challenges and opportunities of adoption, with specific insights drawn from the coffee and dairy supply chain in Ethiopia. A graphical representation of the research framework is provided in Figure 2.

In Paper I, a systematic literature review was conducted to assess current practices in logistics concerning the implementation of digital technologies and to identify factors influencing adoption of digital logistics technologies in low-income countries.

The focus in Paper II was on identifying PIs suitable for low-income countries, using Ethiopia's import-export chain as a case study. The study compared PIs from middle and high-income countries and then assessed their suitability for the context of low-income countries.

In Paper III and Paper IV, case studies were conducted on the coffee and dairy supply chain in Ethiopia. The performance of these supply chains was evaluated regarding adoption of digital logistics technologies and interventions such as traceability, digitalisation and optimisation.

Paper V comprised an empirical study on technology adoption and diffusion. A model of behavioural intention of stakeholders in Ethiopia to adopt digital logistics technologies was developed using a technology acceptance model (TAM) as a framework.

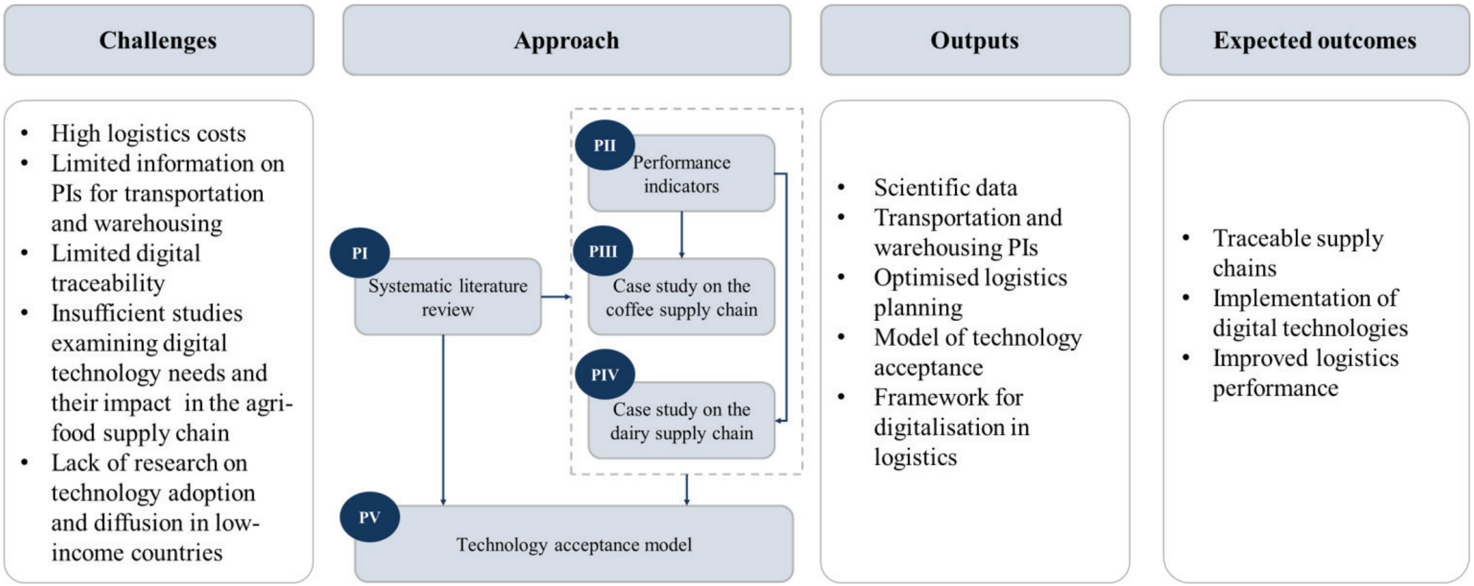


Figure 2. Graphical representation of the research framework applied in this thesis

3. Literature Review

This chapter presents the scientific background to the various topics covered in the thesis. First, PIs for transportation and warehouse operations in developing countries are discussed. Next, the literature regarding digitalisation in logistics and the key processes that are improved as a result are summarised. Finally, some important areas for research are introduced.

3.1 Logistics performance

Logistics, as one component of supply chain management, serves the purpose of ensuring that goods, finances, information and services move from production to consumption in an effective and efficient manner (CSCMP, 2013). Logistics plays a significant role in the economic development of nations (Moldabekova *et al.*, 2021; Rashidi & Cullinane, 2019; Saidi *et al.*, 2020) and imparts competitive advantages to firms (Arvis *et al.*, 2018). For example, an efficient logistics system enables companies to manage their inventory efficiently, minimise losses and plan their collections and distributions. It also leads to cost reductions, thereby enhancing transportation systems and establishing reliable supply chains (Arvis *et al.*, 2018). Measuring logistics performance is crucial in benchmarking best practices and identifying sector-specific challenges and opportunities (Çelebi, 2019). It also helps in eliminating non-value-adding activities within the supply chain (Gunasekaran *et al.*, 2001).

Identifying PIs across strategic, tactical and operational levels is a vital initial step in measuring logistics performance. These indicators play a crucial role in identifying short-term and long-term interventions (Gunasekaran *et al.*, 2001) that are necessary for enhancing overall logistics efficiency, cost-effectiveness, sustainability and service quality (Tadesse *et al.*, 2022).

Logistics encompasses a series of activities, such as transportation and warehousing (Arvis *et al.*, 2018; Frazelle, 2002), to ensure that goods reach customers at the lowest possible cost (Gunasekaran *et al.*, 2001). Transportation, the core component of the logistics sector, serves as a link between transport infrastructure (*e.g.* ports, distribution centres, terminals) and various entities (e.*g*. warehouses, retail shops, production sites) within companies' supply chains. Ideally, it connects stakeholders located upstream and downstream in the supply chain in an efficient and effective manner (Lai *et al.*, 2002). Warehousing is another important value-adding activity in the logistics sector, as it facilitates storage, accumulation and consolidation of products starting from production until the goods reach end-users. One of the objectives of warehouse management is optimising productivity and minimising operational costs, thereby improving overall operations (Chen *et al.*, 2017).

3.2 Digital technologies

Digitalisation involves transformation of key processes by utilising digital technologies. Digitalisation, as defined by McFadden *et al.* (2022), refers to the technological transformation and use of information and communication technologies (ICT) such as internet, mobile devices and data analytics. The process of digitalisation results in socioeconomic and environmental changes stemming from transformed industries (Gradillas & Thomas, 2023). A study by Moldabekova *et al.* (2021) identified a strong correlation between digitalisation and logistics performance on country level. Those authors concluded that integrating digital technologies for various logistics activities would improve the logistics performance of nations, as reflected in reduced logistics costs, efficient inventory management, advanced information sharing, reduced lead times and timeliness in deliveries. All these improvements would in turn promote the economic growth of nations (Ekici *et al.*, 2019).

3.2.1 Product identification technologies

Before the widespread adoption of digital technologies in logistics, product identification and labelling were primarily carried out with the use of alpha-numerical codes (Šenk *et al.*, 2013). However, the advent of digital technologies, such as barcodes, quick response (QR) codes and radio frequency identification (RFID), has transformed product identification processes.

Barcodes are optical machine-readable representations of data that show information about the object to which they are attached when scanned using an optical scanner (Shi *et al.*, 2011). QR codes are special forms of barcodes that can store more information. Another advantage of QR codes over barcodes is that they do not require a dedicated reader and users can instead use their smartphones to identify the object (Tan & Ngan, 2020). This feature makes QR codes a preferable alternative to barcodes.

Alternatively, RFID can be used for automated product identification and communication through radio waves (Alwadi *et al.*, 2017). This technology has several advantages, including long-distance identification, fast reading speed and high reliability (Feng *et al.*, 2019), resulting in increased efficiency of industries (Katayama *et al.*, 2012). RFID technology has numerous practical applications in logistics operations, including warehouse management, object tracking and transportation (Zhao *et al.*, 2014). It has also been used to reduce the loss rate of products, theft and goods damage (Katayama *et al.*, 2012; Shi *et al.*, 2011) and for warehouse and inventory management to locate inventory, consequently reducing lead times (Zhang *et al.*, 2014). RFID has become the leading technology for automatic identification (Lopez *et al.*, 2012), mainly because barcodes and QR codes can only read objects that are in the line of sight of the reader (Fernández-Caramés *et al.*, 2019; Katayama *et al.*, 2012). However, barcodes and QR codes are still widely implemented in supply chains because of their low cost.

3.2.2 Technologies for data storage

Paper-based systems are the oldest and most common form of data storage in most supply chains. They have been preferred by most emerging economies in the past, due to the low associated cost (Setboonsarng *et al.*, 2009). However, electronic record-keeping has become common practice in the digital era. In this type of system, data can be stored in centralised or decentralised systems.

In centralised systems, internal hardware or cloud-based databases can be used to store data collected from supply chains. The database can either be internally developed by the organisation or external (Bravo *et al.*, 2022). Cloud computing (CC) is one of the technologies that has gained in popularity as the amount of data that needs to be stored has increased, making data storage on physical devices difficult (Narwane *et al.*, 2020). Companies can benefit from subscribing to cloud services because they can reduce or even eliminate premise-related expenses relating to *e.g*. software, hardware and maintenance (Adamson *et al.*, 2017). Cloud-based systems are operationally efficient and ensure faster information sharing in the supply chain (Setboonsarng *et al.*, 2009).

Decentralised cloud-based databases have also emerged as storage solutions in the current digital era. Blockchain is one of the novel technologies that has emerged most strongly as a decentralised database. It is a distributed database of transactional records where data are stored in the form of blocks (Kurpjuweit *et al.*, 2019; Longo *et al.*, 2019). It is designed to facilitate transmission of immutable information among stakeholders (Bumblauskas *et al.*, 2020), avoids discrepancies and disputes that usually occur in supply chains (Collart & Canales, 2022), and increases trust among supply chain members (Longo *et al.*, 2019). It also eliminates the need for central authorities to validate transactions (Sharma, 2021; Wang *et al.*, 2019) and instead uses the consensus reached among stakeholders to make transactions valid. Blockchain is advantageous for storing information on the characteristics of products, along with historical data (Rane & Thakker, 2019). This could theoretically be beneficial in the agri-food supply chain, as it can guarantee the safety and quality of products by providing product history. However, implementing blockchain faces challenges such as complexity of the technology and scalability issues (Bettín-Díaz *et al.*, 2018). In addition, the considerable initial investment and high maintenance costs, coupled with the necessity for highly skilled personnel to operate the technology, pose significant implementation challenges (Rejeb *et al.*, 2020).

3.2.3 Product monitoring technologies

Product monitoring in logistics can done with the use of sensors embedded in objects that perform the function of collecting data from the environment and sending that information to a remote server (Alfian *et al.*, 2017), or storing it locally. Sensors have various applications in logistics, *e.g*. they have been applied in the fishery sector by Mondragon *et al.* (2020), while Liu, Zhang*, et al.* (2019) applied sensors to obtain real-time logistics information to enable route optimisation for smart vehicles to enable efficient, green and sustainable logistics systems.

Supply chains worldwide are becoming increasingly 'smart' with the use of IoT, where regular objects have the ability to interact with each other through connecting to a common network (Alwadi *et al.*, 2017). Organisations can function more smoothly when IoT is integrated into their systems (Aeknarajindawat, 2019), as it enables them to ensure supply chain efficiency and quality through product monitoring, tracking and tracing (Garrido-Hidalgo *et al.*, 2019; Han *et al.*, 2015) in real-time applications (Choi *et al.*, 2018).

The data generated from IoT devices can be analysed using big data analytics (BDA) (Keivanpour & Daoud Ait, 2018). This involves analysis of massive and complicated data (Florence & Shyamala Kumari, 2019) characterised by high volume, velocity, variety, veracity and value (Narwane *et al.*, 2020). BDA can play a significant role in reducing logistics costs, improving the relationships among stakeholders, and increasing sales and operations planning abilities (Gawankar *et al.*, 2020).

3.2.4 Technologies for acquiring geospatial information

The global positioning system (GPS) is the most widely used satellite-based positioning system developed by the United States. GPS uses information from satellites to determine the location of an object (Berney, 2008), making it possible to optimise logistics activities (UNCTAD, 2023). Nowadays, usage of in-vehicle GPS systems is common, due to the relatively low cost of installing GPS devices on trucks. In addition to identifying the location of products (Abeyratne, 2016), GPS has been used to plan routes and provide real-time traffic information (Chen & Chen, 2011).

Other satellite-based positioning systems include the Russian GLONASS and the European GALILEO. In addition, the location of objects can be acquired using cellular networks, Wi-Fi systems and RFID. Although these technologies are widely implemented, satellite-based positioning systems give more precise location information (Grejner-Brzezinska & Kealy, 2013).

3.2.5 Traceability in logistics

Traceability involves the tracking and tracing of products as they move along the supply chain (Bosona & Gebresenbet, 2013). It has become a priority in most supply chains, due to the added benefits of a well-functioning tracking and tracing system, including providing reliable services (Çelebi, 2019). In addition, the demand by customers to purchase traceable items, especially food products, has made traceability a vital component of most supply chains (Liu, Chen, *et al.*, 2019). This is because customers nowadays are more inclined to buy traceable food items (Dionysis *et al.*, 2022), where they have access to product data including production, harvesting, processing, transportation and storage information (Šenk *et al.*, 2013).

Stakeholders can choose between different traceability systems, which may be paper-based or digital (Bosona & Gebresenbet, 2013). However, a successful traceability system requires the participation of all supply chain members (Çelebi, 2019; Kelepouris *et al.*, 2007). Implementation of a successful traceability system also requires significant investment (Bravo *et al.*, 2022), especially if the traceability system to be implemented is of a digital nature.

3.2.6 Artificial intelligence (AI)

Artificial intelligence (AI) has become an important tool with the potential to enhance modern logistics. Owing to the vast amount of data generated from IoT devices, AI has numerous applications in supply chains. It assists in automating decision-making and providing insights from real-time data (Chen & Liao, 2023). Besides data analysis from IoT devices, AI is becoming an import at tool in enhancing and automating warehouse operations. It has the potential to aid truck drivers by regulating vehicle speed and maintaining safe distances from other vehicles (Loske & Klumpp, 2021). The potential applications of AI also extend to route planning by efficiently processing real-time data (Loske & Klumpp, 2021).

3.3 Summary

There is widespread under-utilisation of digital technologies by firms in low-income countries. Given the considerable potential of digital technologies and the prevailing logistics trends favouring their adoption, it is crucial to evaluate their feasibility for implementation, taking into account the context of low-income countries. This calls for research addressing the actual necessity for digitalised logistics practices in these regions. In addition, research is needed to assess technology adoption and diffusion within the context of low-income countries.

Previous research on identifying PIs for transportation and warehouse activities focused on their identification at global and local scale. Some studies have attempted to assign weights to these indicators (Hanaoka & Kunadhamraks, 2009; Lam *et al.*, 2015; Srisawat *et al.*, 2017), aiding stakeholders in identifying crucial PIs relevant to their specific context. However, as logistics systems and operational bottlenecks vary significantly between low-income countries and developed nations, it is imperative to assess the indicators deemed important by stakeholders from countries in different income groups, to identify areas for improvement in the sector.

The supply chain structure in low-income countries differs notably from that of its higher-income counterparts, chiefly due to its fragmented nature and heavy reliance on smallholder farmers for production (Setboonsarng *et al.*, 2009). In addition, primary causes of losses in the agri-food supply chain of low-income countries stem from post-harvest inefficiencies, such as inadequate planning, poor material handling, and technical and infrastructural limitations (Chaboud & Moustier, 2021). Consequently, exploring context-tailored solutions for low-income countries is imperative to address the challenges and limitations in their supply chains.

4. Materials and Methods

This thesis explored the possibility for implementing digital technologies in low-income countries, using Ethiopia as a case study. To assess the current performance of Ethiopian supply chains regarding digital technology implementation and to identify factors influencing their adoption, several different methodologies were employed. Analytical hierarchy process (AHP) was used to assign weightings to PIs related to transportation and warehousing (Paper II). A logistics audit was performed on the coffee and dairy supply chain in Ethiopia, to assess traceability, digital technology implementation, and operational efficiency (Paper III and Paper IV). This audit included facility location analysis and route optimisation to improve collection and distribution within the dairy supply chain (Paper IV). Structural equation modelling (SEM) was employed to assess stakeholder acceptance of digital technologies in low-income countries (Paper V). A detailed description of each method is presented below.

4.1 Analytical hierarchy process (AHP)

Analytical hierarchy process is a common multi-criteria decision-making framework that aims to quantify the opinions of experts by conducting expert surveys and assigning weights to each alternative. Originally developed in 1987, AHP transforms subjective expert opinions into objective values by employing a hierarchical structure and pairwise comparisons (Saaty, 1987). This is achieved by presenting experts with a list of alternatives and having them assess the relative importance of each alternative using a Likert scale with values ranging from 1 (equally important) to 9 (extremely important).

The initial step in AHP involves identifying the indicators for comparison (Chang & Lin, 2015). Experts are then asked to conduct pairwise comparisons on the indicators, based on the scale outlined by Saaty (1987). Finally, the weightings of each criterion and the consistency ratio (CR) are computed (Chang & Lin, 2015). The CR value is obtained from the maximum eigenvalue (λ_{max}) by calculating the consistency index (CI) using Equation (1), obtaining the random index (RI) from Saaty (2009), and then finding the ratio between CI and RI (Equation (2)):

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

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

where *n* is the total number of alternatives.

For calculated weightings to be valid, CR should be less than 10%. Otherwise, the weightings should be revised and the experts should be consulted to check if they agree with the newly assigned weightings (Saaty, 2009).

In this thesis, PIs for assessing logistics performance in low-income countries were identified, specifically focusing on transportation and warehousing. A literature review was conducted to identify global PIs and those specific to low-income countries. Experts were then consulted to select relevant indicators pertinent to low-income countries. The transportation and warehousing PIs and those selected by the experts are described in Paper II.

Following identification of indicators, logistics experts actively engaged in Ethiopia's import and export chain, and possessing significant experience in the sector, were tasked with conducting pairwise comparisons. Selection of these experts was performed using a convenience sampling technique, where experts willing to participate in the survey were requested to conduct pairwise comparisons. Accordingly, 35 importers/exporters and 18 freight forwarders were included in the survey.

4.2 Logistics audit

Two supply chains in Ethiopia were taken as case studies to evaluate their performance in terms of factors such as goods handling during transportation and storage, adoption of traceability and digital technologies, and efficient utilisation of facilities, routes and resources. These were the coffee supply chain (Paper III) and the dairy supply chain (Paper IV). The reasoning behind selecting these supply chains as case studies was to represent both the export (coffee) and domestic (dairy) supply chains in Ethiopia. Both supply chains were analysed by following the flow of goods from production to consumption, facilitated by conducting a logistics audit as a primary evaluation tool.

A logistics audit comprises a set of assessments aimed at analysing the performance of logistics systems (Wawrzynowicz & Wajszczuk, 2012). Carrying out a logistics audit aids in identifying the current state of the system, recognising challenges found in the system and formulating measures that could improve the performance of the system (Frazelle, 2002; Sekulová *et al.*, 2014). A successful logistics audit involves identifying the main logistics activities and the key stakeholders within their respective supply chains. In this thesis, this was accomplished through primary desk studies, interviews with key informants and field visits conducted in the study areas.

Logistics audits for the coffee and dairy supply chains were performed in different study areas. Specifically, for the coffee supply chain, interviews were conducted with a range of stakeholders, including eight smallholder farmers from the Sidama region, 30 coffee exporters (12 of whom had commercial farms throughout Ethiopia), 10 transportation companies responsible for coffee bean transport from different Ethiopian regions to Addis Ababa and from Addis Ababa to the port of Djibouti, one large-scale coffee processing firm, and five key informants from the Ethiopian Coffee and Tea Authority and the Coffee Liquoring Unit in Ethiopia (CLU) (Table 1). These interviews were complemented with visits to smallholder coffee farms, a coffee washing station, a large-scale coffee processing firm and CLU.

