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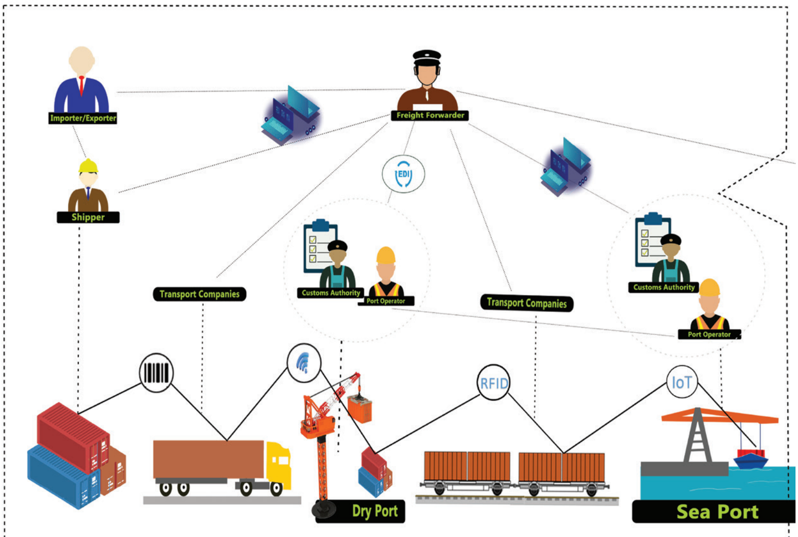
A low-income country perspective

Helen Zewdie Kine



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Helen Zewdie Kine
Faculty of Natural Resources and Agricultural Sciences
Department of Energy and Technology
Uppsala

SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES

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Swedish University of Agricultural Sciences, Department of Energy and Technology, Uppsala, Sweden

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Assessment of digital technology application in intermodal freight transport: A low-income country perspective

Abstract

Intermodal freight transport (IFT), involves the use of two or more transport modes to move goods within a single unit, creating a complex, multi-stakeholder system. Digital tools play a critical role in planning and optimisation of this system. However, the current adoption of digital technologies in low-income countries is considered low and therefore, their potential benefits are not realised. This thesis endeavoured to investigate the potential benefits of digital technology in IFT from the perspective of low-income countries. First, current technological practices and important performance indicators were examined by considering the transport chain from seaport to dry ports and to destinations/origin points in Ethiopia. Second, two studies on dry ports were conducted to explore the application of digital technology in IFT. The research approach included a systematic literature review, qualitative methods including business process mapping, as well as quantitative methods such as multi-criteria decision analysis and modelling. The results revealed that adoption of advanced digital technologies in IFT is limited, particularly in the road transport sector. The presence of basic technologies in the surveyed companies revealed potential for the further digitalisation of IFT. Application of geographic information systems and use of spatial data in dry port location analysis could enhance decision-making with regard to the optimal location of dry ports. Furthermore, the integration of digital technologies, such as online platforms for dry port's information management and document sharing, have the potential to improve time efficiency, which was the second most important performance indicator identified in this study. Overall, the potential of digital technologies to enhance key performance indicators in the IFT of low-income countries should be fully exploited. At the same time, infrastructural and human resource constraints in these economies should be addressed for successful technology adoption schemes.

Keywords: Intermodal freight transport, digital technologies, digitalization, technology adoption, performance, low-income countries

Analys av införandet av digital teknik inom intermodala godstransporter: Ett låginkomstlandsperspektiv

Abstract

Intermodal godstransport (IFT), där två eller fler transportmedel används för att förflytta gods inom en och samma lastbärare, är ett komplext system med flera intressenter där planering och optimering spelar en avgörande roll. Användningen av digital teknik i låginkomstländer bedöms vara låg, och därmed realiseras inte dess potentiella fördelar för. Denna avhandling syftar till att utforska de potentiella fördelarna med digitala teknologier inom IFT ur ett låginkomstlands perspektiv. Först undersöktes nuvarande tekniktillämpningar och viktiga prestandaindikatorer genom att granska transportkedjan från hamn till torrhamnar och vidare till destinations- och ursprungspunkter i Etiopien. Därefter genomfördes två fallstudier om torrhamnar för att undersöka tillämpningen av digital teknik inom IFT. Forskningsansatsen inkluderade en litteraturgenomgång, kvalitativa metoder såsom kartläggning av affärsprocesser, intervjuer och enkäter, samt kvantitativa metoder såsom multikriterieanalys och modellering. Resultaten visade att användningen av avancerade digital teknik är begränsad, särskilt inom vägtransportsektorn. Förekomsten av grundläggande teknologier hos speditörsföretag visar på potential för ytterligare digitalisering av IFT. Användning av geografiska informationssystem och rumslig data för lokalisering av torrhamnar kan förbättra beslutsfattandet kring optimala torrhamnsplaceringar. Dessutom kan integreringen av digital teknik, såsom online-plattformar för torrhamnars informationshantering och dokumentdelning, förbättra tidseffektiviteten, vilket identifierades som den näst viktigaste prestandaindikatorn i denna studie. Sammantaget bör potentialen hos digitala teknologier för att förbättra nyckelprestandaindikatorer inom IFT i låginkomstländer utnyttjas fullt ut. Samtidigt bör begränsningar i infrastruktur- och personalresurser i dessa ekonomier adresseras för att möjliggöra framgångsrika program för teknikinförande.

Nyckelord: Intermodal godstransport, digital teknik, digitalisering, teknikinförande, prestanda, låginkomstländer

Dedication

To my parents Zewdye and Emaye, who are like candles, lighting up the world around them as they burn.

Contents

List of publications

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

I. Kine, H. Z., Gebresenbet, G., Tavasszy, L., & Ljungberg, D. (2022). Digitalization and Automation in Intermodal Freight Transport and Their Potential Application for Low-income countries. *Future Transportation*, 2(1), 41-54.

II. Tadesse, M. D., Kine, H.Z., Gebresenbet, G., Tavasszy, L., & Ljungberg, D. (2022). Key Logistics Performance Indicators in Low-income Countries: The case of the Import-Export Chain in Ethiopia. *Sustainability*, 14 (19), pp. X-Y (in press)

III. Kine, H.Z., Gebresenbet, G., Tavasszy, L., & Ljungberg, D. (2024). State of digital technology adoption in intermodal freight transport: empirical evidence from Ethiopia. *World Review of Intermodal Transport Research*, 11(4), 362-395.

IV. Kine, H.Z., Shiferaw, Z., Gebresenbet, G., Tavasszy, L., & Ljungberg, D. (2024). GIS Based Multi-Criteria Decision-Making Approach for Dry Port Location Analysis: The Case of Ethiopia. *Transport Research and Business Management*. (Submitted).

V. Kine, H.Z., Techane B., Gebresenbet, G., Tavasszy, L., & Ljungberg, D. Implementation of Digital Technologies and The Impact onto improve Dry Port Performances Authors (Manuscript).