Table 1. *Stakeholders in the Ethiopian coffee and dairy supply chains interviewed in case studies*

Stakeholder	Supply chain	
	Coffee	Dairy
Smallholder farmers	8	5
Commercial farmers	12	1
Processors	1	3
Exporters	30	-
Government officials	5	-
Cooperatives	-	6
Transportation companies	10	-

Three major dairy processing companies (referred to as Company A, Company B and Company C) responsible for processing and marketing of dairy products were chosen for the logistics audit of the dairy supply chain. Company A is located in Addis Ababa, Company B in Sebeta (approximately 24 km south-west of Addis Ababa) and Company C in Sululta (approximately 32 km north-west of Addis Ababa) (Figure 3). These companies are actively engaged in collection of raw milk from various regions across the country and distribution of processed milk within Addis Ababa. The logistics audit also included Assela, a small town located 164 km south of Addis Ababa, and surrounding regions, as one of the areas from which Company A collects raw milk (Figure 3).

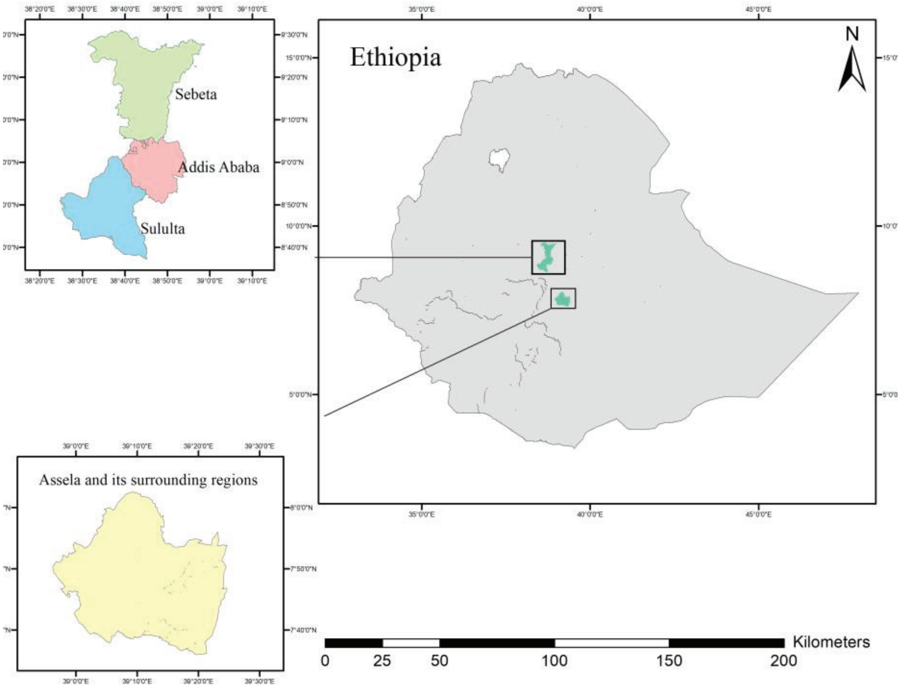


Figure 3. Maps of the study areas for the logistics audit on the Ethiopian dairy supply chain

As part of the logistics audit on the dairy supply chain, further investigations focusing on Company A were carried out. This involved evaluating the placement of the company's chilling centre in Assela through location analysis. In addition, route planning and management for distributing processed dairy products in Addis Ababa were studied, using the vehicle routing problem (VRP) approach.

4.2.1 Location analysis

Location analysis involves positioning logistics facilities such as warehouses, distribution centres and depots at optimal locations, considering factors such as volume of collected/distributed goods and locations of available customers. This process is highly beneficial, as it assists stakeholders in making strategic decisions on facility placement, especially in areas with concentrated orders.

In the dairy supply chain of low-income countries, strategic placement of chilling centres at reasonable distances from farmers and collection points is of significant importance. This is because there are limited number of chilling centres serving a single area and because milk travels under unrefrigerated conditions starting from farm level through the collection points until it reaches the chilling centre (Lokuruka, 2016; Van Campenhout *et al.*, 2021; Yilma *et al.*, 2011). Thus, to reduce the risk of spoilage of fresh milk, it is vital to locate facilities such as chilling centres in optimal positions.

The centre of gravity method is commonly used for determining the ideal location of logistics facilities (Irwanto & Hasibuan, 2018). In Paper IV, this method was applied to optimise raw milk collection within the Ethiopian dairy supply chain. The analysis involved assessing the current location of the chilling facility for Company A in Assela (Figure 3). The choice of Assela for conducting facility location analysis was primarily influenced by Company A's willingness to share information about this chilling centre. Moreover, security concerns in Ethiopia prevented travel to other areas where Company A collects dairy produce.

Following determination of the coordinates of collection points and the total quantity of milk collected at each collection point, the coordinates for the proposed location of the new chilling centre were calculated as the centre of gravity of the collection points:

$$x = \frac{\sum_{i=1}^{n} x_i w_i}{\sum_{i=1}^{n} w_i} \quad , y = \frac{\sum_{i=1}^{n} y_i w_i}{\sum_{i=1}^{n} w_i} \qquad (3)$$

where x and y are the coordinates of the new chilling centre, x_i and y_i are the coordinates of collection point i, and w_i is the volume of milk transported to collection point i.

4.2.2 Vehicle routing problem (VRP)

Efficient route planning is crucial in areas with high traffic congestion, especially when transporting perishable food items such as dairy products. The quality of these perishable items is affected by factors such as travel distance and time, especially when they are not refrigerated during transportation. Therefore, optimising routes and allocating resources such as trucks efficiently for perishable goods is crucial to maintain their quality.

One of the most widely used methods for optimising routes and resources is VRP, which addresses the issue of transporting products from origin to destination at the least possible cost (Lahrichi *et al.*, 2015). It aims to reduce transportation costs and decrease travel distances (Dhurkari *et al.*, 2021;

Rautela *et al.*, 2019), while delivering products to customers on time (Francesconi *et al.*, 2010) by providing optimal routes.

In this thesis, the cloud-based PTV route optimiser software (PTV Group, 2022) was used to solve VRP for dairy distribution by Company A in Addis Ababa. To ensure a fair comparison between the results obtained by the optimiser software and the current operational scenario, existing routes and trucks employed by the company were simulated in the software. Following this, the routes and resources utilised by the company were optimised based on assumptions and parameters outlined in Paper IV.

4.3 Structural equation modelling (SEM)

Structural equation modelling (SEM) helps find the relationship between independent variables (Ullman & Bentler, 2012). This method differs from other statistical methods in that it has the ability to analyse both latent and independent variables. The two main goals of SEM are to understand the covariance among observed variables and to explain these covariances (Kline, 2016). Structural equation models are analysed by first constructing a measurement model and then unitising the values of the measurement model to build a structural model.

Prior to conducting the analysis, the Kaiser-Meyer-Olkin (KMO) test is generally conducted and the chi-square (χ^2) value for Bartlett's test of sphericity is computed, to check if the sample size obtained is adequate for conducting factor analysis. Cronbach's alpha reliability test is also used to check the reliability and internal consistency of the collected sample (Kline, 2016).

Analysis of the measurement model begins with exploratory factor analysis to understand the relationships between measured variables and determine the number of factors needed for analysis. Following this, the measurement model is constructed through confirmatory factor analysis (CFA). The validity and reliability of the measurement model are then checked using Cronbach's alpha test. In addition, item communality and average variance extracted (AVE) are calculated, to check how much of the variance is explained for each observed and latent variable, respectively.

The validity of the structural model is assessed using comparative fit index (CFI), Tucker Lewis index (TLI), root mean square error of approximation (RMSEA) and standardised root mean square residual

(SRMR). The structural model is also evaluated by observing the p-values for each relationship, with hypotheses accepted at p-values below 0.05 (Li *et al.*, 2021).

The SEM approach was employed in Paper V in this thesis to analyse the intention of stakeholders in Ethiopia to adopt digital technologies in their supply chains, using the technology acceptance model (TAM). TAM is recognised as one of the most useful methods to investigate the acceptance and adoption of new technologies by users (Venkatesh & Bala, 2008). Moreover, TAM has been applied to evaluate the adoption of ICT by organisations (Jokonya, 2015).

According to TAM, the attitude that users have towards a technology is dependent upon perceived usefulness (PU) and perceived ease of use (PEU) (Davis, 1989). Perceived usefulness explains how users perceive a technology as beneficial in aiding them in achieving their desired tasks and reflects the potential increase in productivity by the user due to technology usage (Davis, 1989), as well as economic, social and environmental advantages derived from technology adoption. The hypotheses for PU applied in this thesis, based on the theory developed by Davis (1989), were as follows:

H1: The usefulness of digitalisation has a positive impact on the attitudes of stakeholders to implementing digital technologies in their logistics activities.

H2: The usefulness of digitalisation has a positive impact on the behavioural intentions of stakeholders to implementing digital technologies in their logistics activities.

Technologies that are perceived as complex, or requiring significant time to learn, dissuade users from adopting them (Autry *et al.*, 2010). This is why PEU is an important parameter of a technology from the perspective of the potential user (Davis, 1989). The hypotheses regarding PEU applied in this thesis, based on the theory developed by Davis (1989), were as follows:

H3: Ease of use of digitalisation has a positive impact on stakeholder attitudes to implementing digital technologies in their logistics activities.

H4: Ease of use of digitalisation has a positive impact on the usefulness of digitalisation.

In low-income countries, technology adoption behaviour is not only affected by PU and PEU, but also by the presence of resources. These include facilitating conditions (F) such as adequate resources (Musa, 2006) including human resources (HR), finance and infrastructure. Moreover, the presence of policies promoting digitalisation plays a crucial role in determining technology adoption rates (Tadesse *et al.*, 2021). Successful adoption of digitalisation in low-income countries is also determined by user exposure to the technology (Niehm *et al.*, 2010), highlighting accessibility as a significant determinant of technology adoption (Musa, 2006; Tadesse *et al.*, 2021).

Based on the above factors, the following hypotheses were formulated in this thesis:

H5: Accessibility, HR, policies, finance and infrastructure positively influences the usefulness of adopting digital technologies in logistics activities.

H6: Accessibility, HR, policies, finance and infrastructure positively influences the ease of use of adopting digital technologies for their logistics activities.

H7: Accessibility, HR, policies, finance and infrastructure positively influences the attitude of users towards adoption of digital technologies for their logistics activities.

The behavioural intention (BI) of users to adopt technologies is dependent upon their attitudes (AT) towards those technologies (Davis, 1989). When users have a positive attitude towards a technology, they intend to develop a behaviour to adopt that technology in the future. Thus, the following hypothesis was formulated for the relationship between AT and BI, based on Davis (1989):

H8: Stakeholder attitude to adoption of digital technologies for their logistics activities has a positive impact on their behavioural intention to use such technologies.

The resulting model, including hypotheses about interrelations between key constructs, is presented in Figure 4.

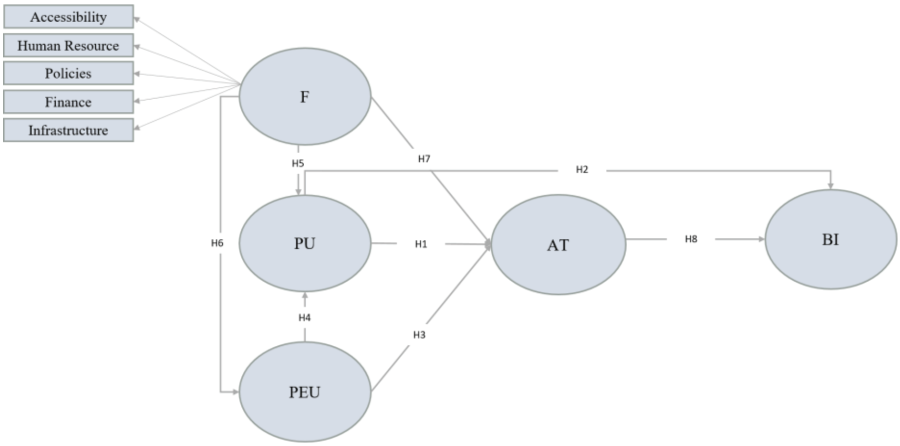


Figure 4. Hypotheses on the effects of perceived usefulness (PU), perceived ease of use (PEU) and facilitating conditions (F) on users' attitude (AT) and their behavioural intention (BI) in adopting digital logistics technologies (based on Davis (1989)

Following formulation of hypotheses *H1-H8*, constructs corresponding to the hypotheses and their indicators were developed as described in Paper V. The constructs obtained were administered to 425 respondents working in the logistics sector in Ethiopia. These respondents included importers, exporters, shippers, manufacturers, transportation companies, processors, wholesalers and retailers. Respondents were chosen via convenience sampling, using an internet-based questionnaire.

5. Case Study

Ethiopia is a low-income country located in East Africa, with a population of over 120 million and an economy significantly dominated by agriculture. Ethiopia is recognised globally as a major coffee growing region, the largest coffee producer in Africa and the fifth largest in the world (ICO, 2021). Coffee is of significant economic importance in Ethiopia, impacting the livelihoods of over 10 million Ethiopians (Bastin & Matteucci, 2007). Moreover, the country has a substantial domestic coffee consumption, with locals consuming half of total production (Georgise & Mindaye, 2020).

Apart from coffee, Ethiopia is renowned for its significant livestock population, which is estimated to be 70 million, with 7.56 million dairy cows (CSA, 2021), making it one of the countries in Africa with the largest cattle population (Mekuriaw & Harris-Coble, 2021). Ethiopia also has one of the largest populations of smallholder dairy farmers in Africa (Gichohi, 2020). Despite these strengths, the Ethiopian dairy sector faces challenges such as low milk production and poor efficiency (Gebreyohanes *et al.*, 2021).

A brief overview of the structure of the coffee and dairy supply chains in Ethiopia is provided below.

5.1 Coffee supply chain

The main actors involved in the Ethiopian coffee supply chain are farmers, cooperatives, local traders, collectors, unions, exporters and quality control bodies (*i.e.* the Ethiopian Commodity Exchange (ECX) and the Coffee Liquoring Unit (CLU) (Figure 5). The main processes involved in the coffee supply chain are (Figure 6):

- *Production*: Coffee production in Ethiopia is carried out by both commercial and smallholder farmers. However, the majority of the production is carried out by smallholder farmers (Tefera & Tefera, 2014).

- *Harvesting*: Farmers are generally responsible for coffee harvesting. The predominant harvesting technique used by farmers in Ethiopia is selective harvesting, where they selectively pick ripe cherries from the coffee tree.
- *Primary processing*: The initial coffee transformation process following harvesting is primary processing. This is done to extract the coffee beans from the coffee cherries using two common processes: a wet process or a dry (natural) process (Figure 6). Primary processing is carried out by farmers, cooperatives (formed by a group of farmers) or collectors (formed by private individuals or groups).
- *Storage*: Cooperatives and collectors are responsible for storing the green beans during the initial stages until they are transported to the next destination. However, coffee can also be stored by exporters and unions (formed by a group of cooperatives who are licensed to export coffee).
- *Transportation*: Smallholder farmers and coffee harvesters use animal transportation, transportation by foot, motorcycles or small trucks to transport the harvested coffee to nearby collection sites. On the other hand, exporters use large trucks for transportation.
- *Secondary processing*: Secondary processing is usually carried out by exporters and unions, and is the second coffee transformation process conducted to make the coffee ready for export. The main processes include polishing, grade separation by colour sorting and parchment removal.
- *Quality control and testing*: Coffee quality is checked at two stages in the supply chain. The initial quality control and testing are performed by ECX. After secondary processing, CLU conducts quality controls to check if the coffee is suitable for export. CLU is part of a government body that operates under the Ethiopian Coffee and Tea Authority, which is responsible for testing and grading the coffee before it can be exported.
- *Export*: In the Ethiopian coffee supply chain, two groups have the right to export: exporters and unions. These two groups sell coffee to international traders located in different parts of the world.

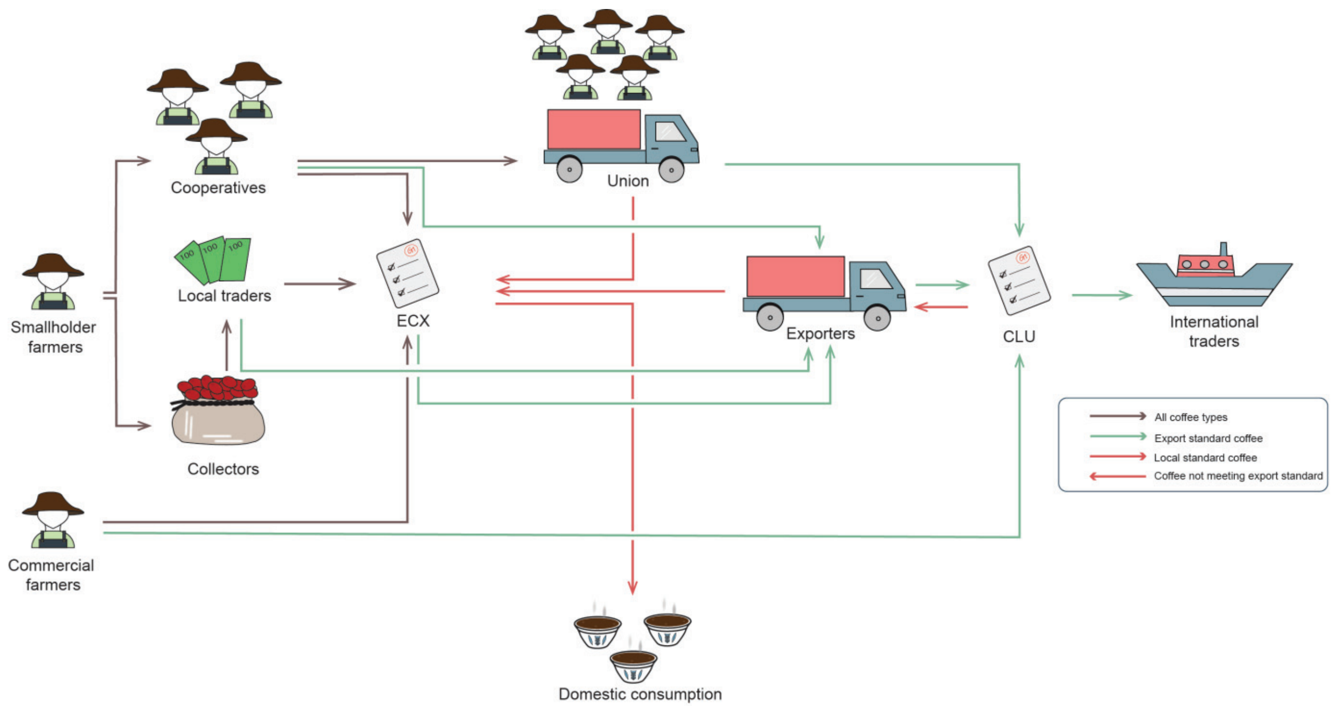


Figure 5. The Ethiopian coffee supply chain (ECX: Ethiopian Commodity Exchange, CLU: Coffee Liquoring Unit)

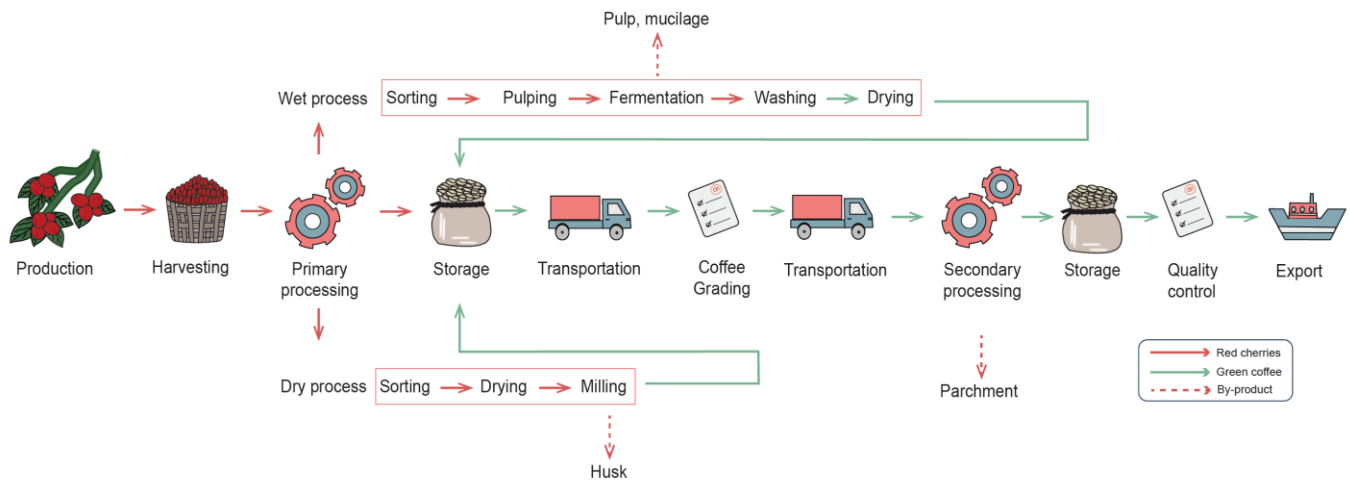


Figure 6. Logistics activities in the coffee supply chain for the export market

5.2 Dairy supply chain

In Ethiopia, dairy products are channelled from producers to consumers via informal and formal marketing systems (Yilma *et al.*, 2017). In the informal marking system, milk is usually sold to retailers and consumers without being processed, and farmers and cooperatives are responsible for selling dairy to retailers or individual consumers. The formal marketing system, which was the focus in this thesis, involves dairy processors who are also responsible for selling dairy to various customers (Getahun *et al.*, 2019; Yilma *et al.*, 2017). Figure 7 shows the structure of the formal dairy supply chain in Ethiopia. The main activities involved in the dairy supply chain are as follows:

- *Production*: Dairy production in Ethiopia is carried out by both smallholder and commercial farmers. Following production, milk is typically stored in non-food-grade plastic containers, especially by smallholder farmers.
- *Collection*: Smallholder farmers usually sell their milk to cooperatives, collectors/traders or processors. In contrast, commercial producers sell their milk directly to processors. When cooperatives and processing companies receive milk from these producers, they transfer it to aluminium cans for storage. The collected raw milk is then transported using open-bed trucks or pickup trucks to the chilling centre or processing plant.
- *Chilling*: After collection, dairy products are stored at a nearby chilling centre before being transported to the processing plant.
- *Processing*: Processing companies that own chilling centres use insulated tanker trucks to transport the milk from chilling centre to processing plant. Some dairy processors also buy raw milk from milk traders that use either aluminium or plastic cans for milk storage and open-bed trucks for transportation.
- *Distribution:* Processors are mainly responsible for dairy distribution in the formal market. Distribution is typically done in box trucks, the majority of which lack refrigeration.

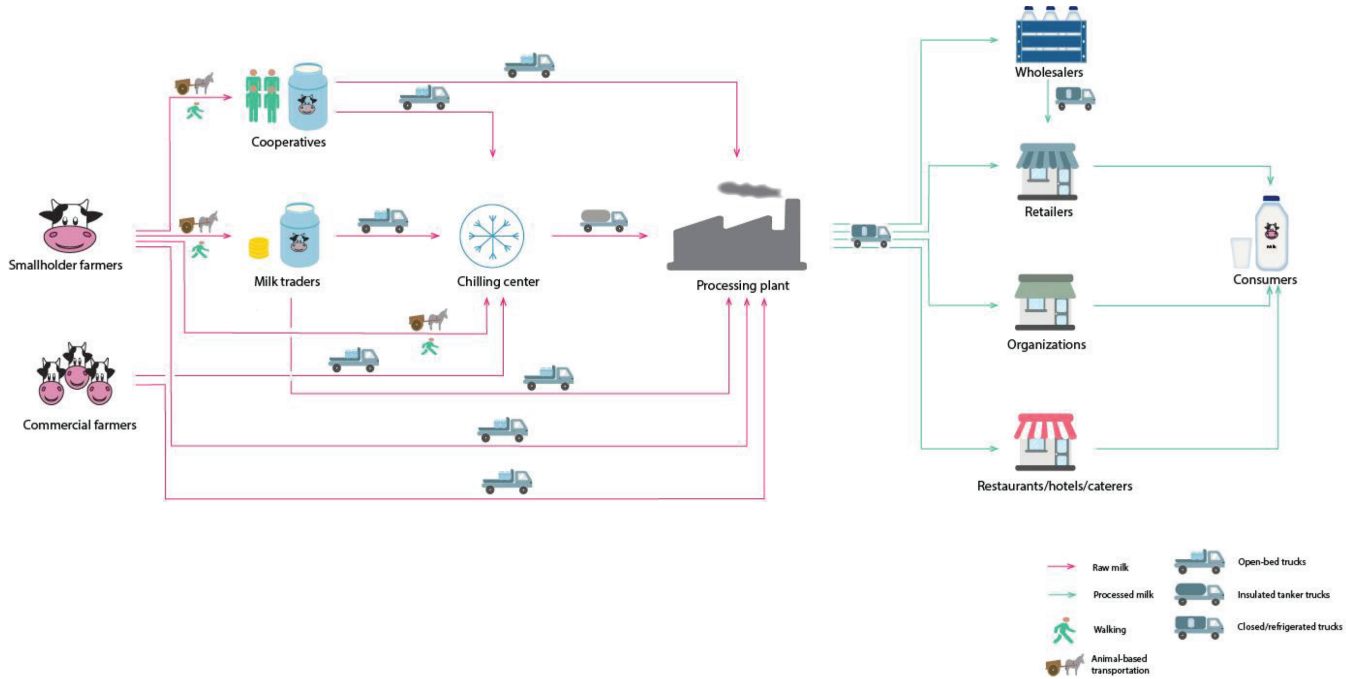


Figure 7. The dairy supply chain

6. Results

This section presents the results of different analyses addressing the research questions concerning the performance of low-income countries in adoption of digital technologies (Papers II, III and IV) and factors influencing technology adoption (Papers I and V).

6.1 Performance of logistics operations

Logistics experts, including freight forwarders, importers and exporters, were requested to perform pairwise comparisons for the AHP (Paper II). The experience of these experts and their education level are shown in Table 2.

Table 2. *Characteristics of the logistics experts asked to perform pairwise comparisons in analytical hierarchy process (AHP)*

Freight forwarders			Importers/exporters		
Variable	Frequency	%	Variable	Frequency	%
Experience			Experience		
<5	1	5.5	<5	12	34.3
5-10	7	39.0	5-10	13	37.1
10-20	6	33.3	10-20	9	25.7
>20 years	3	16.7	>20 years	1	2.9
No response	1	5.5	No response	-	-
Education			Education		
High school	2	11.1	High school	1	2.9
Undergraduate	6	33.3	Undergraduate	24	68.6
≥Masters	10	55.6	≥ Masters	7	20.0
No response	-	-	No response	3	8.6

The results of the AHP revealed six transport PIs relevant for the context of low-income countries (Paper II). These indicators were security, availability, travel time, truck capacity, travel cost and frequency of accidents. Among these indicators, security received the highest ranking (24.4%) in AHP, signifying its great importance in transportation in the context of low-income countries. Frequency of accidents received the lowest ranking among the indicators identified (Table 3).

Among the warehousing PIs analysed, seven PIs were identified as relevant for the context of low-income countries. These indicators were order lead time, order accuracy, backorder rate, warehouse location, warehouse cost, loading/unloading time and damage rate. Further analysis of these indicators in AHP indicated that order lead time had the highest ranking (24.3%), which indicates the importance of ensuring timely order fulfilment in warehouse operations to ensure customer satisfaction and improve operational efficiency. Damage rate received the lowest ranking among the indicators identified (Table 3).

Table 3. *Performance indicators (PIs) and their weightings*

Indicator	Weighting (%)
Transport PIs	
Security	24.4
Availability	20.5
Travel time	15.8
Truck capacity	15.4
Travel cost	12.3
Frequency of accident	11.6
Warehousing PIs	
Order lead time	24.3
Order accuracy	20.7
Backorder rate	17.8
Warehouse location	10.6
Warehouse cost	9.9
Loading/unloading time	8.8
Damage rate	8

6.2 Performance of the coffee and dairy supply chains

Following the logistics audit, it was possible to assess the current supply chain performance in Ethiopia, focusing on both the coffee and dairy sectors. The audit enabled assessment of the adoption level of digital technologies in both the coffee and dairy supply chains. An additional assessment was made on the dairy supply chain regarding strategic facility placement and effective distribution planning.

6.2.1 Digital technology adoption

The key logistics activities in both supply chains consisted of production, processing, transportation, storage and distribution. Digital technologies can be integrated into these processes to enhance traceability, increase visibility and increase the competitive advantage of companies. Despite these potential benefits, adoption of digital technologies in the supply chains of Ethiopia remains relatively low.

The logistics audit conducted on the coffee and dairy supply chains made it possible to identify the logistics processes in these two supply chains where digital technologies were implemented (Table 4). Stakeholders, especially those located upstream of the supply chain, relied on traditional methods for recording data and transmitting information between stakeholders. While the use of digital technologies improved downstream parts of the supply chain, overall utilisation of these technologies remained limited during the audit period. For instance, in the coffee supply chain, only two of the 30 exporters interviewed used barcodes, indicating a low adoption rate of this technology (Paper III). Similarly, the case companies (A-C) examined within the dairy supply chain had not implemented barcodes or QR codes (Paper IV), confirming the prevalence of traditional methods for product identification.

The findings in the logistics audit revealed that stakeholders within both the coffee and dairy supply chains relied on traditional paper-based methods for data storage. The reliance on manual documentation also extended to product monitoring and traceability in both supply chains. Traceability issues were observed in both the coffee and the dairy supply chains, and were caused by inadequate data management practices and mixing of products from different sources. In the coffee supply chain, exporters reported instances where coffee beans from different farms were mixed, especially during primary and secondary processing. This practice raised concerns about maintaining accurate traceability records in the supply chain.

Similarly, in milk collection process of Company A in Assela and surrounding regions, milk sourced from different collection points was pooled together in a single tank at the chilling centre. Such practices pose significant challenges in traceability, especially in instances where food recall actions are required. Thus, there are challenges in both supply chains in terms of real-time monitoring, tracking products as they move along the supply chain and ensuring traceability.

Regarding the adoption of GPS technology for location identification, the results of the audit revealed that GPS penetration was higher in the coffee supply chain than the dairy supply chain. Among the 30 exporters and 10 transportation companies interviewed in the coffee supply chain, four exporters and two transportation companies had integrated GPS technology into their operations. However, among the companies interviewed in the dairy supply chain, none used GPS during transportation.

In both the coffee and dairy supply chains, communication among stakeholders was primarily done using mobile communication methods. This included the use of mobile phones and text messaging, although paper-based communication was also common. However, downstream stakeholders utilised internet-based communication tools such as email to engage with local and international stakeholders.

Table 4. *Digital technology implementation in the coffee and dairy supply chain*

Purpose	Supply chain	
	Coffee	Dairy
Product identification	Barcodes	-
Data storage	-	-
Product monitoring and traceability	-	-
Location identification	GPS	-
Communication	Mobile network	Mobile network

6.2.2 Existing planning practices

Location analysis

In the case study conducted on the dairy supply chain, the role of cooling centres was found to be very significant (Paper IV). Processing companies reported that they often travel considerable distances to collect dairy. As a result, most processing companies have chilling centres located around the areas where they collect dairy. These centres cool and store milk until it is transported to Addis Ababa for processing and distribution.

Company A has a chilling centre in Assela that receives milk from three cooperatives, which supply milk to the company at six different collection points (Table 5). The company provided historical data spanning a period of five months, which were used in the analysis.

Table 5. *Geographical location of collection points and amounts of milk collected by Company A over a five-month period*

Collection centre	Milk quantity (L)	Latitude	Longitude
1	41,494.00	7.759016	39.158379
2	28,990.00	7.753091	39.158866
3	38,748.00	7.757206	39.153385
4	11,810.00	7.753143	39.158880
5	10,636.30	7.8462788	39.1346067
6	37,741.00	7.673254	39.174132

With the current location of the chilling centre in Assela, the truck of Company A travels a total of 97 km and spends 9:09 hours on the road collecting raw milk from the collection points and transporting it to the chilling centre. The analysis showed that relocating the chilling centre to a town such as Sagure (Figure 8) could significantly enhance efficiency by reducing the travel distance to 47 km and travel time to 5:03 hours. This indicated a reduction in distance travelled by 51.5% and travel time by 44.7%.

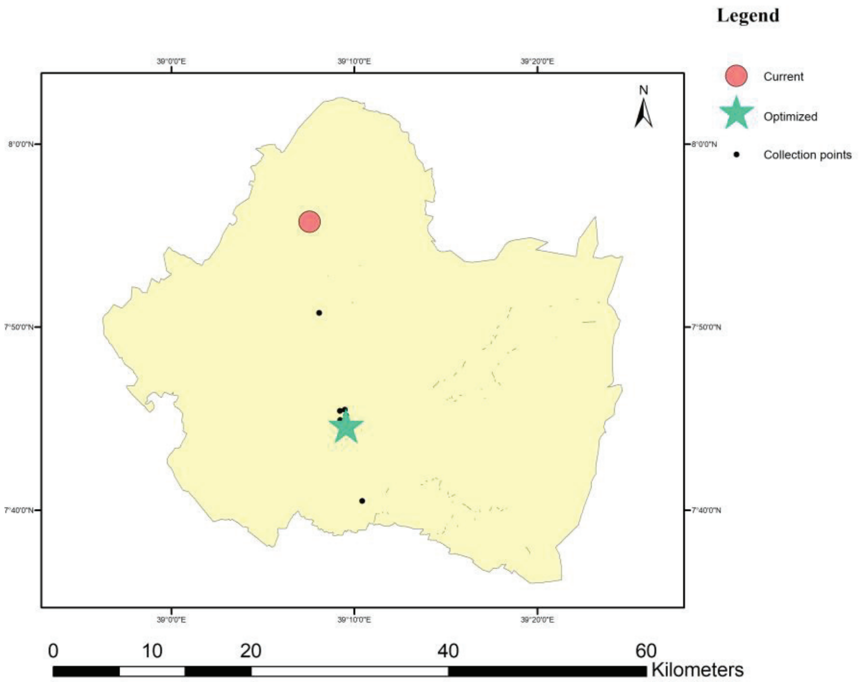


Figure 8. Location of existing and optimised chilling centre in Assela and surrounding regions

Distribution planning

Company A delivers processed dairy products on a daily basis to 203 customers located in Addis Ababa (Figure 9). These customers are categorised into nine zones and the company employs nine closed trucks for dairy distribution (Figure 10a). Distribution planning is currently managed manually by the company, with drivers determining the distribution order based on their experience, road conditions, traffic flow and customer priority.

By simulating the current dairy distribution of Company A, it was possible to obtain the travel distance, travel times and current load rates of the trucks (Table 6 and Figure 11a).

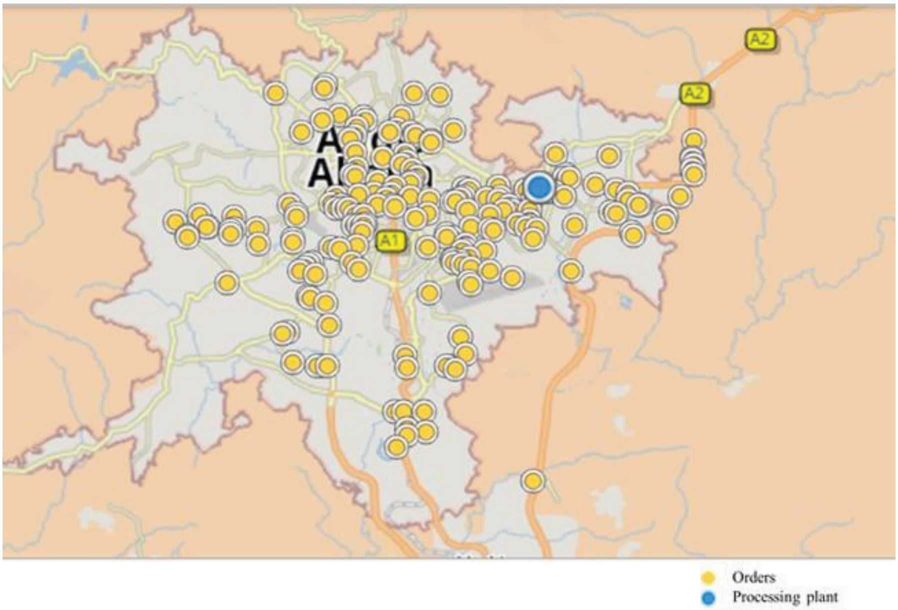
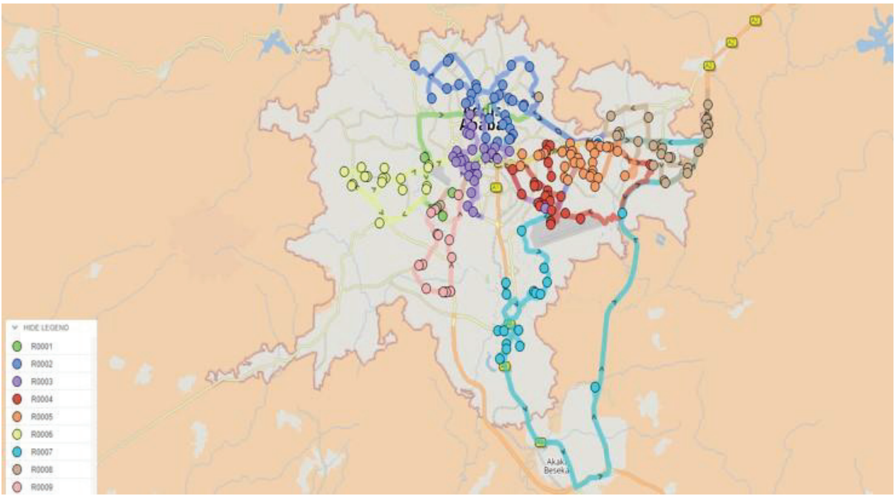


Figure 9. Delivery locations of Company A in Addis Ababa

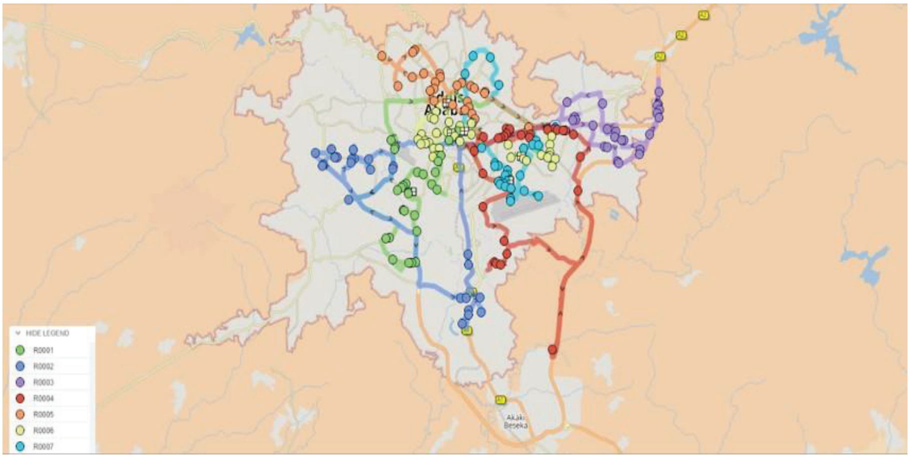
After conducting route optimisation using the PTV route optimiser software, significant improvements were observed in travel time, travel distances and number of vehicles utilised (Table 6). Travel distance was reduced from 443 km to 309 km, travel time decreased from 50:40 hours to 36:51 hours, and the number of vehicles used decreased from nine to seven. This represented a decrease in travel distance and travel time of 134 km (30%) and 13:49 hours (27%), respectively.