Papers I-III are reproduced with the permission of the publishers.

The contribution of Helen Zewdie Kine to the papers included in this thesis was as follows:

I. Conceptualisation, literature retrieval and review, writing and editing after co-authors' review.

II. Conceptualisation, methodology, conduct survey, analysis, writing and editing after co-author's review.

III. Conceptualisation, methodology, conduct survey, analysis, writing and editing after co-author's review.

IV. Conceptualisation, methodology, data collection, analysis, writing and editing after co-author's review.

V. Conceptualisation, methodology, data collection, analysis, writing and editing after co-author's review.

List of tables

List of figures

Abbreviations

AHP	Analytical hierarchical process
AI	Artificial intelligent
BPF	Business process flow
BPMN	Business process modelling notation
DP	Dry port
FF	Freight forwarder
GPT	General purpose technologies
ICT	Information and communication technology
IFT	Intermodal freight transport
IoT	Internet of things
MCDM	Multi-criteria decision-making
RCA	Root cause analysis
RFID	Radio frequency identification
SLR	Systematic literature review
SMART	Simple multi-attribute rating technique
TOE	Technology organization environment

1. Introduction

The use of multiple modes of transport in freight transportation is prevalent, driven by the presence of physical barriers, economic feasibilities and environmental concerns. Intermodal freight transport (IFT) is defined as a door-to-door service for moving goods in a single load unit with a chain of multiple transport modes (Andreas & Hanssen, 2014; Reis & Macario, 2019). The system accounts for most international, sea-crossing trades and a smaller proportion of domestic freight transport. About 80 % of international trade by volume is undertaken by sea (UNCTAD, 2021). In the context of maritime transport, IFT comprises two key components: links, which are corridors connecting transport nodes, and the nodes referring to seaports, terminals or warehouses where transhipment occurs or where the transport chain begins or ends. With the increase in global trade, many seaports are experiencing congestion within and around the port area. Therefore, the hinterland side of the transport chain has become as crucial to reliable delivery as sea transport (Gonzalez-Aregall & Bergqvist, 2019). An important measure to mitigate congestion has been the introduction of dry ports, in which case it becomes an integral part of the IFT system.

As numerous stakeholders are involved in IFT having specific interests, the system has become increasingly complex (Jacobsson et al., 2017). Information and document sharing between stakeholders takes longer and could be a cause of delays and inefficiencies in IFT (Baalsrud Hauge et al., 2011). Detailed planning, effective communications and rapid document sharing between stakeholders are required (Boschian et al., 2009).

IFT is vital to facilitating the import and export of goods in Ethiopia. About 80-90 % of Ethiopia's export and import activity is carried out using sea shipping, with containerised goods accounting for 40-60 % of this number (ESLSE, 2017). As a landlocked country, Ethiopia has faced strains around international trade (Faye et al., 2004) and eight dry ports have been established to mitigate this. In addition to being landlocked, the development of intermodal freight transport is at early stage in the region (Nitsche, 2021) and consequently the planning, operation and monitoring of the system are underdeveloped. High transit and dwell times, logistics costs, port inefficiencies and a significant import-export imbalance are evident in the import-export corridor (Amentae & Gebresenbet, 2015; Takele & Tolcha, 2021). Thus, Ethiopia scores low in the World Bank's logistics performance index (LPI). Previous studies have examined structural, technological, infrastructural and policy measures to improve the low performance of IFT.

Technological interventions can play a major role in enhancing the efficiency of IFT. The application of available and emerging digital and automation technologies supports the seamless and timely flow of information and goods, resulting in a well-integrated, transparent, cost-effective, time-efficient and high-quality IFT (Hricová & Balog, 2015; Altuntaş Vural et al., 2020). Technologies in intermodal transport include networking and communication technologies, sensors, satellite technologies, cloud computing, web-based platforms and automation. Areas of their application include in decision-making, port planning and management, chain management and monitoring, and route optimisation (Ángel González et al., 2008; Scholliers et al., 2016; Heilig et al., 2017; Wang et al., 2017; Muñuzuri et al., 2020). However, the adoption of digital technologies in low-income countries is low. Thus, crucial questions regarding impact of digital technology on the IFT performance in low-income countries include:

- Which digital technologies are implemented in the current IFT system and are best practices for low-income countries?
- What are the performance indicators of IFT and their importance level?
- What is the state of digital technology adoption in IFT?
- How can the application of digital technologies improve the planning and performance of intermodal freight transport?

To investigate the impact of digital technology on IFT performance, it is crucial first to assess the key performance indicators of IFT. In addition, assessment of IFT involves exploring the current use of digital technology among stakeholders engaged in the system. Studying the level of technology adoption in the transport system helps uncover the potential benefits of digitalisation and identify areas in which technological improvements are required (Davies et al., 2007; Philipp, 2020). Measuring the level of digitalisation comprises both qualitative and quantitative aspects. The existing literature in IFT mainly focuses on the use of ICT in road haulage and ports (Davies et al., 2007; Marchet et al., 2009; Evangelista and Sweeney, 2014; Philipp, 2020), while structured quantitative measurement of technology adoption in this sector is lacking.

Subsequently, studies analysing the applications of digital technologies affecting decisions and operations in IFT are necessary to design efficient IFT systems for the future. Proposing optimal dry port locations is one such area for study. According to Rodrigue & Notteboom (2012), site selection is one of the five primary criteria affecting the efficiency of dry ports. Moreover, choosing the location for a dry port is a crucial aspect of ensuring an efficient logistics and transport system, which can impact the entire supply chain (Ng & Cetin, 2012). Moreover, digital technologies play a key role in optimising dry port locations with computational powers of spatial analysis in Geographic Information System (GIS). The application of digital technologies in dry port processes to smooth their operation is another area that requires evaluation. Modelling tools such as Petri net and closed queuing networks use discrete event modelling to explain the processes and forecast the impact of ICT measures on improving IFT (Dotoli et al., 2014; Cavone et al., 2016). Activity-based costing is another method for evaluating the impact of technologies on IFT performance with a focus on cost aspects (Miragliotta et al., 2009; Marchet et al., 2012). However, there is a gap in the literature in terms of giving consideration to dry port processes when studying the potential of digital technology to improve performance, particularly in the context of low-income countries.

To address these knowledge gaps, this thesis proposes a framework that examine how the adoption and application of digital technology impact the performance of intermodal freight transport. The hypothesis is that digitalisation can be one measures to mitigate the low performance of IFT in low-income countries.

2. Aims and Scope

2.1 Aim and objectives

The aim of this thesis was to assess the application of digital technology in order to improve intermodal freight transport performance in the context of low-income countries, focusing on Ethiopia.

The specific objectives were to:

- Assess frontline digital technology in IFT and their potential benefits for low-income countries (Papers I, V)
- Determine the most important performance indicators in IFT (Paper II)
- Explore the level of digital technology adoption in IFT (Paper III)
- Investigate the application of digital technology in planning and operation of dry ports (Paper IV, V).

2.2 Research framework and approach

The five papers that make up this thesis focused on intermodal freight transport and digital technologies in Ethiopia. Ethiopia is an example of landlocked low-income country with a concept of dry port and intermodal freight transport becoming increasingly important for the growing economy. A case study approach was used to gain detailed perspective on the research questions supported by data specific for the actual context. Paper I provided the theoretical basis for all the subsequent studies as it identified the technologies applied in intermodal freight transport at a global level and their potential application in low-income countries.

The existing system was then assessed from two perspectives. First, the key performance indicators were identified in paper II and second the level of adoption of digital technology in IFT in the study area were explored in paper III. Following these studies, two case studies investigating the application of digital technologies were conducted with a focus on the dry port component of IFT. In this context, a location analysis study was performed using the GIS tool and the impact of digital technologies on dry port performance studied in Papers IV and V, respectively. Figure 1 depicts the overall research framework.

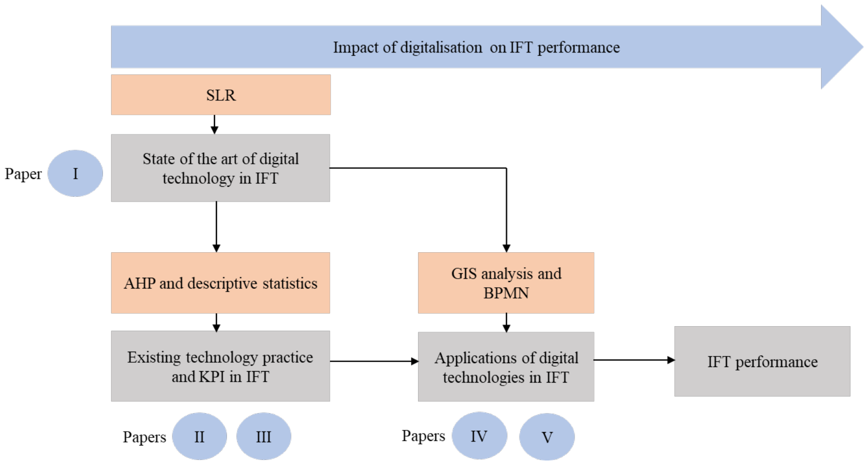


Figure 1. Research framework to study the impact of digital technology on IFT performance. The framework encompasses three main steps of assessing current adoption, potential application and performance implications of digital technology.

2.3 Scope and limitation

The scope of this thesis was to assess the role of digital technology in IFT systems in a low-income country. The inland part of international maritime intermodal transport chains in Ethiopia was the main focus of the analyses. Most of the analyses relied on survey results and expert opinions, could be reinforced by first-hand measurement of performance indicators and the impacts of digital technologies. Insufficient spatial data on economic activities and production areas could impact the robustness of location analysis results and hence such databases are essential.

3. Literature review

3.1 Introduction

There are few researches studying the impact of digital technologies on IFT performance, but the focus on low-income countries has been limited. The following review provides the background to the research questions addressed in this thesis by examining the existing literature on digital technologies and performance indicators in IFT. After identifying the gap in the literature, this section reinforces the need for further study.

3.2 Intermodal freight transport

Each mode of transport offers distinct advantages and disadvantages within the freight transport sector. Road transport is preferred for its flexibility and door-to-door service, but contributes significantly to environmental issues and heavily affected by congestion (Lowe, 2005; Rodrigue et al., 2016). Rail transport is a better inland transport option with regard to environmental concerns and for longer distances, but lacks flexibility (Kordnejad, 2016). Sea transport is preferred for large and long-distance transport of goods, whereas air transport for sensitive and express transport (Rodrigue et al., 2016). The concept of intermodal freight transport intends to utilise multiple means of transport in a cost-effective and efficient way. In theory, it is defined as the seamless transportation of goods using multiple modes of transport, characterised by the use of a single load unit, a single bill of lading (for international transport), good integration and a door-to-door service (Jones et al., 2000; Vasco & Macário, 2019).

After the introduction of standard freight containers in the 1960s, IFT has evolved and became an important component of freight transport, especially in international trade (Konings et al., 2008). The combination of modes in IFT includes road-rail, sea-road, sea-rail, and air-road. Road-rail, sea-road and sea-rail are the most common IFT combinations. Intermodal freight transport can be applied in both domestic (mostly rail-road) and international freight transport. Domestic intermodal freight transport involving rail is mainly driven by environmental concerns and is most prevalent in Europe (Lowe, 2005). Its effectiveness depends on geographical and demographic conditions (Konings et al., 2008). IFT can also be classified as maritime IFT and continental IFT (Chenikwi & Wang, 2019). In the US, use of IFT is relatively limited and a high proportion of freight transport relies on road transport. Nevertheless, a report from UNCTAD (2021) shows that over 80 % of international trade is undertaken by maritime transport, and this number is even higher for developing economies. The main driver of international IFT is geographical barriers such as seas and difficult terrains. In Europe, IFT accounts for 74 % of international trade (Eurostat, 2023).

There are several physical components involved in IFT, including modes of transport, infrastructure, intermodal facilities such as ports, machinery for transhipments and load units. The integration of these components is crucial if IFT is to be efficient. The aim of the ongoing institutional and technological innovations in intermodalism is to minimise the transaction costs at transfer points (Konings et al., 2008). This is due to the high costs and inefficiencies observed at such nodes. In addition, various stakeholders participate in the systems. Stakeholders such as hauliers focus on their share of tasks in the transportation chain and have an interest in improving their services and staying competitive in the market (Shardeo et al., 2020). Other stakeholders such as freight forwarders are mainly responsible for the integration of the chain and providing as seamless a transportation in the system as possible. The extensive information and document exchanges apparent in the system present major challenges. Low visibility, timely services, transhipments and integration are major bottlenecks in IFT (Woxenius, 1998). A comprehensive definition of intermodality needs to incorporate the physical, institutional and informational elements that facilitate cargo shipments in a seamless manner across different modes (Konings et al., 2008). Coordination of all stakeholders is required for the system to be effective.

Railway infrastructure is relatively uncommon in many developing economies where freight transport is primarily undertaken by road (Kumar & Anbanandam, 2020). The intermodal transport concept is not mature in low-income countries, mainly due to a lack of integration (Wanzala & Zhihong, 2016). The low interconnectivity of infrastructure makes intermodal freight transport challenging (Chenikwi & Wang, 2019). For instance, a report from world bank indicated that roads are the primary mode of transport across Africa, with limited and fragmented rail networks constraining the development of a cohesive, continent-wide rail-based intermodal freight transport (IFT) system (World Bank, 2009). Existing intermodal freight transport systems are mainly in international transport and are influenced by geographical features such as the sea (Werikhe & Zhihong, 2015). Infrastructural issues, a reliance on old trucks, fragmented information exchange between stakeholders, a lack of access to technology and a shortage of skilled personnel are evident in the intermodal freight transport system in low-income countries (Shibasaki et al., 2017, Okyere et al., 2019, Nitsche, 2021). Sea intermodal freight transport in landlocked countries incurs additional costs and challenges due to the dependence on neighbouring countries for seaport access. Offloading seaport activities to dry ports offers major benefits to such countries, while mitigating the congestion in and around seaports.