Table 6. *Summary of route optimisation results for Company A in Addis Ababa*

Routes	Existing routes		Optimised routes	
	Distance (km)	Time (hours)	Distance (km)	Time (hours)
R1	40	03:05	24	05:21
R2	45	06:25	53	05:27
R3	34	06:01	43	05:21
R4	57	06:42	53	05:00
R5	50	06:23	36	05:21
R6	66	05:47	73	05:00
R7	58	06:12	27	05:21
R8	43	05:39		
R9	50	04:41		
Total	443	50:40:00	309	36:51:00

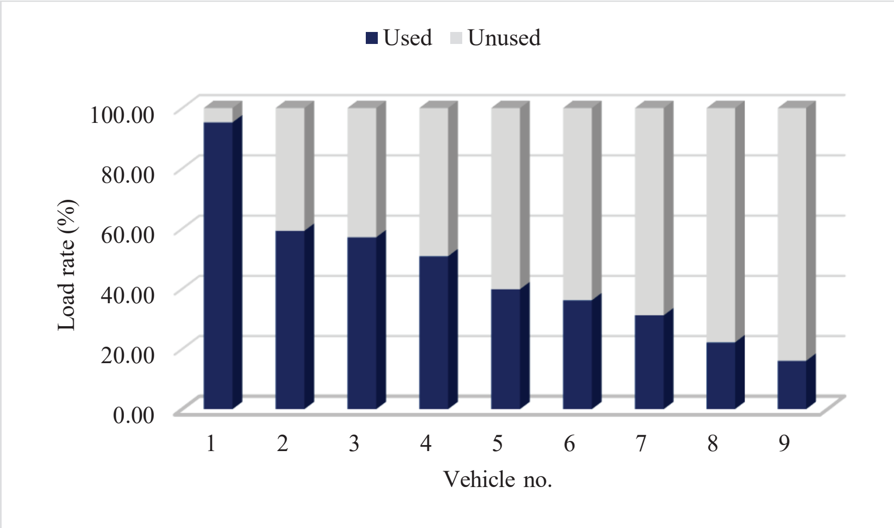


(a)

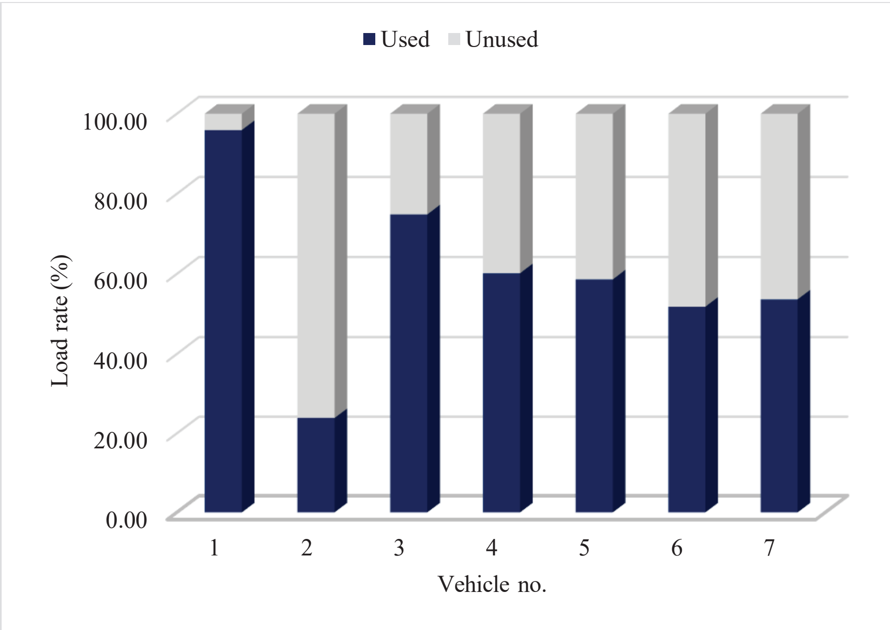


(b)

Figure 10. Routes for Company A (a) before and (b) after route optimisation



(a)



(b)

Figure 11. Load rates for Company A (a) before and (b) after route optimisation

As can be seen in Figure 11a, the load rates of the vehicles before optimisation were very low, with the exception of vehicle 1. However, by using optimisation strategies, Company A could potentially decrease the number of vehicles used, while increasing the load rates of the remaining vehicles (Figure 11b). This indicates the importance of effective route and resource planning for the processing company, as it can lead to efficient resource utilisation and subsequent cost savings.

6.3 Modelling acceptance of digital technologies

To develop the TAM in Paper V, data were gathered from 425 respondents. The characteristics of these respondents, including their work experience, education level, age and the size of the company for which they work, are presented in Table 7. A significant proportion of the respondents reported having over five years of work experience, possessing at least an undergraduate degree, being below the age of 35 and being affiliated with a large-scale enterprise.

Table 7. *Descriptive statistics on characteristics of the respondents*

Variable	Frequency	%	Variable	Frequency	%
Experience			Age		
<5	108	25.4	<35	230	54.1
5 to 10	140	32.9	35 to 50	185	43.5
10 to 20	154	36.2	>50	9	2.1
>20 years	23	5.4	Enterprise size		
Education			SME	155	36.5
High school	1	0.2	Large	267	62.8
Undergraduate	205	48.2			
Postgraduate	219	51.5			

SME: Small and medium sized enterprise

The results of the TAM are presented below, for the measurement model in section 6.3.1 and for the structural model in section 6.3.2.

6.3.1 Evaluation of the measurement model

Evaluation of the measurement model for the TAM was conducted using confirmatory factor analysis (CFA). The initial factor analysis showed that PEU2 and PEU3 did not load sufficiently on the latent variable PEU, and therefore they were removed from the model. Table 8 shows the factor loading on all five factors after PEU2 and PEU3 had been removed, whereupon each measured variable loaded sufficiently on its subsequent factor.

Table 8. *Summary of the measurement model results for different latent variables (facilitating conditions (F), perceived usefulness (PU), perceived ease of use (PEU), users' attitude (AT) and their behavioural intention (BI))*

Latent variable	Indicator	Loadings	Item communality	Composite reliability	Average variance extracted, AVE
F	Accessibility	0.893	0.755	0.900	0.707
	HR	0.881	0.777		
	Policies	0.846	0.719		
	Affordability	0.805	0.667		
	Infrastructure	0.776	0.572		
PU	PU1	0.918	0.813	0.939	0.879
	PU2	0.971	0.885		
	PU3	0.936	0.855		
	PU4	0.954	0.877		
	PU5	0.908	0.809		
PEU	PEU1	0.833	0.763	0.698	0.605
	PEU4	0.719	0.776		
AT	AT1	0.956	0.795	0.874	0.909
	AT2	0.952	0.800		
BI	BI1	0.927	0.816	0.870	0.901
	BI2	0.971	0.826		

The item communality value for all observed variables exceeded 0.4 (Table 8), indicating that an adequate amount of variance was explained by each observed variable (Costello & Osborne, 2005). In addition, the AVE values exceeded 0.5, confirming convergent validity.

6.3.2 Evaluation of the structural model

Running the SEM resulted in coefficients for the paths indicated in Figure 12. The CFI value for the model was 1.000, the TLI value was 1.000, the RMSEA value was 0.006 and the SRMR value was 0.042. A good fit is indicated by CFI values above 0.90, TLI values above 0.95, and RMSEA and SRMR values below 0.08. All values met these criteria, indicating acceptable fit of the model.

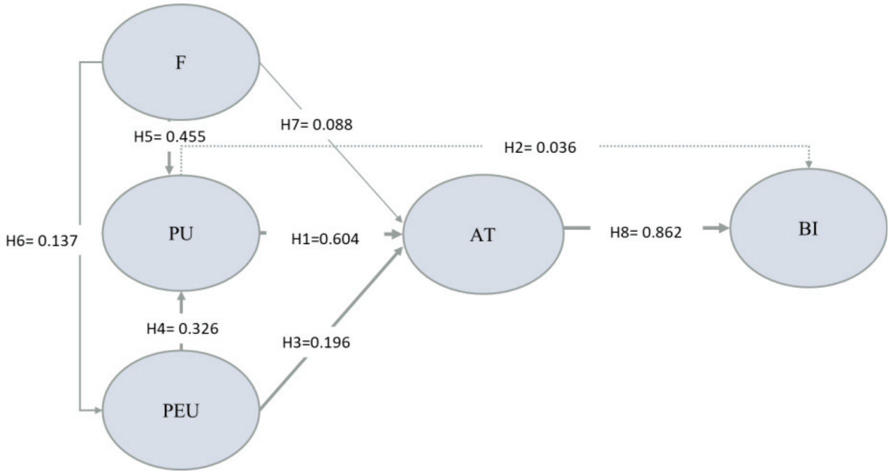


Figure 12. Estimates obtained for the structural model

Based on the results, the hypotheses for all paths were accepted except for *H2*, which showed the relationship PU→BI (Table 9). The *p*-value for *H2* was 0.486, resulting in the hypothesis being rejected.

Table 9. *Hypothesis test results for the structural model*

Hypothesis	Regression path	*p*-value	Hypothesis verification
H1	PU → AT	0.000	Accepted
H2	PU → BI	0.486	Rejected
H3	PEU → AT	0.000	Accepted
H4	PEU → PU	0.000	Accepted
H5	F → PU	0.000	Accepted
H6	F → PEU	0.000	Accepted
H7	F → AT	0.002	Accepted
H8	AT → BI	0.000	Accepted

Figure 12 indicates that PU was the main contributor to technology adoption, rather than PEU or F. F had a significant impact on both PU and PEU, while PEU had a significant impact on PU and AT.

7. Discussion

7.1 Logistics performance with digital technologies

Among the transportation PIs analysed in this thesis, experts ranked security as the highest priority. A study by Thai (2007) found that security is also one of the main concerns in international trade in Vietnam. Security plays an essential role in transportation, as it helps prevent disruptions that could impact the flow of goods in the supply chain (Ekwall & Lantz, 2017). Issues such as theft, robbery and political instability (Tadesse *et al.*, 2022) are recurring problems in most supply chains (Ekwall & Lantz, 2017), impeding transport operations and causing significant disruptions (Khan & Yu, 2020). However, security threats in middle and high-income countries are lower than in low-income countries, further worsening the logistics performance of the latter (World Bank, 2023).

Certain segments within supply chains are more susceptible to security threats during transportation than others (Ekwall & Lantz, 2017). Therefore, it is crucial to identify regions with heightened security concerns and enhance security measures in those areas. Truck telematics could be installed by truck owners to monitor trucks and drivers during transportation. These systems could include GPS on trucks and sensors on both cargo and driver compartments. Such measures allow for monitoring transported goods and driver behaviours, including braking patterns and fatigue (Hopkins & Hawking, 2018), ensuring smooth flow of goods along the supply chain while also mitigating security concerns.

During the interviews conducted with logistics experts in Paper II, the experts reported a shortage of trucks that meet the volume requirement of customers. However, optimisation of distribution trucks for the dairy supply chain for Company A in Paper IV indicated that fewer trucks could handle dairy distribution. The optimisation process also revealed that the current load rates of the trucks were low, indicating problems with resource allocation and under-utilisation of available truck capacity (Figure 11a). This suggests that the challenge lies not only in the absence of trucks meeting customer volume requirements, but also in improper allocation of resources. Challenges also stem from inadequate coordination and planning within the logistics sector (Debela, 2013). Therefore, measures promoting coordination and collaboration within the supply chain are crucial. This would enable matching the right truck to each customer's needs, ensuring optimal truck loading.

The experts interviewed in Paper II also indicated high importance of travel time in their transportation operations. Reduced travel time of trucks not only leads to cost savings, but also contributes to lower emissions (Kinobe *et al.*, 2015). Therefore, travel time can be a key indicator in enhancing logistics performance, especially in low-income countries. Inefficiencies in travel time could be mitigated by utilising route management software and tracking technologies such as GPS. The results obtained in Paper IV demonstrated the effectiveness of these strategies in reducing travel distances and time and maintaining the quality of dairy while being transported in unrefrigerated conditions, which in turn lead to reduced environmental impact. Similar findings were made by Chen *et al.* (2019), Ruiz-Meza *et al.* (2020) and Bosona *et al.* (2013). To ensure effective route planning, it is important to consider the challenges in route optimisation, including navigating dynamic traffic conditions. Stakeholders could adopt real-time route planning solutions that enable them to handle disruptions such as traffic congestion, accidents or variations in customer orders during transportation. This could be achieved by installing GPS and IoT devices on the trucks and coupling them with CC (Tang, 2023). This dynamic approach could ensure timely adjustments of routes, ensuring deliveries reach customers within the specified time window.

Among the warehousing PIs identified in the literature, experts in Paper II gave the highest ranking to order lead time. A study by Gunasekaran *et al.* (2001) also indicated high significance of having reliable and consistent lead times in enhancing logistics performance. In landlocked countries such as Ethiopia, the lead time of orders is particularly long due to multiple border crossings and rigorous customs procedures (Debela, 2013). Addressing these challenges requires appropriate policies and improved border relations with neighbouring countries. The lead time of orders could also be improved through implementation of digital technologies such as barcodes, QR codes and RFID, as these technologies ensure efficient product identification. This would in turn improve logistics performance and increase customer satisfaction (Kembro & Norrman, 2022; Shahadat *et al.*, 2023).

Minimising wastage and losses in the agri-food supply chain is a crucial strategy for enhancing logistics performance. This is of particular importance in low-income countries, where the majority of losses occur post-harvest as a result of improper goods management during transportation and storage (FAO, 2015; Nicastro & Carillo, 2021). One of the most effective methods for reducing losses is implementing a cold chain. However, the case study in Paper IV revealed that the participating processing companies did not use refrigeration during transportation. This delays chilling of milk once it leaves the farm, causing the shelf-life of milk to be lower in low-income countries (Ajmal *et al.*, 2018).

In low-income countries, affording refrigeration facilities is difficult, especially for smallholder farmers. Therefore, to maintain the quality of dairy, it is critical to reduce transportation time (Burduk *et al.*, 2018). This could be done by strategically locating chilling centres at optimal locations. The facility analysis conducted in Paper IV highlighted the potential benefit of relocating existing chilling centres closer to milk collection points. This could result in significant reductions in travel time and distance, thereby decreasing the time milk spends without refrigeration during transportation. Consequently, this could lead to decrease in milk rejection rates by processors (Lokuruka, 2016). Other factors that influence decisions on the location of a chilling centre include access to electricity, water and roads.

7.2 Digital technology adoption in low-income countries

The findings in Papers III and IV revealed limited adoption of digital technologies among producers in both the coffee and dairy supply chains in Ethiopia. Stakeholders in these sectors demonstrated a preference for traditional methods of data recording, which could lead to challenges in accurate information transfer. In addition, it could create opportunities for corruption and unequal financial distribution in the supply chain, as found by Karami *et al.* (2021) in Indonesia and Abdulai *et al.* (2023) in Ghana.

Despite the fact that downstream supply chain actors in both supply chains have better economic capabilities, implementation of digital technologies in their logistics activities remains limited. Some progress has been made with GPS implementation by truck owners in the coffee supply chain and barcode adoption by exporters in the coffee supply chain (Paper III). However, the case study on the dairy supply chain indicated lack of implementation of digital technologies among the case companies and their associated stakeholders (Paper IV). The reluctance to adopt digital technology could be driven by the costs associated with implementing such technologies.

Paper III showed that stakeholders located downstream of the supply chain use internet-based communication, such as email. This indicates that the use of internet-based communication advances downstream rather than upstream. Similarly, a study by IMF (2020) found that use of email-based communication was more common in large-scale firms in Sub-Saharan Africa.

While the diffusion of digital technologies is low, especially in Sub-Saharan Africa, mobile phone technology is widely used (Myovella *et al.*, 2020), due to its affordable price (Albiman & Sulong, 2017). In addition, the usage of digital financial services in most Sub-Saharan countries has increased (IMF, 2020; Myovella *et al.*, 2020). These advances indicate a potential pathway for bridging the digital divide across low-income countries.

7.3 Factors influencing technology adoption

Technology adoption in low-income countries depends on various factors, such as perception, technology accessibility, availability of skilled human resources, presence of supportive policies and regulations, affordability and infrastructure. It is vital to take these factors into account when developing frameworks for digital technology adoption in low-income countries.

7.3.1 Perception

Paper V showed the importance of stakeholder perception, expressed in terms of PU and PEU, in successful adoption of digital technologies. Perceived usefulness has emerged as the most significant indicator influencing technology adoption in other studies in low-income countries, with Bracci *et al.* (2021), Chowdhury *et al.* (2022), Gao and Bai (2014) and Venkatesh and Davis (2000) reporting high significance of PU in determining users' attitudes to adoption of new technologies.

Perceived ease of use was the other indicator that had an impact on technology adoption. In a previous study on users' intentions to use electric cargo vehicles in Vietnam, Ngoc *et al.* (2023) found that users were more likely to adopt vehicles they perceived as easy to use. Chen and Chen (2011) reported similar findings in a study on the adoption of in-vehicle GPS systems.

A study by Abdinoor and Mbamba (2017) found that one of the key contributors to users' adoption of technologies in Tanzania is awareness. In a study on Ugandan dairy farmers, Ahikiriza *et al.* (2022) concluded that increased awareness about technology leads to a positive shift in the perception of users. These findings indicate that when users have information about how new technologies function and their potential benefits, they are likely to adopt the technology (Fall *et al.*, 2020).

To improve users' perception and increase their technology awareness, it is vital to launch various initiatives such as training, capacity building and awareness programmes (Ahikiriza *et al.*, 2022). These programmes should aim at educating users about the functionalities of the technology and its applications, and should be undertaken by both the public and private sector to transform users' perception of digital technologies.

7.3.2 Facilitating conditions

Technology access

A significant challenge facing digital technology adoption is limited availability in low-income countries (Musa, 2006). The findings in Paper V also showed that access to technology plays a crucial role in stakeholders' intention of adopting the digital technologies. This supports findings by Niehm *et al.* (2010) that technologies which are accessible are more likely to become successful after adoption.

The restricted access to digital technologies in low-income countries is mainly due to the fact that advanced digital technologies used in logistics are primarily developed in developed nations. As a result, low-income countries need to go through rigorous import procedures to have access to these technologies, leading to low penetration rate in low-income countries.

Human resource

Paper V showed that presence of a skilled HR makes a positive contribution to technology adoption, confirming previous findings (Abdinoor & Mbamba, 2017; Kittipanya-ngam & Tan, 2020b).

In low-income countries, there is shortage of skilled workers able to operate digital technologies. This is particularly true for smallholder farmers, where one of the factors hindering them from adopting digital technologies is a low level of digital literacy (Abdulai *et al.*, 2023). Studies have also shown that existing workforces are usually resistant to adoption of digital technologies (Autry *et al.*, 2010), fearing loss of their jobs since digitalisation usually replaces low-skill jobs (Ghobakhloo & Fathi, 2020). However, this could be mitigated by developing the skills of the existing workforce through different training and education programmes (Ghobakhloo & Fathi, 2020; Niehm *et al.*, 2010). This can be an effective technique for informing stakeholders in the supply chain regarding the current bottlenecks in logistics and the digital technologies that could tackle these.

Finance

The results obtained in Paper V also indicated the importance of finance in adoption of digital technologies in logistics. Similar findings have been made by Ghobakhloo and Tang (2013) in a study on e-commerce adoption in Iran, where small business owners identified affordability as a challenge. In a study on dairy farmers in Uganda, Ahikiriza *et al.* (2022) found that these farmers are more inclined to adopt affordable mobile-based solutions. Farmers in Greece report greater likelihood of adopting a new technology if the cost of adopting it is manageable (Pappa *et al.*, 2018), while Høyer *et al.* (2019) concluded that the implementation cost of RFID may dissuade some manufacturers from adopting it. Thus, it is vital to choose digital technologies that are affordable and accessible to stakeholders across the supply chain.

Infrastructure

The presence of adequate infrastructure facilitates adoption of digital technologies (Abdinoor & Mbamba, 2017). Paper V highlighted the significance of infrastructure to digital technology adoption in low-income countries. Infrastructure, including uninterrupted internet access in rural and urban areas alike, is fundamental for digitalisation (Jang, 2021; Lechman & Popowska, 2022). However, low-income countries, especially those located in Sub-Saharan Africa, face challenges with limited internet infrastructure (Myovella *et al.*, 2020).

A country's digitalisation level is reflected in the number of ICT subscriptions that country has (Jang, 2021). Low-income countries have lower levels of ICT subscriptions, with only 19.1% of individuals having internet access. Furthermore, there is limited internet access in rural areas of low-income countries (Deichmann *et al.*, 2016). Given that the majority of agricultural production in low-income countries is carried out by smallholder producers located in rural areas (Tefera & Tefera, 2014), it is essential to ensure that rural regions have adequate internet access to bridge the existing digital divide.