3.3 Dry ports as an integral part of intermodal freight transport

3.3.1 Overview of the dry port concept

Increasing demand for container transport has exacerbated congestion at seaports and thus it is essential to integrate dry ports into the IFT system. In addition, dry ports primarily offer services such as customs clearance, trans-loading and storage, as well as secondary services such as container maintenance and forwarding (Nguyen & Notteboom, 2019). The three main roles of dry ports are to increase seaport capacity, act as consolidating centres and serve as transhipment nodes, depending on their distance from the seaport (Rodrigue & Notteboom, 2012; Abdoulkarim et al., 2019). The introduction of dry ports into the intermodal transport system has the potential advantage of creating a more seamless, economically feasible and environmentally friendly transport chain. As defined by Roso et al. (2009) and Nguyen & Notteboom (2016), a dry port is an inland terminal performing seaport activities and is directly linked to the seaport by high-capacity inland transport, mainly rail. It is interchangeably used with terms such as an inland terminal, inland port, inland container depot (ICD) and logistics centre (Özceylan et al., 2016; Nguyen & Notteboom, 2019).

The concept of dry ports and their functions vary depending on the regional economy, geographical setups and regulations in different countries (Rodrigue & Notteboom, 2012). In Europe the deregulation of rail transport that began in the 1990s resulted in numerous railway operators entering the market, with the hub-and-spoke network expanding from this time. Rail deregulation in North America began in the 1970s and specialist operators dominate the sector. International ownership is common in the region and each carrier has its own market along the segment it controls. This has resulted in only two rail operators having intermodal terminals (Konings et al., 2008). The development of dry ports in Asia followed those in Europe and North America, while in Africa it is in its early stages (Gerald & Jin, 2016). Ethiopia started constructing dry ports in 2009 and there are currently eight dry ports in the country. A typical IFT system including dry ports is shown in Figure 2. The main connection between dry ports and sea ports is by rail, but roads can sometimes be used in this section. Some goods can be transported directly to/from the end destinations/origins without passing through dry ports.

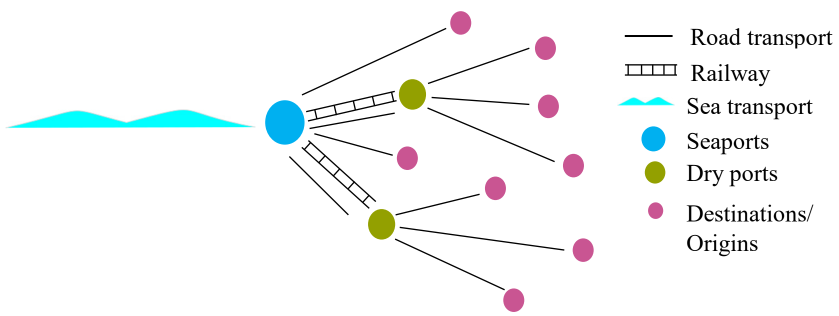


Figure 2: The intermodal freight transport containing dry port as an integral part

3.3.2 Dry port location analysis

The selection of sites for dry port installation requires intensive planning and careful decision-making. In recent decades, dry port location analysis has been the focus of substantial attention in dry port studies. Optimisation and the MCDM approach are the most frequently applied methods. Optimisation of transportation, environmental, investment, shipping and social costs have been the primary targets of modelling approaches (Ambrosino & Sciomachen, 2014; Wang et al., 2018; Tsao & Thanh 2019, Bouchery et al., 2021; Kurtuluş, 2023). These methods are usually used to compare existing or proposed dry ports with regard to their suitability. Incorporating a GIS tool in such analyses allows identification of the best locations for dry ports.

The MCDM method first identifies the criteria that are important for making an optimal choice about dry port location. Mohan & Nasser (2022) performed a literature review on location selection criteria and categorised them into economic, proximity, site-specific, social and environmental factors. Similarly, criteria such as the proximity to transport infrastructure and industrial zones, slope, distance from water bodies and forest zones, distance to population density, land and construction costs have been covered in various dry port location analysis studies (Núñez, 2013; Nguyen & Notteboom, 2016; Özceylan et al., 2016; Abbasi & Pishvaee, 2018; Augustin et al., 2019; Raad et al., 2022). As shown in Table 1 the criteria can be classified into economic, topographical, environmental, infrastructural, social and political factors. Notteboom (2011) has also categorised criteria based on the perspectives of stakeholders such as dry port users and service providers. The broadest classifications of the criteria are restrictive criteria and factor criteria (Table 1). Restrictive criteria encompass conditions that constrain the construction of any dry port, such as the presence of water bodies. These criteria are not prone to weighting. Factor criteria, meanwhile, comprise the factors that have an impact on the dry port location, without restricting its selection. Examples of this include slope, proximity to infrastructure and distance from seaports.

Table 1. Summary of criteria used for determining optimal dry port location

Criteria	Sub-criteria	Sources
Restrictive criteria		
Non-building zones		Abbasi & Pishvaee, 2018; Augustin et al., 2019
Presence of water bodies		Abbasi & Pishvaee, 2018; Augustin et al., 2019
Permanent areas with political instability		Notteboom, 2011; Augustin et al., 2019
Conserved areas		Abbasi & Pishvaee, 2018; Augustin et al., 2019
Availability of electricity		Notteboom, 2011; Chang et al., 2015; Mohan & Nasser, 2022
Factor criteria		
Topographic criteria	Slope	Abbasi & Pishvaee, 2018; Mohan & Nasser, 2022
	Vegetation	Chang et al., 2015; Augustin et al., 2019; Tadic et al., 2020
Infrastructural criteria	Road hierarchy network	Chang et al., 2015; Abbasi & Pishvaee, 2018; Tadic et al., 2020
	Distance from road network	Abbasi & Pishvaee, 2018; Mohan & Nasser, 2022
	Distance from railway	Abbasi & Pishvaee, 2018; Mohan & Nasser, 2022
	Accessibility to transport infrastructure	Mohan & Nasser, 2022
	Information infrastructure	Mohan & Nasser, 2022
	Intermodal connectivity	Notteboom, 2011; Tadic et al., 2020