In addition to providing internet accessibility, enhancing overall infrastructure in both rural and urban areas is crucial. Tesfachew (2022) highlighted the recurrence of power blackouts in Ethiopia, even in urban areas where there is sufficient access to power. Hence, ensuring access to electricity and reducing power outages are essential for both urban and rural populations.

Supporting policies and regulations

To ensure the successful adoption of digital technologies, policies that promote digitalisation should be present. These policies are vital to allocate the necessary budget to building infrastructure that could improve internet access and reachability in both rural and urban areas. In addition, policies that ensure digital literacy are vital for successful technology adoption.

To ensure that food safety is maintained in the agri-food supply chain, the existing food regulations should be tightened. This includes laws that require stakeholders to provide traceability information when needed (Li *et al.*, 2021). In addition, introducing mandatory traceability (Pappa *et al.*, 2018) in the food supply chain would not only ensure food safety and quality, but also increase product transparency for producers.

7.4 Framework for digital technology adoption

Digitalisation of supply chains is a resource-intensive task and in some cases might require phasing out of old systems and hardware (Ghobakhloo & Fathi, 2020). The work in this thesis revealed several prerequisites for successful digitalisation. However, even when these prerequisites are met, it is crucial to choose digital technologies that align with the objective of the user adopting them. This is because poor technology choices can introduce uncertainty and lead to project failure (Yang *et al.*, 2021). This indicates a need to develop a framework tailored to policy-makers and practitioners in low-income countries. Accordingly, this thesis developed two digitalisation frameworks: gradual digitalisation and end-to-end digitalisation.

7.4.1 Gradual digitalisation

This thesis showed that affordability is a significant contributor to digital technology adoption. Therefore, investing in affordable digital solutions is important, since the added cost of adopting new technologies can dissuade users from adopting them (Abdinoor & Mbamba, 2017). Firms can do this by first adopting cost-effective and readily available technologies for certain supply chain activities (Fall *et al.*, 2020; Ghobakhloo & Fathi, 2020) and then implementing the technology in the rest of the supply chain, based on the success of these initial implementations. This could involve the implementation of barcodes or QR codes for product identification or GPS for tracking, route planning and route optimisation.

In addition, stakeholders could use low-cost digital technologies by utilising existing resources. Most stakeholders throughout the supply chain already have access to mobile phone services, so they could leverage the usage of mobile phone-based digital technologies. This would gain acceptance by most stakeholders in the supply chain, including smallholder producers, as they are already familiar with using mobile phones (Abdulai *et al.*, 2023). For instance, farmers in Zambia have started obtaining supply chain information, including the prices of commodities and details of transportation systems they want to use, using short message service (SMS)-based technology (Deichmann *et al.*, 2016). Similar trends have been observed in Kenya, where farmers are able to obtain price information using SMS technology (Deichmann *et al.*, 2016) . Thus, this approach could be one strategy for minimising the financial burdens associated with adopting digital technologies.

7.4.2 End-to-end digitalisation

Employing simpler technologies in the initial digital transformation process could ensure successful digitalisation in the long term (Myovella *et al.*, 2020). This is particularly feasible in low-income countries where access to advanced digital technologies such as blockchain is limited. The path to digitalisation varies for each firm, depending on their digitalisation goals (Yang *et al.*, 2021). Accordingly, a four-step digitalisation process was suggested in Paper III in this thesis, based on the work of Bravo *et al.* (2022) and Dabbene *et al.* (2014) (Figure 13).

The first step in end-to-end digitalisation is ensuring that all supply chain processes are recorded manually. This is categorised as a Level 1 system, where the supply chain is paper-based with no intervention of digital technologies. In a Level 2 system, information is recorded on paper, as in a Level 1 system, but is also stored digitally so it can be accessed by all supply chain members. In a Level 3 system, all processes are digitised and information in the supply chain is collected using product identification devices such as barcodes or QR code readers, and stored in databases. During transportation, trucks could be equipped with GPS, enabling route planners to know the location of their trucks and re-route them in the event of unprecedented incidents. In warehousing, technologies such as barcodes, QR codes and RFID could be used to enhance product identification. This could result in reduced lead times in warehouses, improved accuracy in picking orders, and assurance that the right products reach customers.

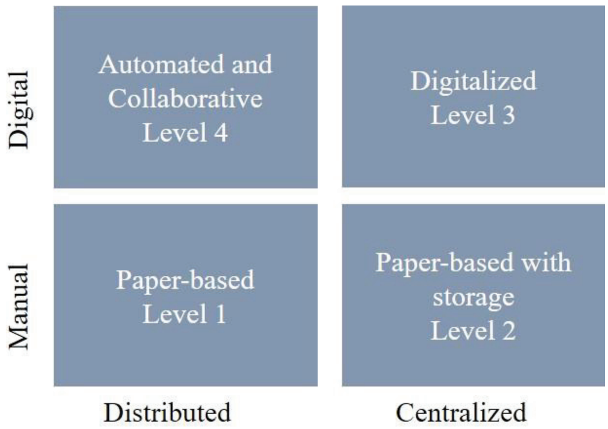


Figure 13. Framework for digital transformation of supply chains in low-income countries

Finally, in Level 4 systems, stakeholders could adopt an automated system that incorporates not only barcodes or QR codes, but also advanced technologies such as IoT for monitoring supply chains and blockchain for data storage in a distributed ledger. This type of digital supply chain is described by Yang *et al.* (2021) as a highly digital system that allows real-time data collection.

The challenge of incorporating end-to-end digitalisation in supply chains is that it requires a high level of supply chain coordination where data are shared across firms (Yang *et al.*, 2021). However, not all stakeholders in the supply chain are willing to share their information, due to lack of trust (Yadav *et al.*, 2020). In addition, most supply chains in low-income countries are highly disintegrated and involve multiple stakeholders, leading to challenges in seamless information sharing. However, end-to-end digitalisation could be feasible in short supply chains where the products only go through limited stakeholders and processes before they reach end-users.

8. Conclusions

This thesis evaluated the feasibility of integrating digital technologies to enhance logistics efficiency in low-income countries, with a particular emphasis on supply chains in Ethiopia. A systematic literature review enabled in assessing prevailing practices in the adoption of digital logistics technologies. Utilising multi-criteria analysis aided in identifying transportation and warehouse performance indicators that require attention. Using tools such as a logistics audit, it was possible to evaluate the coffee and dairy supply chains in terms of digital technology implementation. Perception of digital technologies by stakeholders in low-income countries was assessed using TAM. The main conclusions of this thesis were as follows:

- Literature highlighted the widespread adoption of digital technologies in middle and high-income countries, but rather limited adoption in low-income countries. Furthermore, literature showed that various technologies for product identification, data storage, product monitoring and positioning have been implemented in the agri-food sector to improve its performance.
- Enhancing logistics performance in low-income countries, particularly in the agri-food sector, requires addressing transportation and warehousing activities that lead to losses. Experts interviewed identified security and order lead time as the two most critical factors in transportation and warehousing. This highlights the need of digital technologies for goods tracking, planning and scheduling, which could improve security conditions during transportation and reduce order lead times.
- A logistics audit carried out on the coffee supply chain indicated partial adoption of digital technologies, with barcodes being used for

product identification and GPS for location tracking. Meanwhile, the audit of the dairy supply chain indicated no utilisation of digital technologies for product or location identification.

- The logistics audit revealed severe shortcomings in the implementation of cold chain throughout the dairy supply chain, which is problematic given the perishable nature of dairy products. Therefore, sensor-based cold chain systems could be introduced for traceability and monitoring.
- Location analysis conducted for a chilling centre in the dairy supply chain indicated possible reductions in distance travelled by 51.5% and travel time by 44.7% if the existing chilling centre for Company A was relocated. This indicated the importance of location analysis for strategical logistics decisions.
- In the dairy sector, route optimisation reduced travel distance by 30%, travel time by 27%, and the number of trucks utilised. This implies the maintenance of product quality and the reduction of transportation costs and environmental impacts. These results indicate the importance of route optimisation as a viable short-term option to enhance collection and distribution efficiency.
- For successful adoption of digital technologies in low-income countries, the results of the TAM indicated that stakeholders' perception of usefulness and ease of use had significant impact in driving technology adoption. When stakeholders have a positive perception of technologies in terms of usefulness and ease of use, they are more behaviourally inclined to adopt.
- Adoption of digital technologies is influenced by the presence of facilitating conditions such as access to the technology, skilled HR, policies, finances and infrastructure. From these factors, access to the technology and skilled HR had a strong impact on usefulness and ease of use of digital technologies.
- A technology adoption framework was formulated using two approaches in this thesis. These were gradual digitalisation and end-to-end digitisation. These frameworks offer policy-makers and practitioners strategies in transitioning from traditional supply chains to digitalised supply chains.

As a whole, this thesis provided insights into the current digital practices in low-income countries concerning the adoption of digital technologies. The insights provided in this thesis can assist policy-makers and regulatory bodies in identifying gaps related to digital technology adoption by firms in low-income countries and providing necessary support to encourage stakeholders to adopting digital technologies for their logistics activities.

9. Future Research

The following areas are interesting for further investigation:

- This thesis identified important PIs for transportation and warehousing. Future research could identify PIs for other logistics activities tailored for the context of low-income countries. This could help in identifying areas in their logistics sector that need improvement.
- This study assessed implementation of digitalisation within the agri-food supply chain considering two case studies: coffee and dairy. Future studies could explore other supply chains to identify digitalisation gaps and requirements.
- This thesis modelled technology adoption and diffusion in low-income countries taking Ethiopia as a case study. Future studies could focus on technology adoption and diffusion in rural communities where access to basic services such as internet is limited. Future studies could also model diffusion and acceptance of each type of digital technology by stakeholders in low-income countries.
- This thesis presented two frameworks for digital technology adoption in low-income countries. Future studies should investigate the implementation of these frameworks, considering the context of each low-income country.

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Popular science summary

Logistics is a vital component of supply chains, ensuring efficient flow of goods. The performance of logistics systems could be enhanced by integrating digital technologies such as barcodes, QR codes and GPS. Low-income countries, such as Ethiopia, currently often have deficient logistics systems and limited adoption of digital technologies. Therefore, it is crucial to explore the potential benefits and to identify factors influencing adoption of digital technologies in low-income countries.

A literature review conducted within the scope of this work provided information on the use of digital technologies in logistics. In an interview study conducted in Ethiopia, experts were consulted to identify areas within transportation and warehousing operations that need improvement. Following this, an evaluation of Ethiopia's coffee and dairy supply chains was conducted, to determine the degree of use of digital technologies in planning, transportation and warehousing tasks. The results revealed limited implementation of digital technologies across both the coffee and dairy supply chains, with many stakeholders still relying on traditional methods for planning, product identification and data storage.

Next, a study was carried out to identify the factors governing adoption of digital technologies in logistics in low-income countries. Surveys and modelling work identified important factors that industry and government can target to encourage the adoption of digital technologies. The assessment revealed the importance of enhancing stakeholders' perceptions through training and capacity-building programmes and of improving internet accessibility in urban and rural areas. Addressing limiting factors such as poor finance, technology access and lack of supportive policies is also key for successful digital technology adoption in the logistics systems of low-income countries.

Populärvetenskaplig sammanfattning

Logistik är en viktig komponent i försörjningskedjor, för att säkerställa ett effektivt varuflöde. Prestanda hos logistiksystem kan förbättras genom att integrera digital teknik såsom streckkoder, QR-koder och GPS. Låginkomstländer, som Etiopien, har för närvarande bristfälliga logistiksystem och begränsad användning av digital teknik. Därför är det viktigt att utforska de potentiella fördelarna och att identifiera faktorer som påverkar införandet av digital teknik i låginkomstländer.

En litteraturgenomgång som genomfördes inom ramen för detta arbete gav information om användningen av digital teknik inom logistik. I en intervjustudie genomförd i Etiopien har experter konsulterats för att identifiera vilka områden inom transport- och lagerverksamhet som behöver förbättras. Efter detta genomfördes en analys av Etiopiens försörjningskedjor för kaffe och mejeriprodukter för att avgöra i vilken mån digital teknik används inom planering, transport och lagerhantering. Resultaten visade på begränsat införande av digital teknik inom både kaffe och mejeriförsörjningskedjorna, där många intressenter fortfarande förlitar sig på traditionella metoder för planering, produktidentifiering och datalagring.

Vidare genomfördes en studie för att identifiera faktorer som styr användningen av digital teknik för logistik i låginkomstländer. Enkätundersökningar och modellstudier identifierade viktiga faktorer som industri och myndigheter kan rikta in sig på för att främja införandet av digital teknik. Utvärderingen visade på vikten av att stärka intressenternas uppfattning genom utbildning och kapacitetsbyggande program samt förbättra tillgängligheten till internet i urbana områden och landsbygd. Att hantera begränsande faktorer som dålig ekonomi, tillgång till teknik och brist på stödjande policy är också nyckelfaktorer för ett framgångsrikt införande av digital teknik i låginkomstländers logistiksystem.

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I

future transportation

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].

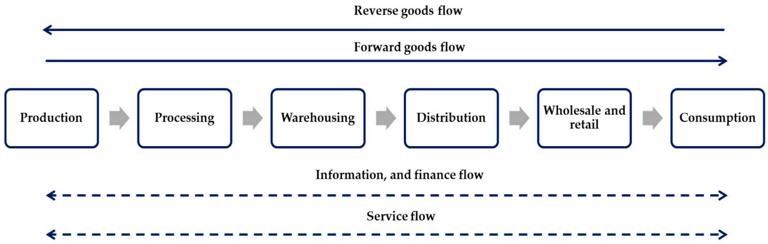

Figure 1. Basic steps in the logistics process.

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.

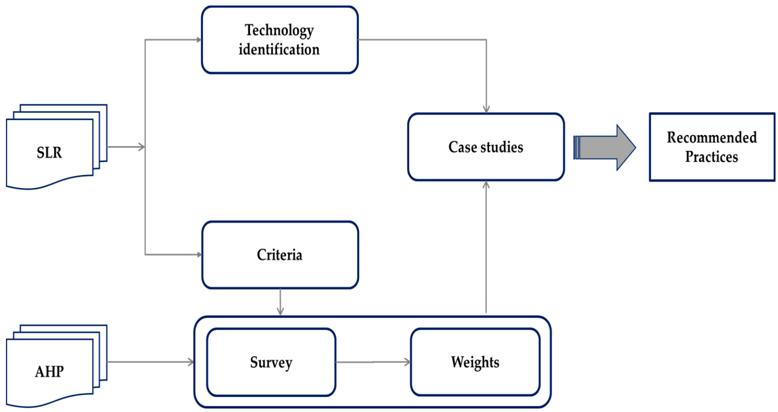

Figure 2. Methodology followed in this research.

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).

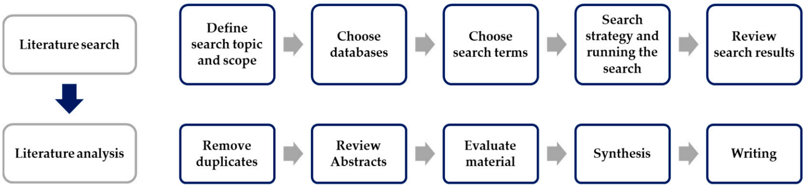

Figure 3. Steps followed in the systematic literature review (SLR).

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].

n	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.

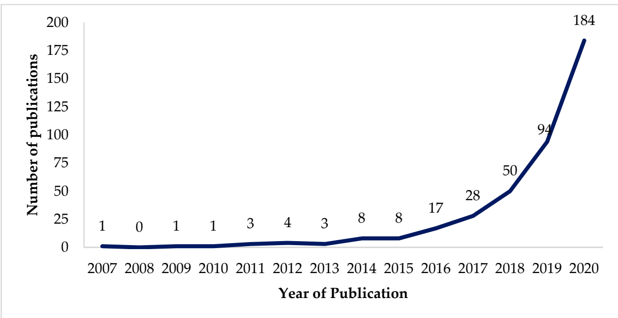

Figure 4. Trend in publication of papers related to logistics technologies in recent decades.

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 Africa	42 6	48	12
Upper middle income	Asia Europe Latin America Africa	94 13 9 3	119	29
High income	Europe North America Asia Oceania	156 37 32 10	236	59

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).

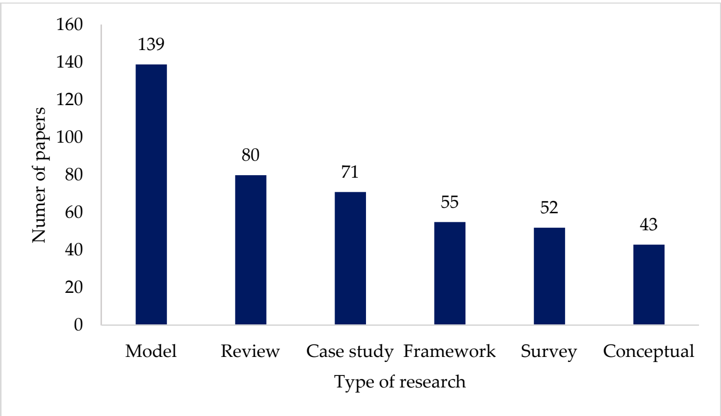

Figure 5. Distribution of articles based on the type of research.

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.

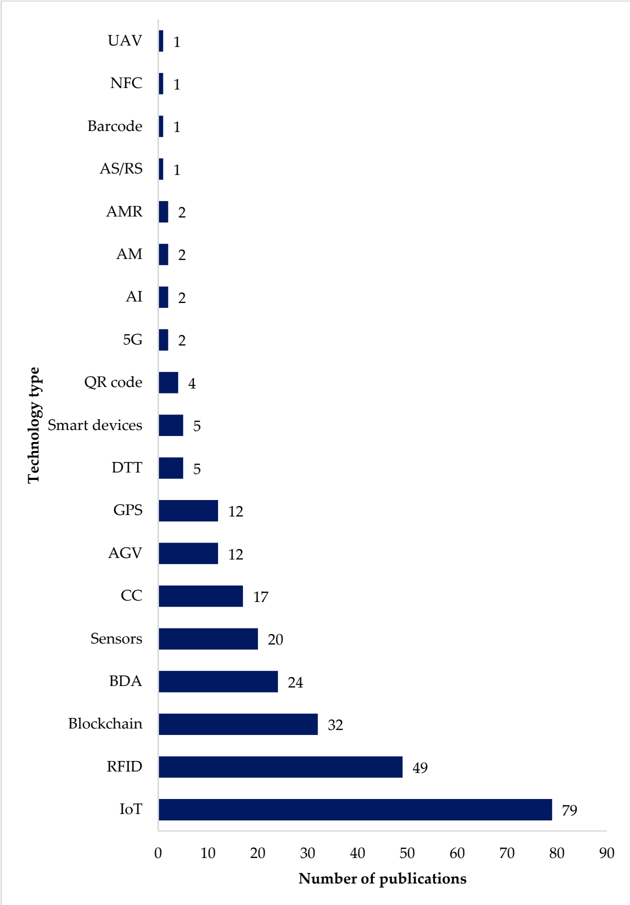

Figure 6. Distribution of the papers reviewed based on type of technology covered. IoT = internet of things; RFID = radio frequency identification; BDA = big data analytics; CC = cloud computing; AGV = autonomous guided vehicles; GPS = global positioning system; DTT = digital twin technology; QR code = 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).

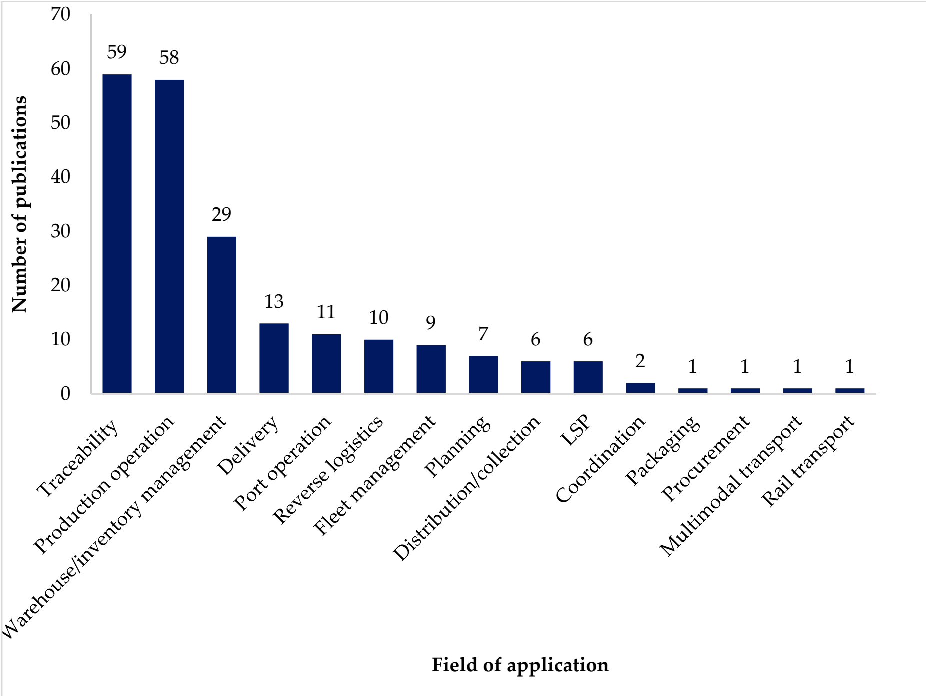

Figure 7. Distribution of the papers reviewed based on field of application. LSP = logistics service providers.

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).

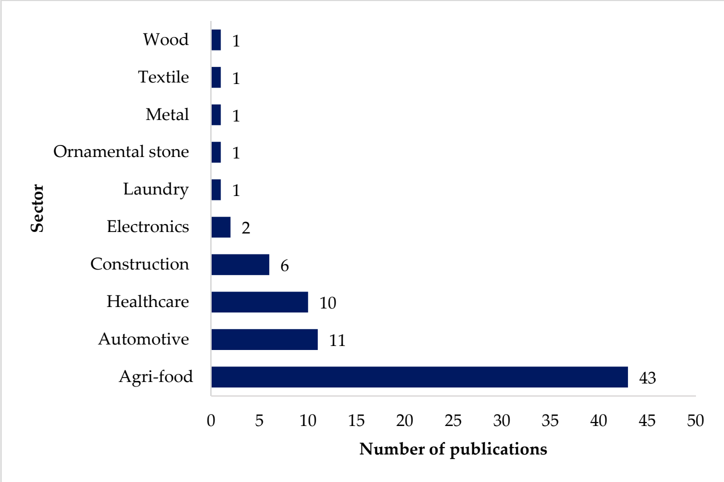

Figure 8. Distribution of the papers reviewed based on the sector(s) focused upon.

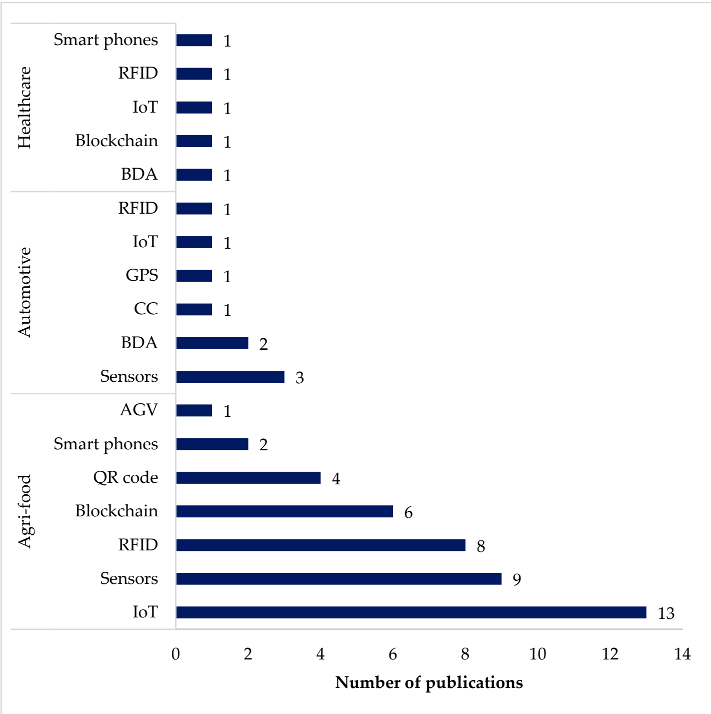

Figure 9. Type of technology applied in the three common sectors.

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.

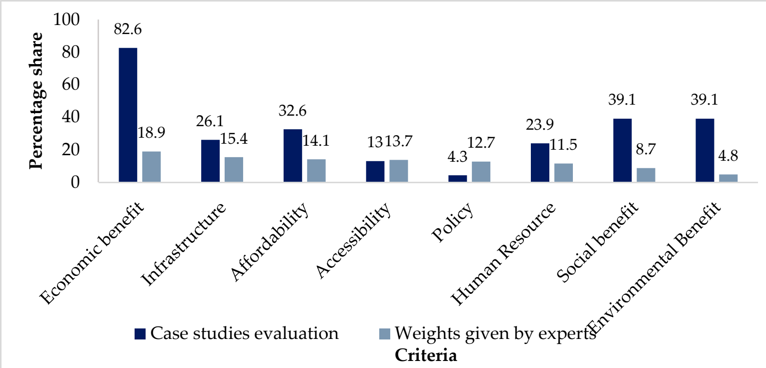

Figure 10. Total number of case studies considering each of the eight criteria.

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).

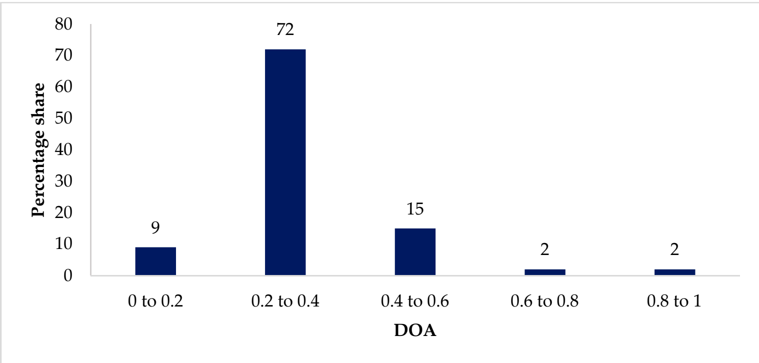

Figure 11. Percentage distribution of degree of applicability (DOA).

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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Key Logistics Performance Indicators in Low-Income Countries: The Case of the Import–Export Chain in Ethiopia

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Abstract: Performance evaluation in logistics is crucial in identifying improvement opportunities. This study assessed performance indicators (PIs) for import–export logistics chains, including transport, dry ports, transhipment and warehouses, focusing on Ethiopia. PIs were identified by means of a literature review. An expert survey based on the analytical hierarchy process (AHP) was used to obtain weightings for the indicators to allow an evaluation of the overall performance of the country's import–export chains. Key challenges faced in the sector were also identified. Indicators such as turnaround time and damage frequency were given high weightings by experts for dry port PIs, security was given the highest weighting for transport PIs, and order lead time was given the highest weighting for warehouse PIs. Technological advancements, human resource capacity building and government policies were found to be the main areas that could improve the performance of logistics operations and address the challenges faced by the sector. These findings could provide a new and comprehensive picture of the key performance indicators of Ethiopian import–export logistics chains.

Keywords: performance indicators; logistics; low-income countries; dry ports; landlocked countries

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1. Introduction

Logistics connects suppliers and customers internationally, making it critical for global trade [1]. It is, therefore, a crucial component in economic development that enables the delivery of the right product, at the right place, at the right time, in the right condition, at the right cost and in the right quantity to the right customer. A high standard of logistics performance increases profitability, advances the national economy and improves competitiveness [2], while also easing business transactions, making countries attractive places in which to conduct international trade. Thus, organisations can improve their logistics performance by identifying bottlenecks in their operations, optimising processes, building better infrastructures, improving policies and training workforces.

The overall quality of a logistics chain depends on the performance of logistics components. A typical import–export corridor involves the components of port activities, transport, warehousing and customs checks [3,4]. Dry ports are also integral parts of the import–export chain, particularly in landlocked countries, and are defined as ports that are located inland where the temporary storage of cargo, inspection and customs clearance take place [5]. The purpose of dry ports is to improve accessibility between seaports and inland trade zones, while also relieving constraints at seaports [6]. Transport provides a link between seaports, dry ports and warehouses, adding both time and space utilities to the goods being transported. Inefficiencies in transportation in the import–export sector cause major losses in terms of efficiency and profitability. Inefficiencies in transportation usually take place due to incompetent drivers, aged trucks, issues related to loading and unloading, availability of trucks, traffic accidents and security threats. Warehousing is another important activity in the import–export chain. Warehouses are used to store raw, partially assembled or finished products, accumulate and consolidate products, and receive, pick and ship products to customers [1]. The way goods are handled, tracked and stored in warehouses has a huge impact on the import–export chain. Companies that have effective warehouse and inventory management make major cost savings due to lower levels of damage and loss.

The occurrence of logistics inefficiencies and bottlenecks affects the performance of the import–export chain. One method for addressing logistics bottlenecks in the import–export chain is through the application of enabling technologies. Bottlenecks due to inefficiency, lack of integration and poor responsiveness have been addressed by previous studies following the increased use of enabling technologies [7–10]. Visibility of port operations can be improved through the use of tracking technologies [11], while automation technologies are used to improve throughput and port accessibility [7–9]. In transport, information and communication technology (ICT) solutions have been used to make transport choices and goods movements less costly and more efficient [12]. Using virtual clustering in transport, which is a temporary virtual cooperation network, logistic companies can choose cost-effective transport services, while at the same time reducing their environmental impact by increasing the load factor [13]. Furthermore, technologies have also been implemented in warehouses to reduce loading and unloading time, costs and damage rate [14,15].

The measurement of logistics performance is a critical step in logistics management. Logistics performance has been evaluated by many researchers at both a national and international level [3,16,17]. The World Bank has also been measuring and ranking the logistics performance of nations since 2007. This ranking is based on the logistics performance index (LPI), which comprises customs, infrastructures, ease of arranging shipments, quality of logistics services, timeliness, and tracking and tracing. A report by Arvis et al. [18] revealed that, based on the World Bank's LPI, the top logistics performers were from high-income countries, whereas low-income countries were the least effective performers.

Numerous studies have measured logistics performance, but few have assigned weightings to indicators using the multi-criteria method. One of the most common multi-criteria methods used in the literature is the analytical hierarchy process (AHP). Bolat et al. [19] used AHP to identify factors affecting port congestion, while Chiu et al. [20] used this method to analyse factors that contribute to green ports, applying the weightings they obtained to evaluate the green performance of three ports in Taiwan. The application of AHP has also been extended to measure the performance of transportation. For instance, Hanaoka and Kunadhamraks [21] evaluated the performance of intermodal transportation using a fuzzy AHP method. This method also has a wide range of applications in warehouse management. Lam et al. [22] applied it to rank the risk factors in warehouse order fulfilment and develop a logistics operation strategy. Srisawat et al. [23] used fuzzy AHP to prioritise performance indicators (PIs) related to logistics efficiency.

According to UN-OHRLLS [5], compared with coastal countries, it costs landlocked countries double the amount and takes them almost twice as long to import or export goods. Thus, the high costs and long lead times incurred by landlocked countries reduce their competitive advantage in the international market. In addition to being a landlocked country, Ethiopia is a low-income country with limited infrastructures, causing the country's logistics performance to become poor. Its aggregated ranking in terms of the World Bank's LPI is 131 out of 160 countries [18]. In contrast, countries such as Botswana, Rwanda and Uganda are also landlocked countries in the region but have better logistics performances, with aggregate LPI rankings of 58, 65 and 72, respectively [18]. One of the reasons for Ethiopia's poor logistics performance is its lack of access to seaports, while another is the lack of technological advancement in logistics components [24–26]. Inefficiencies during customs operations, poor road infrastructures, deficient storage and material handling techniques, and inadequate freight vehicles have led to a deterioration in the country's logistics system [25].

When looking at the import–export chain in Ethiopia, previous research has focused on different aspects of the chain. For instance, Nitsche [27] mapped current challenges faced by the Ethiopian import–export chain and recommended strategies to address them; Gebrewahid and Wald [28] evaluated the export barriers confronting the Ethiopian leather industry; and Amentae and Gebresenbet [3] assessed intermodal freight transport services in Ethiopia. However, none of the above studies identified PIs for the Ethiopian import–export chain considering different weightings for these PIs. Studies argue that criteria should be provided with weightings because not all criteria are equally important to the overall performance of the chain [29,30].

In low-income countries with a poor logistics performance similar to that of Ethiopia, major costs arise from port handling, transport and warehousing [31]. Therefore, it is important to understand the performance of these sectors and identify the bottlenecks within them. The aim of this study was, therefore, to develop PIs for dry ports, transportation and warehouse operation, and to weight their importance in terms of the overall performance of the Ethiopian import–export chain. The most important challenges faced by the sector were also assessed.

2. Materials and Methods

2.1. Overview

To identify the key PIs for dry ports, transportation and warehousing, first of all, a review was undertaken of earlier studies in these areas. The literature was categorised into low-income countries and high-income countries based on the study area on which they focused. The literature on the two categories was then compared to identify sets of PIs that are relevant for low-income countries. These sets were then presented to experts working in government offices influencing logistics activities in Ethiopia to check their relevance and the need for additional indicators. The offices contacted included the Ethiopian Shipping and Logistics Services Enterprise (ESLSE), the Ethiopian Maritime Authority (EMA) and the Ministry of Transport (MoT). The experts contacted from these organisations were team leaders and operation managers with a minimum experience of 7 years. The final set of indicators were then presented to customers and service providers in order for them to weight each indicator. Using the analytical hierarchy process (AHP), the weighting for each indicator was determined. The overall methodology followed in the study is depicted in Figure 1.

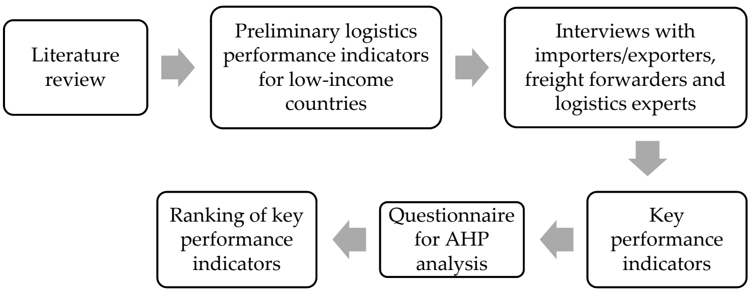

Figure 1. Methodology followed in this study.

2.2. Literature Review

An extensive review of previous studies was conducted by evaluating journals and reports from around the world focusing on import–export chains, which allowed the major activities affecting their efficiency to be identified, along with criteria for measuring the performance for each of these activities. Thus, indicators were obtained for dry port operations, transportation and warehouse management.

2.3. Expert Survey

A survey was carried out in two stages in the study. The first stage was interviews with logistics experts working in government offices. The purpose of this interview was to assure the relevance and adequacy of the indicators gathered from the literature for the case of Ethiopia (Appendix A). After the completion of this step, lists of performance indicators that were to be weighted in the following stage were obtained. In the second stage of the survey, paper-based questionnaires were distributed to customers and service providers (Table 1). The questionnaire is presented in Appendix B. The purpose of this was to weight the PIs according to their importance. The experts required for the survey were divided into two categories, service providers and customers, because it was assumed that the importance of each criterion might be different for stakeholders in the respective groups.

Table 1. Stakeholders approached in the survey.

Customers	Number of Respondents	Service Providers	Number of Respondents
Importers/exporters	35	Ethiopian shipping and logistics service enterprise (ESLSE)	6
Freight forwarders	18	Ethiopian Maritime Authority (EMA)	2
		Ministry of Transportation (MoT)	1

The experts in the survey were selected using a purposive sampling technique. This is a type of non-probability sampling technique where respondents are deliberately selected for the information they can provide that cannot be obtained from other sources [32]. When using the AHP method for conducting pairwise comparisons and obtaining weights, a large sample size is not required as long as the consistency ratio (CR) is within the acceptable limits [33]. Hence, using the purposive sampling technique, interviews were conducted with 53 customers and 9 service providers. The customers interviewed included importers, exporters and freight forwarders that had significant experience in the field of logistics. The service providers interviewed included staff working in the Ethiopian Shipping and Logistics Service Enterprise (ESLSE), the Ethiopian Maritime Authority (EMA) and the Ministry of Transportation (MoT) (Table 1). The experts that were interviewed represented the views of their organisations and not their personal views.

Importers and exporters were asked to undertake pairwise comparisons for port operations, transport and warehouse management. The reason for this is that these experts are involved in all three stages of the operation (i.e., dry port operation, transportation and warehousing). In contrast, freight forwarders were only asked to conduct pairwise comparisons for port operations and transport, as these two aspects fall within the scope of their responsibilities. Staff at ESLSE, EMA and MOT were only asked to conduct pairwise comparisons for the dry port PIs, as they are responsible for providing dry port services.

The questionnaire used in the study comprised three sections. The first section asked respondents to provide general information. The second section provided lists of PIs for the respondents to provide their opinion on their importance level using the scale provided by Saaty [34], which is based on a Likert scale with values ranging from 1 to 9. According to Saaty [34], the values 1, 3, 5, 7 and 9 on the Likert scale represent equally important, slightly important, moderately important, very important and extremely important, respectively, while 2, 4, 6 and 8 are intermediate values between two adjacent scales. This section was required to conduct pairwise comparisons using the AHP method. Finally, the last section required respondents to list the challenges they faced in the sector.

2.4. Analysis

The AHP method is a type of multi-criteria decision-making (MCDM) framework that is used for making pairwise decisions when faced with several competing choices [35]. According to Brunelli [36], the main objective of AHP is to assign weights to a set of alternatives using pairwise comparisons. The method is useful for the analysis of both qualitative and quantitative attributes [37]. The method assumes that the decision makers are rational and that they can assign weights to each criteria using positive real numbers [35].

The other common MCDM methods include Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [21], the Best Worst Method (BWM) [30] and Decision-Making Trial and Evaluation Laboratory (DEMATEL) [35]. Table 2 summarises the strengths and limitations of these MCDM methods. However, the AHP method is preferred over the other methods as it is one of the highly accepted MCDM methods [21] with a wide range of applications. Additionally, the AHP method integrates the judgments of multiple stakeholders and quantifies their judgments [33].

Table 2. Some of the common MCDM methods along with their strengths and weaknesses.

MCDM Method	Strengths	Limitations
AHP	Ability to evaluate both qualitative and quantitative data [38]	Pairwise comparisons increase as the number of variables increase [39] Issues with inconsistency [40]
TOPSIS	Does not require pairwise comparisons [40] No issues with inconsistency [40]	Needs to be combined with other methods to have quantitative results in qualitative problems [41]
BWM	Lesser pairwise comparisons [39] Weights are always consistent [39]	Complex calculation process
DEMATEL	Can weight dependent alternatives [42] Understands cause and effect relationship [42]	Individual weightings of experts are not used to obtain the final weighting for an alternative [42]

AHP has been used for the identification of potential risk factors in warehouse management [22], the selection of appropriate locations for intermodal freight logistics centres [42], the selection of the location of a manufacturing plant [37] and the identification of the most important criteria for implementing digitalised logistics in low-income countries [43].

The main steps in the AHP method, according to Chang and Lin [37], are: (1) identification of criteria for comparison, (2) pairwise comparisons based on the scale outlined by Saaty [34], (3) calculation of the weightings for each criterion and (4) calculation of the consistency ratio (CR). The CR is obtained from the maximum eigenvalue by first calculating the consistency index (CI) using Equations (1) and (2):

$$CI = (\lambda\_max - n)/(n - 1) \quad (1)$$

$$CR = CI/RI \quad (2)$$

where n is the number of criteria and RI is the random consistency index. The value for RI depends on the number of criteria and is obtained from Saaty [34]. The weightings obtained in step (3) are acceptable if the CR calculated in step (4) is less than 10%. If the CR is greater than 10%, the weights should be revised and the participants should be consulted to check whether they agree with the newly assigned weightings.