Criteria	Sub-criteria	Sources
Social and environmental criteria	Distance from urban areas	Notteboom, 2011; Tadic et al., 2020; Mohan & Nasser, 2022; Mohan & Nasser, 2022
	Opportunity for expansion	Notteboom, 2011; Augustin et al., 2019; Mohan & Nasser, 2022
	Noise and air pollution	Tadic et al., 2020; Mohan & Nasser, 2022
	Proximity to production base	Mohan & Nasser, 2022
	Potential marketing area	Mohan & Nasser, 2022
	Proximity to other logistics platforms	Mohan & Nasser, 2022
Economic criteria	Distance from seaport	Tadic et al., 2020; Abbasi & Pishvaee, 2018; Mohan & Nasser, 2022
	Cost of land	Notteboom, 2011; Mohan & Nasser, 2022
	Potential labour force	Notteboom, 2011; Mohan & Nasser, 2022
	Population density	Notteboom, 2011; Mohan & Nasser, 2022

3.4 Digital technology in intermodal freight transport

The widespread adoption of computers and the internet in the 1990s marked the beginning of rapid growth in digital technologies. Global connectivity was boosted hugely by the increasing use of digital technologies. Services became faster with the reduction or elimination of numerous in-person meetings and extensive paperwork, which in turn enhanced business and service efficiency (Fonseca, 2018; Shubailat et al., 2024). In addition, new business models emerged and the way in which society engaged in trade underwent significant change. Artificial intelligence (AI), blockchain, 5G connectivity, smart facilities, automations and the like are emerging digital technologies. Furthermore, with the growth of digital technologies arises the issue of data security, privacy concerns, interoperability, employment and regulatory issues (Schwab, 2016; Altuntaş Vural et al., 2020).

The application of digital technology are manifold in road and rail transport, including in route optimisation, tracking and tracing, coordination and have a potential in reducing accidents (Yingli & Potter, 2007; Wang et al., 2017; Muñuzuri et al., 2020). Similarly, in port real-time planning and management, customer satisfaction and security could be facilitated by the adoption of digital technologies (Heilig et al., 2017). Digital technologies could enhance communications between various IFT stakeholders, port operations and transport services, and may contribute to an integrated, swift and efficient IFT system. The integration of various stakeholders involved in IFT may create the potential of digital technologies to improve the system.

3.5 Measuring level of digitalisation in intermodal freight transport

A crucial step in improving understanding of the role of digital technologies is to establish the level of current adoption. This is required for strategic planning in technology adoption, improving competitiveness by introducing best practices from highly digitised sectors and regions, identifying opportunities for efficiencies, and formulating effective policies (Fruth & Teuteberg, 2017; Sanchez-Gonzalez et al., 2019). Global indices such as the Digital Adoption Index (DAI), ICT Development Index (IDI) and Network Readiness Index (NRI) are used to quantify the level of digital technology adoption by countries, businesses and individuals (The World Bank, 2016; International Telecommunication Union (ITU), 2017; OECD, 2020; World Economic Forum, 2020). Based on how quickly they adopt technologies, countries, businesses and individuals can be categorised as leading or lagging.

The main technologies considered in the indices include computers, telephones, the internet and web services. These are considered to be general-purpose technologies (GPT) because they are versatile and disruptive in nature. They can be classified as industry 2.0, 3.0 and 4.0 (Cirera et al., 2021). The incorporation of these technologies and the level of advancement in various services could imply how digitised an organisation can be. There can be cases where GPT are adopted but not integrated and it is vague to establish whether the businesses/services are digitalised. Therefore, while the presence of the technologies alone is not a sufficient way to quantify the level of digitalisation, it is indicative of the potential of digitisation. Various theories suggest elements such as technology attributes, organizational factors, and external factor like market, perception and adaptability affect the decision to adopt emerging technologies and digitalisation (Hillmer, 2009; Taherdoost, 2017; Alraja et al., 2020). Cirera et al. (2021) studied level of technology adoption by considering general purpose technology and sector specific technology in a study that aimed to conduct a technology adoption survey. In intermodal freight transport, the adoption level can be studied by considering different components such as modes of transport, nodes or chain integration. However, study quantifying technology adoption by considering these components is lacking in the existing literature.

3.6 Intermodal freight transport performance and digital technology

3.6.1 Intermodal freight transport performance indicators

The two prominent infrastructures within IFT are nodes and links. Performance of transport is measured by infrastructural, economic quality of service and environmental factors (Easley et al., 2017, Stoilova et al., 2020). In low-income countries, performance indicators such as safety, infrastructure and vehicle conditions are the main factors considered in low-income countries (Table 2).

Table 2. Transport performance indicators

Dimensions	PIs	Sources
Service quality	Travel time (dwell time, processing time, transit time)	Varma, A, 2008; Easley et al., 2017
	Travel time reliability	Easley et al., 2017
	Delay/out-of-date deliveries	Varma, A, 2008; Domingues, M.L et al., 2015; Hagler, 2021
	Safety	Varma, A, 2008; Easley et al., 2017
	Vehicle operating costs	Easley et al., 2017
	Accessibility	Varma, A, 2008; Domingues, M.L et al. 2015; Easley et al., 2017; Stain, N et al., 2018;
	Truck capacity	Easley et al., 2017;
	Loss and damage frequency	Varma, A, 2008; Domingues, M.L et al. 2015; Hagler, 2021;
	Accident	Varma, A, 2008; Domingues, M.L et al 2015
Financial	Transport costs	Varma, A, 2008
	Distance travelled per day	Varma, A, 2008
	Turnover per km	Varma, A, 2008
	Delivery frequency	Varma, A, 2008
	Profit per delivery	Varma, A, 2008
	Vehicle loading capacity utilised per journey/vehicle	Varma, A, 2008
Environmental	Infrastructure condition	Easley et al., 2017
	Congestion	Easley et al., 2017
	CO_2 emissions	Easley et al., 2017

The performance of dry ports is generally measured from operational and financial perspectives. Operational aspects include time, service quality and environmental performance indicators, as indicated in Table 3.