2.5. Study Area

Ethiopia's main access to the sea is through the port of Djibouti, and over 90% of trade in Ethiopia is conducted through the Ethio-Djibouti corridor [44]. Ethiopia also has eight dry ports located in different parts of the country (Figure 2). The focus of this research was on the Modjo dry port located approximately 73 km from the capital city, Addis Ababa. The Modjo dry port is also the country's largest dry port, with an operational capacity of 17,539 Twenty-foot Equivalent Unit (TEU) at a time, and it handles 78% of the country's imports [45].

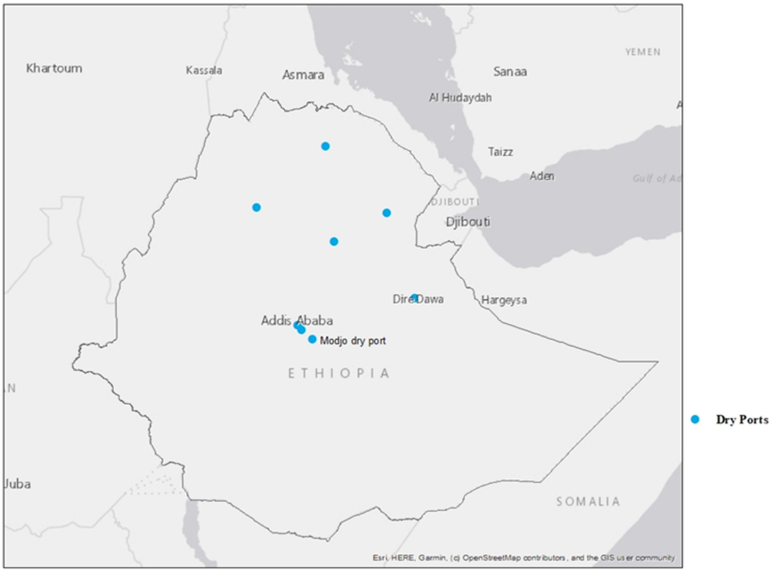

Figure 2. Location of the eight dry ports in Ethiopia.

3. Results

3.1. Preliminary Sets of Logistics Performance Indicators

The identification of logistics PIs enables areas in the supply chain that need improvement to be established. Several authors have measured the performance of various aspects of it. Table 3 summarises the contributions of selected authors on logistics performance.

Table 3. Selected literature focusing on logistics performance.

Author	Contributions
Çelebi [46]	Studied the impact logistics performance has on promoting international trade by comparing countries by their income levels. The authors found that countries from all income groups should collaborate to improve their logistics performance.
Gunasekaran et al. [47]	Developed a framework to measure supply chain performance at strategic, tactical and operational levels. The supply chain performance framework developed by the authors enables the identification of areas in the supply chain that require improvement.
Jin and Wang [48]	Categorised the performance measurement levels in logistics as infrastructure, operational and user-level performance measures.
Kabak et al. [49]	Developed a new approach for investigating the relationship between logistics performance and export. The authors found a direct relationship between logistics performance and export level. Their findings indicate that countries should improve their logistics performance to improve their export levels.
Liebetruth [50]	Studied the various approaches for measuring logistics performance. The authors then studied the possibility for integrating sustainability aspects for measuring the performance of supply chains.
Lin [51]	Studied the factors affecting the adoption of new technologies in Taiwan to improve logistics performance. Their findings indicate that adopting new technologies improves the performance of supply chains.
Rashidi and Cullinane [52]	Used a new approach known as sustainable operational logistics performance to measure the logistics performance of selected countries. The authors compared the logistics rankings with the World Bank's LPI. The approach used by the authors can be used with the World Bank's LPI to identify inefficiencies in logistics performance.
Özceylan et al. [53]	Measured the logistics performance of provinces in Turkey using geographic and economic indicators. The authors then developed a logistics performance map of countries. The findings of the authors facilitate making logistics decisions based on a Geographic Information System (GIS).

Although the aforementioned literature in Table 3 has shed light on various aspects of logistics performance, studies that develop logistics PIs and assigned weightings for the context of low-income countries are still lacking. On the other hand, several authors have taken an interest in measuring the performance of specific logistics activities. The sections below discuss the literature that focuses on logistics PIs for dry port operation, transportation and warehouse management.

3.1.1. Performance Indicators for Dry Ports

There is a considerable amount of literature on the performance of dry ports. Some studies have suggested key PIs that should be used to evaluate dry ports. Others have applied the indicators to evaluate certain ports, compare different ports and model how interventions in port operations affect port performance. Ha et al. [54] classified port PIs considering the goals and objectives of stakeholders in port operations. Accordingly, the indicators were classified into core activities, supporting activities, financial strength, user satisfaction, terminal supply chain integration and sustainability goals. The authors considered human capital, including the knowledge, skill and work ethics of human resources, as port PIs, which were not included in most of the literature. Operational, finance, quality, environmental and safety aspects were recommended as port PIs by Martin et al. [55]. Carboni and Deflorio [56] studied the effect of technologies on environmental and operational PIs, including time-related indicators, loss and damage frequency, utilisation rate and delays. Overall throughput, time aspects and financial aspects were considered in many studies. The indicators shown in Table 4 were found in most of the articles.

Table 4. PIs for dry ports obtained from the literature.

Dimension	PI	Source
	Global PIs for dry ports	
Financial	Throughput	[54,55,57,58]
	Equipment costs	[55]
	Profitability	[55]
	Turnover revenues/expenditures	[55,57]
	Labour costs	[55]
	Maintenance costs	[55]
Efficiency	Storage area utilisation	[55,59]
	Equipment productivity and utilisation	[26,54–56,60]
	Labour productivity and utilisation	[26,54,55,60]
Time	Turnaround time	[54]
	Cut-off time [1]	[56]
	Entrance waiting time	[56]
	Exit waiting time	[56]
	Average waiting time under crane	[54]
	Document exchange time	[56]
Service quality	Handling costs	[26,54,56,60]
	Loss frequency	[26,56,60]
	Damage frequency	[26,56,60]
	Supply chain visibility	[26,56,60]
	Information availability	[26,56,60]
Environmental	Carbon footprint	[54,56]
	Water consumption	[54]
	Energy consumption	[54,56]
	Noise emission	[56]
Multi-modality aspects	Multimodality rate [2]	[26,58,60]
	Expandability	[26,58,60]
	Distance from city centre, commercial areas and industrial zones	[26,58,60]
	Intermodal connectivity	[26,58,60]

Table 4. *Cont.*

Dimension	PI	Source
	Dry port PIs in low-income countries	
Financial	Throughput	[61]
Efficiency	Distribution of plants and equipment [3] Average number of vessels Capacity utilisation	[61]
Time	Turnaround time Berth occupancy	[61]

[1] time interval between the last container delivered and vehicle departure. [2] percentage of multimodal shipments over total. [3] shows how much of the port area is utilised.

Similar to the global indicators, the financial and time aspects of dry port PIs have attracted a great deal of attention in low-income countries (Table 4).

3.1.2. Performance Indicators for Transport

Transportation provides vast and multi-dimensional services. Several studies have measured the performance of transport. For instance, Hanaoka and Kunadhamraks [21] measured the logistics performance of intermodal transport using the fuzzy AHP method. Lai et al. [62] developed a performance measurement system for measuring the performance of transport logistics that reflected the performance of shippers, transport logistics service providers and consignees. Stoilova et al. [63] used infrastructural, economic and technological criteria to assess the performance of railway transport. Šakalys et al. [64] identified the main indicators influencing synchro-modality and used multi-criteria to obtain the weightings of each indicator. Studies conducted in the area have focused on infrastructural service quality and its impact on the environmental aspects of transport performance [65]. Table 5 summarises the categories of these indicators.

Table 5. PIs for transport obtained from the literature.

Dimensions	PIs	Sources
	Global PIs for transport	
Service quality	Travel time (dwell time, processing time, transit time)	[65,66]
	Travel time reliability	[65]
	Delay/out-of-date deliveries	[66–68]
	Safety	[65,66]
	Vehicle operating costs	[65]
	Accessibility	[65,66,68,69]
	Truck capacity	[65,66,68,69]
	Loss and damage frequency	[66–68]
	Accident	[66,68]
Financial	Transport costs	[66]
	Distance travelled per day	[66]
	Turnover per km	[66]
	Delivery frequency	[66]
	Profit per delivery	[66]
	Vehicle loading capacity utilised per journey/vehicle	[66]
	Infrastructure condition	[65]
Environmental	Congestion	[65]
	CO_2 emissions	[65]
	Transport PIs in low income countries	
	Safety	[70]
	Infrastructure	[70,71]
	Vehicle condition	[71]

Transport PIs in low-income countries were also identified from the literature focusing on low-income countries. The studies on low-income countries focused mainly on safety, infrastructure and vehicle condition, as shown in Table 5.

3.1.3. Performance Indicators for Warehouses

Warehousing is the other value-adding activity in supply chain management that facilitates activities involved in the availability of inventory, customisation of products and consolidation [1]. A number of researchers have measured the performance of warehouses. For instance, Chen et al. [72] conducted case studies to identify the critical functions and operations involved in warehouse management and then used their findings to develop key performance indicators (KPIs) focusing on quality, accuracy, costs, security and timeliness of warehouse operations. Karim et al. [73] developed warehouse KPIs by focusing on the productivity dimension, while Kusrini et al. [74] identified warehouse KPIs by conducting a case study in a construction materials warehouse. The global PIs obtained from the literature for warehousing are presented in Table 6.

Table 6. PIs for warehousing obtained from the literature.

Dimension	PI	Source
Global PIs for warehousing		
Time	Timely shipping	[72,75]
	Lead time	[1,47]
	Loading/unloading time	[73,75,76]
	Warehouse location	[1,77]
Quality	Order accuracy	[72,75,76]
	Damage rate	[72,75,78]
	Delivery accuracy	[72]
Financial	Operational costs	[72,76]
	Storage space costs	[1]
	Shipping costs	[1]
	Labour costs	[1]
	Material handling equipment costs	[1,78]
Productivity	Inventory turnover	[73,79]
	Storage space utilisation	[72,73,78,79]
	Backorder rate	[75]
	Labour productivity	[73,79]
	Throughput	[73,76,79,80]
Warehouse PIs in low-income countries		
	Order lead time	[81]
	Inventory turnover ratio	[81]

Few studies have focused on identifying and evaluating warehouse PIs for low-income countries. The PIs obtained from the literature for warehousing are presented in Table 6.

The initial evaluation of the indicators by experts developed a suitable list of indicators at a regional level that are representative of local conditions [23]. Thus, taking into consideration the global indicators in the first part of Tables 4–6 and indicators focusing on low-income countries in the second part of Tables 4–6, a preliminary list of PIs depicted in Table 7 were presented to experts from government offices.

Responses from the experts showed that the given indicators were relevant for the evaluation of performance in dry ports, transportation and warehousing for the case of Ethiopia. Feedback, for example, on combining indicators representing similar aspects, was also provided and, based on this, transhipment time and cut-off time were combined to give the turnaround time as a dry port PI. Indicators that comprised economic aspects were put into financial PIs, as shown in Figure 3. Based on the perspectives of transport users, indicators such as number of trips per month were removed from the list. Finally, the PIs depicted in Figure 3 were analysed further.

Table 7. Preliminary list of PIs for the three sectors.

Dry Port PIs	Transport PIs	Warehouse PIs
Distance from commercial areas	Availability	Loading/unloading time
Transhipment time	Travel time	Inventory turnover rate
Transhipment costs	Travel costs	Damage rate
Cut-off time	Integration with other means of transport	Inventory carrying costs
Turnaround time	Frequency of accident	Order accuracy
Damage frequency	Security	Backorder rate
Loss frequency	Number of trips per month	Order lead time
Process utilisation rate	Truck capacity	On-time delivery rate
Environmental impacts		Total warehouse costs
Throughput		Accessibility from road
		Quantity error rate
		Stock accuracy
		Excess inventory rate

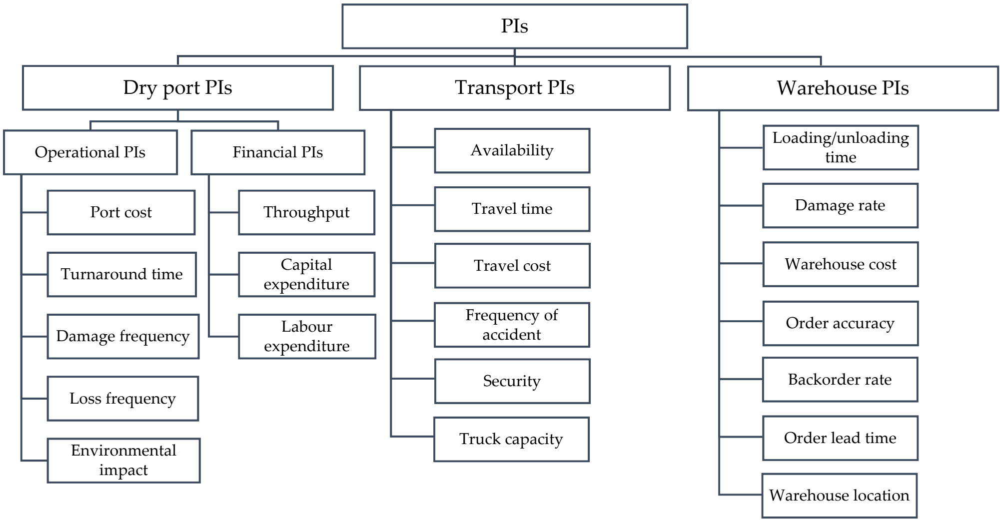

Figure 3. Final list of PIs presented to experts for pairwise comparisons.

3.2. Assessment of Weightings for Each PI

Following the identification of suitable indicators, the experts in the two categories of service providers and customers were asked to perform a pairwise comparison, based on a Likert scale, with values ranging from 1 to 9. The weightings of the PIs shown in Figure 3 were then assessed using the AHP method.

3.2.1. Dry Port PIs

The criteria for the PIs of dry ports were divided into two categories: operational port PIs and financial port PIs. Customers were asked to perform pairwise comparisons for the operational port PIs, while service providers were requested to perform pairwise comparisons for both the operational and financial port PIs.

Operational Dry Port PIs

To obtain the operational dry port PIs, customers (importers/exporters and freight forwarders) and service providers were asked to conduct pairwise comparisons. The results of the pairwise comparison showed that customers gave the highest weighting to turnaround time, with a value of 30.4%. In contrast, service providers gave the highest weighting to damage frequency, with a value of 29.6%. Both customers and service providers gave the lowest weighting to environmental impact, with values of 14.4% and 10.4%, respectively (Figure 4). The CR obtained was 10% for the customers and 7% for service providers. Since the CRs were within the acceptable limits, the calculated weightings were accepted.

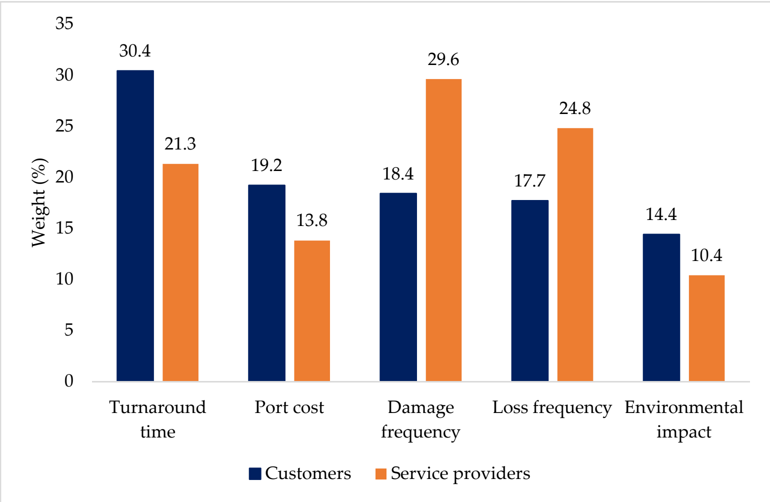

Figure 4. Weightings given by experts for operational dry port performance.

Financial Dry Port PIs

To obtain the weightings for dry port financial PIs, service providers were asked to conduct pairwise comparisons. They gave the highest weighting to capital expenditure per tonne of cargo (53.6%) and the lowest weighting to labour expenditure per tonne of cargo (15.9%) (Figure 5). The CR for financial dry port PIs was 0.2%, making the weightings obtained accepted, as they were within the acceptable range.

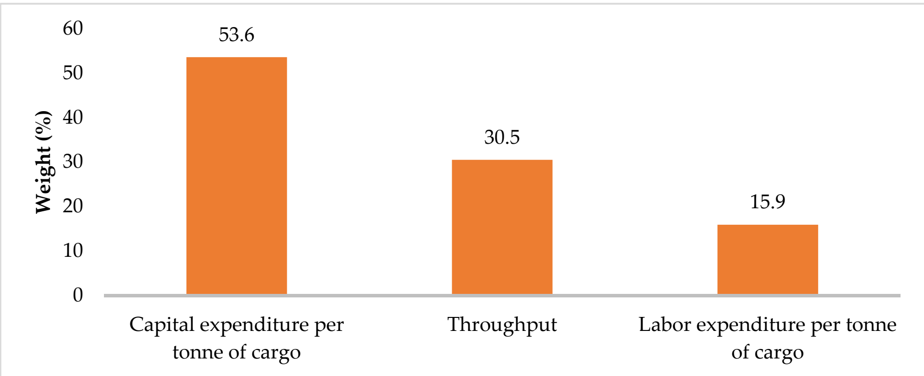

Figure 5. Weightings given by service providers for financial dry port performance.

3.2.2. Transport PIs

Customers of transport services in the import–export chain, including freight forwarders, importers and exporters, gave their opinion about the importance of each criterion. Accordingly, the experts gave the highest weighting to security (24.4%), followed by availability (20.5%). Frequency of accident was found to be the least important criterion, with a weighting of 11.6% (Figure 6). The CR obtained for transport PIs was 9.7%, resulting in the weightings being accepted.

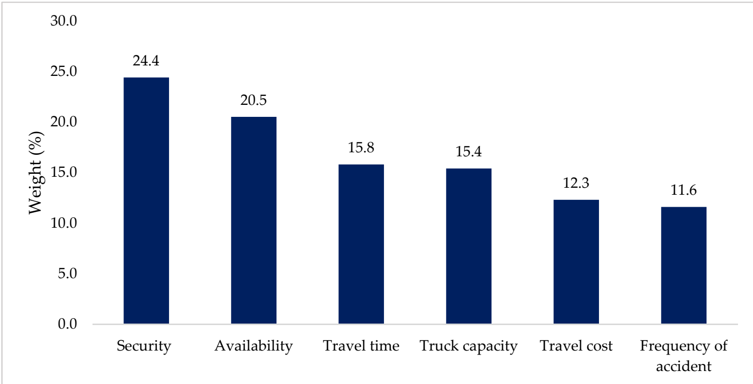

Figure 6. Weightings given by experts for transport performance.

3.2.3. Warehouse PIs

Importers and exporters conducted pairwise comparisons to obtain the weightings of warehouse PIs. The results of the AHP analysis showed that importers and exporters weighted order lead time as the most important criterion, at 24.3%, followed by order accuracy, with a weighting of 20.7%. The analysis also showed that the respondents gave the lowest weighting to damage rate, with a weighting of 8% (Figure 7). The CR obtained for warehouse PIs was 1.3%, resulting in the weights being accepted.

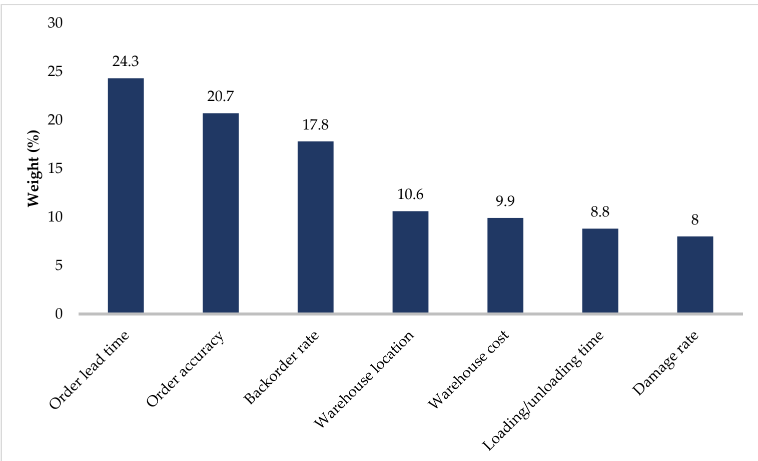

Figure 7. Weightings given by experts for warehouse performance.