Table 3. Dry port performance indicators

Dimension	PI	Source
Financial	Throughput	UNCTAD, 1976; De Langen, 2013; Ha, M.H et al., 2017; Martin, E et al., 2017
	Equipment costs	Martin, E et al., 2017
	Profitability	Martin, E et al., 2017
	Turnover revenues/expenditures	UNCTAD, 1976; Martin, E et al., 2017
	Labour costs	Martin, E et al., 2017
	Maintenance costs	Martin, E et al., 2017
Efficiency	Storage area utilisation	De Langen, 2013; Nathnail et al., 2016; Martin, E et al., 2017
	Equipment productivity and utilisation	Ha, M.H et al., 2017; Martin, E et al., 2017; Carboni & Deflorio, 2018; Georgise, 2020
	Labour productivity and utilisation	Ha, M.H et al., 2017; Martin, E et al., 2017; Georgise, 2020
Time	Turnaround time	Ha, M.H et al., 2017
	Cut-off time	Carboni & Deflorio, 2018
	Entrance waiting time	Carboni & Deflorio, 2018
	Exit waiting time	Carboni & Deflorio, 2018
	Average waiting time under crane	Ha, M.H et al., 2017
	Document exchange time	Carboni & Deflorio, 2018
Service quality	Handling costs	Nathnail et al., 2016; Ha, M.H et al., 2017; Carboni & Deflorio, 2018; Georgise, 2020
	Loss frequency	Nathnail et al., 2016; Carboni & Deflorio, 2018; Georgise, 2020
	Damage frequency	Nathnail et al., 2016; Carboni & Deflorio, 2018; Georgise, 2020
	Supply chain visibility	Nathnail et al., 2016; Carboni & Deflorio, 2018; Georgise, 2020
	Information availability	Nathnail et al., 2016; Carboni & Deflorio, 2018; Georgise, 2020

Dimension	PI	Source
Environmental	Carbon footprint	Ha, M.H et al., 2017; Carboni & Deflorio, 2018
	Water consumption	Ha, M.H et al., 2017;
	Energy consumption	Ha, M.H et al., 2017; Carboni & Deflorio, 2018
	Noise emission	Carboni & Deflorio, 2018
Multi-modality aspects	Multimodality rate	De Langen, 2013; Nathnail et al., 2016; Georgise, 2020
	Expandability	De Langen, 2013; Nathnail et al., 2016; Georgise, 2020
	Distance from city centre, commercial areas and industrial zones	De Langen, 2013; Nathnail et al., 2016; Georgise, 2020
	Intermodal connectivity	De Langen, 2013; Nathnail et al., 2016; Georgise, 2020

3.6.2 Role of digital technologies in IFT performance

Studies have used different approaches to quantify the impact of digital technologies in IFT. The cost and benefit of adopting interoperable technologies were analysed empirically by Jacobsson et al. (2020). The authors suggest that interoperable technologies reduce turnaround time and increase access reliability, precision and flexibility in seaports. In a ViWaS research and development project, Behrends et al. (2016) claim that smart telematics in wagons will increase the share of railway users by introducing transparency into the system. The effect of ICT in terminal management and utilisation has been analysed using the Petri net model (Dotoli et al., 2014; Cavone et al. 2016), while a parametric method of activity-based costing was adopted by Marchet et al. (2012) and Miragliotta et al. (2009), with both studies showing that these technologies minimise costs in terminal operation and logistics flow.

3.7 Summary

Overall, in today's world where technological advancement is the key to societal progress, those who are slow to adopt new technologies will fall behind their competitors. This makes low-income countries technology lag in technology adoption, and research into this subject is therefore crucial. By addressing the gap in the little research that has been undertaken so far in the area, this thesis endeavours to highlight the role of digital technologies in IFT in low-income countries and analyse the technological gap in current practice as well as how digital technologies could improve the system.

4. Methods and Materials

4.1 Overview

The approach adopted to meet the aim of this thesis is illustrated in Figure 3. This includes the methods followed in the five papers that make up the thesis including the type of data collected, the stakeholders involved and the analysis applied. The first paper employs a systematic literature review to present the current state of digital technology utilisation in IFT globally and its applications in low-income countries. Performance indicators, challenges, technology practices, and the perceived barriers and benefits of digital technologies in the sector are explored in Papers II and III. Papers IV and V are dedicated to investigate application of digital technologies in dry port planning and operation respectively. Data collection was undertaken in three phases: the first phase from July to October 2019, the second phase from June to October 2021 and the final phase from January to March 2023.

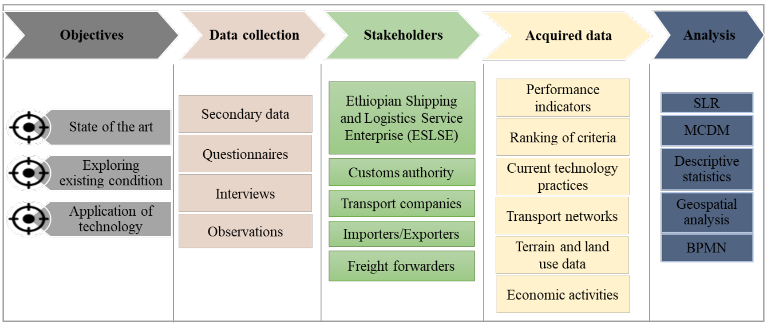
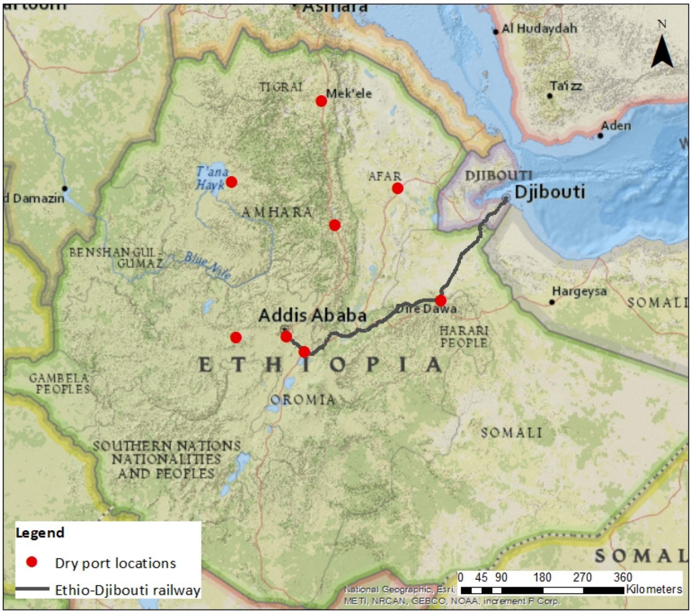


Figure 3. Methodological overview showing the type of data, survey respondents and analysis methods used in the studies of this thesis.

4.2 The study area

The empirical studies in this thesis are based on data collected from Ethiopia. As a landlocked low-income country, dry ports and intermodal freight transport is important for the growing economy. More than 90% of Ethiopia's import and export takes place through Djibouti port. Therefore, the Ethio-Djibouti corridor was the focus of the study. There are eight functional dry ports in the country, three directly connected to seaport through railway. Mojo dry port is the busiest and most crucial dry port of the intermodal freight transport system in the region. It is the first constructed dry port in Ethiopia, spanning an area of 144 ha and incorporating infrastructure such as offices, warehouses, terminal lights and roadways. Machinery such as reach stackers, forks and empty handlers are used in the dry port and it can accommodate 14,908 TEU containers.



(a)

(b)

Figure 4: The study area a) showing main import/export corridor of Ethiopia b) Mojo dry port.

4.3 Data collection

4.3.1 Stakeholders

As the primary focus of this thesis was the hinterland segment of maritime transport, stakeholders such as importers/exporters, freight forwarders, road transport operators, rail operators, dry port operators, customs authority and customs clearing agents play a crucial role in facilitating the movement of goods within this chain. Each stakeholder has a particular interest and role in the system, and the case in Ethiopia is explained in Table 4. The opinions of 35 importers/exporters, 18 freight forwarders and eight logistics experts were used to rate performance indicators in Paper II, while 13 logistics experts were asked to rate location criteria in Paper IV. In paper III the adoption of technologies by 57 road transport companies, the railway company, 37 freight forwarders and the dry port authority is assessed (Table 4). The road transport companies were considered in three groups of level I, II and III depending on the company size and the age of trucks they own. Level I transport companies are the biggest and own latest trucks than level II and III. Paper V focused on dry port processes.

Table 4. Information about the stakeholders involved in the studies

Stakeholders	**Roles**	**Sample size**	**Type of institution**
Importers/exporters	End users/clients in the chain	35	Private
Freight forwarders	Plan and transport goods on behalf of importers and exporters	55	Private
Road transport operators	Responsible for the road transport	57	Private
Rail operator	Responsible for the rail transport	7	Public
Ethiopian Shipping and Logistics Service Enterprise (ESLSE)	Solo multi-modal operator, owns and manages dry port, provides shipping services	6	Public
Customs	Estimates and collects tax, ensures compliance of goods	25	Public
Logistics experts	Policy making, planning, research in logistics	13	Public

4.3.2 Data description and collection tools

This thesis utilises both primary and secondary data. The secondary data are from literature reviews for the cases presented in Papers I and II. Recorded data on road networks, economic activities such as production and market basins, and terrain data were collected for Paper IV. Surveys administered in terms of a questionnaire and interview were the primary research tool used. Stakeholders' opinions in order to identify and rank performance indicators in Paper II and the criteria for dry port location selection in Paper IV were gathered using questionnaires. In Paper III, different questionnaire was used to survey an inventory of digital technologies currently utilised within the sector. The questionnaire placed technologies in three categories: general-purpose technologies, business technologies and sector-specific technologies. Interviews and observation were used to investigate activities in dry port in paper V. Measurement of time the activities consumed were collected using recording sheets. The service times were recorded for three weeks considering weekday and weekend variations from February to March 2023, while inter-service times were surveyed from 20 respondents.

4.4 Methods and techniques

4.4.1 Systematic literature review (SLR)

The strict steps of a systematic literature review (SLR) were undertaken to analyse the state of the art in IFT digital technologies. The steps followed in the SLR included first defining the questions to be addressed by the review papers (Petticrew & Roberts, 2006; Wee & Banister, 2016), before formulating key words and running the search in the selected databases. Articles collected in this manner were then screened to identify articles dealing with the scope of the research question. Consequently, 147 articles were retrieved and analysed in Paper I.

4.4.2 Multi-criteria decision-making (MCDM) approach

Two MCDM approaches – the analytical hierarchical process (AHP) and the simple multi-attribute rating technique (SMART) – were used in Papers II and IV respectively. AHP was implemented to weight the key performance indicators in IFT, while SMART was used to weight the criteria used in the location analysis.

AHP is a widely applied MCDM approach in logistics. First, all the criteria considered for comparison are identified and then are presented to respondents to rank them. The ranking is given on a scale of 1 to 9 for each pairwise comparison of criteria, as outlined by Saaty (2009). The weighting of the criteria is then calculated after collecting the responses. The consistency of weighting is checked using a consistency ratio that is obtained from the maximum eigenvalue from the consistency index (CI) using equations 1 and 2:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{................ (1)}$$

$$CR = CI/RI \qquad \text{................ (2)}$$

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 (2009). The calculated CR value should be less than 10 % in order to accept the weighting result.

Similar to AHP and other MCDM processes, the first step in SMART is to define the criteria. However in contrast to the pairwise comparison on a scale of 1 to 9, respondents are required to give each criteria a value from 10 to 100 based on their relative importance. The relative importance is then normalised using the formula in equation 3:

$$NW_j = \frac{W_j}{\sum_{j=1}^{n} W_j} \qquad \text{................. (3)}$$

where NW_j is normalised weight of criteria j, W_j is the weight value of criteria j, and $\sum_{j=1}^{n} W_j$ is the total sum of weight of all criteria.

4.4.3 Descriptive analysis

Three categories of technologies general-purpose technologies (GPT), business technologies and sector-specific technologies were analysed for different road transport and freight forwarding companies in Paper III. The companies adopting the GPT were presented in percentage. The difference in adoption level among different levels of road transport companies was investigated using t-test. The percentage of companies practicing different technologies in business and sector-specific activities were also presented.

The business activities considered are communication with customers and payment methods. Sector-specific activities in transport companies are communication with drivers, routing and scheduling, tracking and tracing, managing delivery error and providing proof of delivery (POD). Sector-specific in freight forwarding companies are providing documents to port and customs authorities, tracing goods, and facilitating or providing transport services. The GPT were indexed based on whether or not the technologies were adopted in the companies. Similarly, the digitisation score was given from the use of methods implemented by companies to run business and sector-specific activities. These scores were used to establish the correlation between the adoption of general-purpose technologies and the digitalisation of services.

4.4.4 Geospatial analysis

The optimal locations of dry ports were suggested using a GIS tool for Paper IV. Layers of the criteria considered for selecting optimal dry ports were prepared using ArcGIS and then classified based on their impact on the selection of dry ports. Accordingly, the areas favourable for dry ports were given a higher value and vice versa. The seven criteria prepared in a GIS file and their classes were distance from road, distance from railway, proximity to production, slope, proximity to potential marketing area, distance from urban areas and sea port.

The weighted overlay function was used in ArcGIS to combine the above layers and map out suitable areas. The analysis was undertaken using the following formula:

$$Dry\ port\ suitablity = W1 * C1 + W2 * C2 + W3 * C3 + W4 * C4 + W5 * C5 + W6 * C6 + W7 * C7$$

where Wi is the weight of each criterion and Ci is the value of each criterion.

4.4.5 Modelling and scenario analysis

The dry port process was modelled taking Mojo dry port in Ethiopia as the case study to evaluate the impact of digital technologies on dry port performance. The business flows in the dry port were mapped using business process modelling and notation (BPMN). BPMN is a standard graphical illustration and modelling of business processes and has been used to simulate port operations and assess the impact of technologies in their performance (Cimino et al., 2017). After identifying the procedures followed in dry ports, data regarding current practices and the time taken at each stage were collected. The consequential procedures from the BPMN diagram were modelled in Matlab (2022b version) to estimate the time required to clear port procedures. The procedures that can be replaced by digital technologies were identified and their impact on overall process time was estimated.