3.3. Challenges in the Import–Export Sector

The import–export sector faces a number of challenges related to dry ports, transportation and warehouse management. In response to the question about the challenges faced in the elements of the import–export chain, the respondents' answers are summarised in Table 8.

Table 8. Main challenges faced in the import–export chain.

Activity	Main Challenges
Dry port	Inadequate technology implementation, long waiting times, lack of skilled staff, unfair/inconsistent tax, misplaced containers, corruption, high port fees, bureaucracy
Transport	Aged trucks, low truck availability, poor security, poor road infrastructure, lack of standardised tariffs, poor driver behaviour
Warehouse management	Inadequate technology implementation, lack of skilled staff, high rental costs, warehouse location, poor storage conditions

4. Discussion

4.1. PIs for Low-Income Countries

Results from the literature review showed that, in contrast to high-income countries, the literature focusing on low-income countries used dry port PIs that mainly consider financial aspects. This is likely because dry port services need to be sustained before there can be any focus on providing a quality service and, therefore, operations focus on financial performance. Dry port PIs related to service quality, human resources and their environmental impact are given less attention in low-income countries. This could possibly be because the system is still developing and the priority is on basic indicators.

The literature on transport performance showed that there is a great similarity in the indicators used for both high-income and low-income countries. The limited infrastructure in low-income countries has led to less emphasis being placed on interconnectivity and the traceability aspect of PIs. Indicators related to sustainability are lacking in the literature on low-income countries. This is something that needs attention given the large impact of the transport system on the environment.

For the warehouse PIs, the literature from high-income countries mainly focused on improving quality by reducing damage to the inventory. Furthermore, the literature also focused on improving the productivity of warehouses by increasing throughput and improving the utilisation of storage spaces. However, adequate literature covering the performance of warehouses in low-income countries is lacking. The available literature from low-income countries focused on order lead time and inventory turnover ratio.

4.2. Importance Level of the PIs

For dry port operations, customers from the expert survey gave the highest weighting to turnaround time, with a value of 30.4% (Figure 4). This shows that customers prefer to have their customs and clearance processes handled as soon as possible to avoid incurring high port fees due to the prolonged stay of their shipment in the dry port. A longer turnaround time also poses a risk for customers' importing/exporting time for sensitive or seasonal products. Turnaround time is a critical factor affecting logistics performance in landlocked countries, as outlined by Arvis et al. [82]. The timeliness of logistics service, which is in the World Bank's LPI, can be reflected by reduced turnaround times in ports.

Service providers gave the highest weighting to damage frequency, with a value of 29.6% for dry port operations (Figure 4). The amount of goods damaged or lost during port operations reflects the quality of service provided by the agencies. This is also a measure of the reliability of the service provided. Reliable services ensure predictability and certainty in the supply chain [18] and thus help improve customer satisfaction. This, in turn, likely results in more customers using the port services, thereby increasing the throughput in the port. Hence, port operations in low-income countries should focus on improving the quality of their service to achieve greater reliability [46].

From the financial dry port PIs, service providers gave the highest weighting to capital expenditure per tonne of cargo, with a value of 53.6% (Figure 5). This shows that service providers want to reduce the expenditure that results from investing in port equipment. However, investing in technological advancements and increasing the number of cranes can improve the throughput in the port and increase the efficiency and profitability of the dry port. In contrast, labour expenditure per tonne of cargo was given the lowest weighting, implying that labour is readily available and not costly in port operations, especially in low-income countries.

For both customers and service providers, the environmental impact was given the lowest weighting, with values of 14.4% and 10.4%, respectively (Figure 4). Although there have been some initiatives in Ethiopia to reduce the impacts of climate change [83], the results of the survey showed that this issue has not gained much traction in dry port operations. This might be because the impact that dry port operations can have on the environment has not been well addressed and awareness of their consequences has not been raised. Instead, both customers and service providers are looking for options that boost their profit, mostly at the expense of the environment. Nath and Behera [84] state that low-income countries have fewer initiatives to combat climate impacts, and this is not a priority for governments in these countries. However, strong initiatives and policies should be in place to reduce the impact of climate change in low-income countries to create a sustainable environment. Additionally, seminars and training courses can be provided to learn how other more environmentally friendly ports are operated [20].

From the transport PIs, customers gave the highest weighting to security, with a weighting of 24.4% (Figure 6). The respondents also stated that one of the biggest challenges they face in the transport of containers from dry ports to warehouses is issues related to security. Security threats can arise in the import–export corridor due to political instability, theft and robbery. The issue with security is also a recurring problem in other low-income countries. For instance, it has hindered efficient port operations in Ghana [85]. Security threats due to political instability might cause loaded trucks to be stuck either in the dry port or along the corridor. This leads to delays in delivering products to end users, resulting in supply shortages. Furthermore, if the goods that are to be transported are time sensitive, such as food or medicine, then the products might be spoiled or expire due to poor storage conditions in trucks.

For warehouse management, importers/exporters gave the highest weighting to lead time, with a value of 24.3% (Figure 7). Lead times are generally longer for landlocked countries such as Ethiopia, where imported products have to cross borders and pass through long and bureaucratic customs clearance processes. This could explain the highest weighting given to lead time by importers/exporters. Furthermore, longer lead times also cause stock-outs due to unmet demands. Organisations in countries such as Ghana, Kenya, Uganda and Nigeria also have problems controlling and holding inventory [86]. In addition to improved customs services, lead times in low-income countries can be improved by having effective inventory management systems. Thus, schemes that can enable them to manage their inventories effectively and efficiently are recommended.

4.3. Challenges in the Import–Export Sector

The experts reported that they faced challenges such as long waiting times, high port fees and bureaucracy (Table 8). A survey of ESLSE customers conducted by Amentae and Gebresenbet [3] on the efficiency of services given by the service provider also showed that customers experienced cumbersome customs clearance processes and long waiting times. According to UN-OHRLLS [5], extensive documentation during customs and border clearance is an issue in other landlocked, less developed countries such as Botswana. Challenges faced by respondents, such as long waiting times, high port charges and bureaucracy in dry port operations, are captured by the identified PIs (Figure 4). Measurement and evaluation of these PIs enables progressive improvement to be monitored in areas that present challenges. Interventions related to improvement of these indicators should be given priority, since, based on the survey results, customers gave these a high weighting. One type of intervention that can help in addressing the challenges and improve PIs is the adoption of technologies.

The experts also reported that there is a lack of skilled and professional staff (Table 8). According to the case study of Ansah et al. [85], issues related to shortages of skilled staff have been observed in Ghana's dry port operations. The lack of skilled staff hinders the smooth operation of dry ports, transportation and warehouses, leading to customers receiving a poor service, and delays and inefficiencies in how they are run. To address this issue, training courses and capacity-building programmes should be provided for employees so that they can become more competent at their jobs. There are different alternatives to carry out training and capacity building. One way is by formulating collaboration with higher education institutions. Applying for funding in interested organisations is another way of financing budgets. For big organisations, allocating a specific budget for capacity building is also an alternative. Government policies should also address issues associated with human capital [10]. In addition, the challenges related to skilled staff performance in dry port, transportation and warehouse operations are not included in the identified PIs. Few studies have considered employee performance as an indicator. Therefore, indicators focusing on the performance of human resources, including those working in dry port operations, as truck drivers and in warehouse operations, should be formulated.

The other challenge the experts mentioned was poor technological advancements in port operations (Table 8). They also stated that they experienced delays in receiving services due to poor network or system failures. Poor network availability is a recurring issue in other low-income countries as well, resulting in inefficiencies during port operation [87]. Although advances in information technology can improve information flow and facilitate customs clearance, a low level of technology implementation is an issue in other dry ports, such as in Ghana [85]. UN-OHRLLS [5] also state that landlocked, less developed countries face challenges related to technological advances in their ports. The report states that drawbacks for most landlocked countries in relation to the adoption and implementation of information technologies are related to accessibility, affordability and skills.

Improvement in government policies can help reduce the high documentation requirements for import and export. According to the interview with the experts, the Ethiopian government has commenced the implementation of a single-window service. This service facilities the submission of documents and information required for import/export through a single entry point, thereby reducing delays, facilitating clearances and improving transparency [87]. Trade portals are implemented in dry ports for customs declaration and verification [88], yet the integration with customers and other actors is low because of their lack of use of digital technologies. By providing visibility and control over goods in ports, tracking technologies such as RFID ensure the safety of goods [11]. Automation of equipment in ports results in low environmental impacts, short turnaround times and high equipment utilisation, and increases throughput and port accessibility [7–9]. Smart ports are the next emerging technologies with minimal human involvement in carrying out tasks, thus ensuring accurate and rapid port operations. To guarantee the effectiveness of these technologies, PIs measuring the implementation of technologies should also be in place. This enables an audit of the technologies addressing the challenges faced in the sector.

A commonly observed challenge during the transportation of containers from dry ports to warehouses is the extensive use of aged trucks (Table 8). Freight transportation services in Ethiopia are marked by a prevalence of aged trucks and lack of traceability [28]. According to Kine et al. [89], the use of aged trucks is a common problem in other low-income countries as well. They are not only a cause of traffic accidents along the route, but also a huge contributor to the emission of pollutants to the environment. Furthermore, drivers of these trucks are mostly inexperienced, making them a threat not only to the security of the goods being transported, but also to other road users. Thus, to counteract the risk posed to the environment and society by aged trucks and incompetent drivers, fleet modernisation is important. Fleet modernsation could occur by implementing technologies on the existing trucks or replacing the aged trucks with new ones. The cost of replacing aged trucks is not cost intensive, as the cost of buying new trucks is compensated by avoiding the huge cost encountered in maintaining and running old trucks. In addition, government intervention could be crucial, as government policies could allow the use of aged trucks to be limited and regulate the minimum number of years' experience required by drivers before they are able to drive heavy trucks.

The experts also stated that they faced challenges in finding trucks that can transport their containers from the dry port to warehouses, particularly during peak seasons (Table 8). This explains the high weighting given by the experts to availability when conducting the pairwise comparisons (Figure 6). Using ICT solutions, transport choice and goods movement become less costly and more efficient [12]. Using virtual clustering in transportation, logistic companies choose less costly transport services and at the same time reduce their environmental impact by increasing the load factor [13]. Behrends et al. [90] discuss how installing telematics in railways can improve their share of use by increasing responsiveness, reliability and wagon efficiency. Hence, implementation of truck telematics and other ICT solutions can alleviate the challenges faced by experts in relation to truck availability. The cost for the implementation of telematics for trucks and other ICT solutions depends on the degree of implementation of the technologies. The government could subsidise some of the encountered costs to promote technology implementation. The cost also depends on a number of factors, including type of truck, specific solutions required, type and amount of data that needs to be collected and installations of tools.

In terms of warehouse management, the experts stated that there were few or no technologies in place for handling and/or managing inventory (Table 8). Warehouse operations lack integration with selling points and visibility, and are highly reliable on manpower [29,30]. This causes damage to goods during loading/unloading and loss of inventory due to theft, as there are few or no means for tracking inventories. Digital technologies make management of warehouses and inventories efficient. The use of digital technologies significantly reduces loading time, costs and damage rates in warehouses [14,15].

To improve the performance of dry ports, warehousing and transportation, technology adoption plays a vital role. However, the adoption of new technologies, particularly in low-income countries, is dependent on the economic advantages of the technologies, the presence of necessary infrastructure and the affordability of the technologies [43]. Thus, detailed studies regarding the technologies and ways on how to implement them is important.

5. Conclusions

This study developed PIs for dry ports, transportation and warehouse operations, and the importance of these indicators were weighted. The results of the study show that customers in the expert survey considered time-related PIs such as turnaround time important for dry port operations and order lead time important for warehouse activities. For transportation, customers considered security and availability as the most important PIs. Service providers considered damage frequency as the most important PI. The survey results also show that both customers and service providers gave a low weighting for environmental impact.

The PIs identified in this study could be adopted by other low-income countries to improve the performance of their dry port operation, transportation and warehouse management by taking local conditions into account. Moreover, the approach and methodology used to obtain the PIs in this paper could be used by other low-income countries to assess areas of logistics activities that require improvement.

The study showed that the logistics-related challenges faced in the import–export chain included high costs, low utilisation level of digital technologies, scarcity of skilled and professional workforce, aged trucks and the lack of integrated systems. To address these challenges, implementation of digitalisation and automation technologies, together with appropriate policy, could be recommended. These technologies could improve the performance of dry ports, transportation and warehouse management by increasing throughput, improving accessibility, boosting efficiency, lowering costs and reducing damage and losses. In addition to technological interventions, capacity-building programmes are recommended to develop skilled workers to make services efficient. The public institutions could play an important role in improving logistics services by making systems more transparent, better coordinated and less bureaucratic.

Although this study developed and weighted the performance indicators of dry ports, transportation and warehousing, seaports are also seen as a critical part of the import–export chain. Thus, further research studies could be recommended for the seaports. Furthermore, measuring the impact of the performance of dry ports, transportation and warehouse operations on supply chains and the required improvement of performance from the perspective of low-income countries could be recommended.

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Appendix A. The First Round Questionnaire Deployed in the Study

Appendix A.1. Introduction

The purpose of this survey is to identify key logistic performance indicators in the import–export chain of Ethiopia. For this, logistics performance indicators for the main import–export components, including dry ports, transport and warehouses, are collected from the literature and presented. Please provide your responses for the following questions.

Appendix A.2. General Information

a. What is the name of the company?

____

b. What is your position in the company?

____

c. What is your education level?

____

d. How many years of experience do you have?

____

Appendix A.3. Dry Port

The table below shows the performance indicators of dry ports that are found from the literature. The indicators suitable for low-income countries are selected and presented here. Please rate the relevance of the performance indicators to measure dry port performance in Ethiopia.

Table A1. Dry port PIs.

Performance Indicators	Not Important	Important
Distance from commercial areas		
Transhipment time		
Transhipment costs		
Cut-off time		
Turnaround time		
Damage frequency		
Loss frequency		
Process utilisation rate		
Environmental impacts		
Throughput		

a. Are there any dry port performance indicators other than the ones mentioned above?

____

b. If your response to part a is yes, please provide the indicators in the space provided below.

____

c. Do you perform performance evaluation in your company?

____

d. What performance indicators do you implement in your company (can be from the list above or any different indicators?)

____

Appendix A.4. Transport

The following table shows the performance indicators of transport that are gathered from the literature. The indicators suitable to low-income countries are selected and presented here. Please rate the relevance of the performance indicators to measure transport performance in Ethiopia.

Table A2. Transport PIs.

Performance Indicators	Not Important	Important
Availability		
Travel time		
Travel costs		
Integration with other means of transport		
Frequency of accident		
Security		
Number of trips per month		
Truck capacity		

a. Are there any transport performance indicators other than the ones mentioned above?

____

b. If your response to part a is yes, please provide the indicators in the space provided below.

____

c. Do you perform performance evaluation in your company?

____

d. If yes, what performance indicators do you implement in your company (can be from the list above or any different indicators?)

____

Appendix A.5. Warehouse

The following table shows the performance indicators of warehouses that are gathered from the literature. The indicators suitable to low-income countries are selected and presented here. Please rate the relevance of the performance indicators to measure warehouse performance in Ethiopia.

Table A3. Warehouse PIs.

Performance Indicators	Not Important	Important
Loading/unloading time		
Inventory turnover rate		
Damage rate		
Inventory carrying costs		
Order accuracy		
Backorder rate		
Order lead time		
On-time delivery rate		
Total warehouse costs		
Accessibility from road		
Quantity error rate		
Stock accuracy		
Excess inventory rate		

a. Are there any warehouse performance indicators other than the ones mentioned above?

____

b. If your response to part a is yes, please provide the indicators in the space provided below.

____
____

c. Do you perform performance evaluation in your company?

____

d. What performance indicators do you implement in your company (can be from the list above or any different indicators?)

____
____

Appendix B. The Second Round Questionnaire Deployed in the Study

Appendix B.1. Introduction

The research aims to develop logistics and supply chain management performance indicators for low-income countries, focusing on the export and import chain.

Accordingly, a multi-criteria decision framework is used in this questionnaire to identify the key performance indicators where a set of factors is given to you, and you rate the relative importance of each factor compared to its corresponding alternative. The relative importance is measured on a scale of 1 to 9. The meaning of each number value can be found in Table A4 below.

Table A4. Legend for performance indicator rating numbers.

Importance Scale	Definition of Importance Scale
1	Equally important preferred
2	Equally to moderately important preferred
3	Moderately important preferred
4	Moderately to strongly important preferred
5	Strongly important preferred
6	Strongly to very strongly important preferred
7	Very strongly important preferred
8	Very strongly to extremely important preferred
9	Extremely important preferred

Appendix B.2. Respondent's Information

a. What is the name of the company?

____

b. What is your position in the company?

____

c. What is your education level?

____

d. How many years of experience do you have?

____

e. Do you own a truck? If yes, how many

____

f. Do you own a warehouse? If yes, how many?

____

Appendix B.3. Performance Indicators of Dry Ports

The following performance indicators are related to the dry port performance. Please rate the relative importance of each performance indicators in the row to the performance indicators along the column on a scale of 1 to 9. Please find the meaning of each number value in Table A4.

1. Operational Performance Indicators

Table A5. Pairwise comparisons for operational dry port PIs.

Factors	Turnaround Time	Port Cost	Damage Frequency	Loss Frequency	Environmental Impact
Turnaround time					
Port cost					
Damage frequency					
Loss frequency					
Environmental impact					

2. Financial Performance Indicators

Table A6. Pairwise comparisons for financial dry port PIs.

Factors	Capital Expenditure Per Tonne of Cargo	Throughput	Labour Expenditure Per Tonne of Cargo
Capital expenditure per tonne of cargo			
Throughput			
Labour expenditure per tonne of cargo			

a. What are the main challenges you face in port operations?

____

b. Are there any forms of digitisation or automation implemented in your company? __________

If yes, please list them?

____

Appendix B.4. Performance Indicators for Transport Services

The following performance indicators are related to transport performance. Please rate the relative importance of each performance indicator in the row to the performance indicators along the column on a scale of 1 to 9. Please find the meaning of each number value in Table A4.

Table A7. Pairwise comparisons for transport PIs.

Factors	Security	Availability	Travel Time	Truck Capacity	Travel Cost	Frequency of Accident
Security						
Availability						
Travel time						
Truck capacity						
Travel cost						
Frequency of accidents						

a. What are the main challenges you face in transport operations?

____

b. Are there any forms of digitisation or automation implemented in your company? __________

If yes, please list them?

____

Appendix B.5. Performance Indicators for Warehousing

The following performance indicators are related to warehouse performance. Please rate the relative importance of each performance indicator in the row to the performance indicators along the column on a scale of 1 to 9. Please find the meaning of each number value in Table A4.

Table A8. Pairwise comparisons for warehousing PIs.

Factors	Order Lead Time	Order Accuracy	Backorder Rate	Warehouse Location	Total Warehouse Cost	Loading/Unloading Time	Damage Rate
Order lead time							
Order accuracy							
Backorder rate							
Warehouse location							
Total warehouse cost							
Loading/unloading time							
Damage rate							

a. What are the main challenges you face in warehouse operations?

____

b. Are there any forms of digitisation or automation implemented in your company?

____

If yes, please list them?

____

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This study explores digital technology adoption in logistics within low-income countries, focusing on Ethiopia. It identifies relevant transportation and warehouse performance indicators, evaluates coffee and dairy supply chain performance and assesses stakeholders' acceptance of digital technologies. Findings reveal limited adoption of digital technologies in both supply chains. Key factors influencing adoption include stakeholders' perceptions, infrastructure, finance, technology access, human resources and supportive policies. The study proposes a framework for technology adoption, supporting policymakers and practitioners in transitioning to digitalised supply chains.

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