Based on the detailed process mapping, parameters that sum up the time components that follow the path of each business flow were assigned using Matlab R (2022b). For this, new code was written in Matlab using the Live Script tool. This covers the four primary process paths following different procedures. The flow groups were classified based on the risk group decision from the customs authority. According to this, the red risk group undergoes a physical inspection, the yellow group undergoes a document inspection, and the green group is not subject to any inspection. The flows are grouped into the red risk group following CFS inspection (BPF1), the red risk group following warehouse inspection (BPF2), the green risk group (BPF3) and the yellow risk group (BPF4).

For this, data cleaning was performed in a spreadsheet to check and fix errors, unrealistic values and outliers that are much higher or lower than the average values. The clean data were then imported into the Matlab modelling environment. The model calculated the time taken to complete the entire process from start to finish following different port business process flows (BPFs), and conducted a comparison analysis using recorded or estimated process/service times at each event along the BPFs. The model was tested and validated using some of the data collected during the data survey, i.e. the output obtained from Matlab was checked to verify whether it was comparable with the input time components.

5. Results

5.1 Introduction

This section presents the findings of the research making up this thesis. The subsequent sub-sections contain the results from the systematic literature review followed by the results exploring key performance indicators and technology practice in IFT. Finally, the results from dry port studies including location analysis and dry port process optimization results are presented.

5.2 State of the art: Systematic literature review

Bibliometric results from the SLR showed that most studies focusing on digital technologies and IFT were carried out on the port and terminal components of IFT (Fig. 5). Among the enabling technologies covered in IFT, communication technologies were addressed by a significant number of studies, as shown in Figure 6.

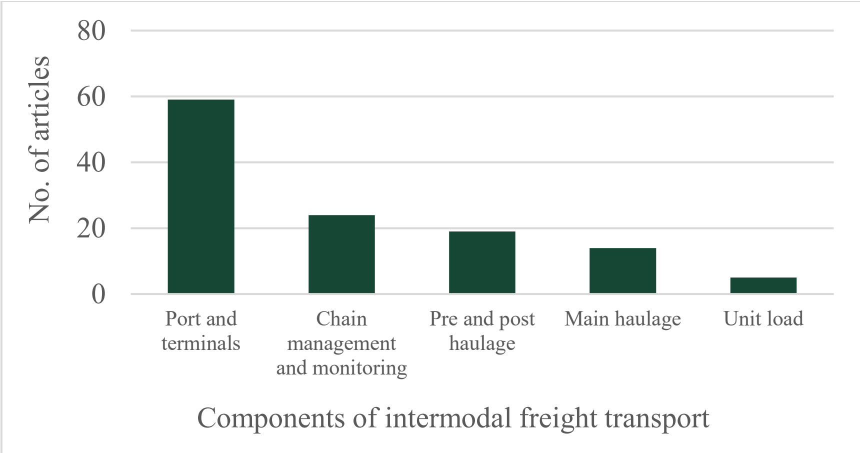


Figure 5. The proportions of intermodal freight transport components on which articles focused

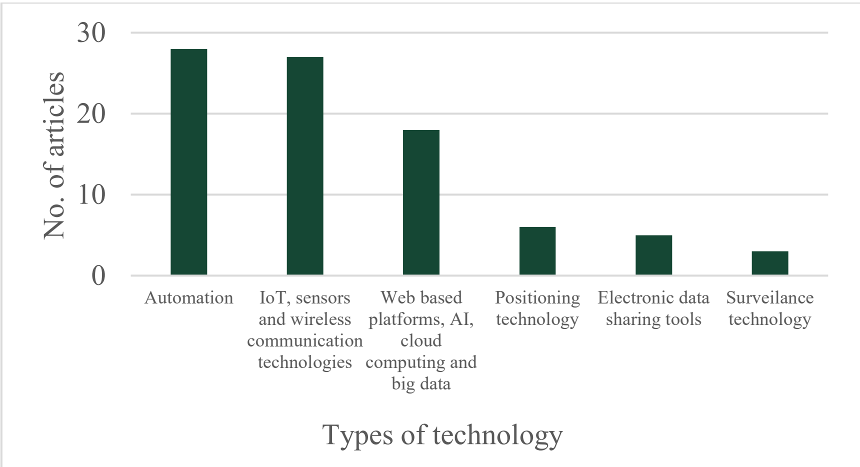


Figure 6. Enabling technologies applied in IFT

The application of technologies in components of IFT is summarised in Table 5. The findings indicated that there are manifold applications of digital technologies in various components of IFT.

Table 5. Application of technologies on different components of intermodal freight transport

Enabling technologies	Components of intermodal transport				
	Ports and terminals	**Chain management and monitoring**	**Pre and post haulage (PPH)**	**Main haulage**	**Load unit**
Automation	Automation of equipment Automatic information exchange	*	Automatic data collection Automated trucks and platoon operations	Autonomous underground transport and ships	*
IoT, sensors and wireless communication technology	Automatic identification of units at gates, security of containers and real-time tracking and tracing in ports	Send signals for control Optimise mode choice using real-time data	Efficient port calling process Provide real-time information from trucks to stakeholders	Monitor vibration during transportation and report anticipated risks	*
Web-based platforms, AI, cloud computing and big data	Broadcast schedules in port Clear presentation of required information to stakeholders	Select best transport chain Enable fast and reliable decision support system Provide visibility of goods	Decision support system for logistics providers Establish collaboration Online matching between shipping request and service	Information access on the status of vehicles	Centralised and fast container booking system
Positioning technology	Used to locate trucks, containers and equipment	Ensures traceability	Real time truck locations Determine shortest path route		
Electronic data-sharing tools	Quick administration in port calling, customs declaration, clearance notification Port-EDI for a one-stop service	n/a	Exchange booking and boarding instructions between consignee and freight forwarders	Information about position of ships	n/a
Surveillance technology	Safety of cargo under port processes Automatic plate number identification	Ensures cargo safety along the chain	Controls security of cargo and drivers in inland transport	*	Automatic extraction of container identity code

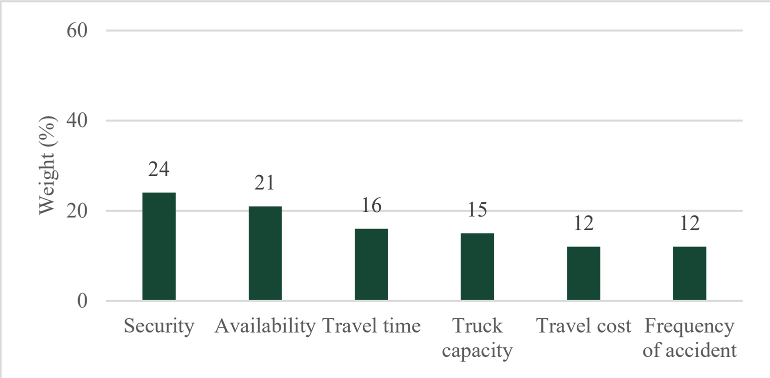
* no article found
n/a not applicable

5.3 Existing IFT system and technology practices

5.3.1 Performance indicators and challenges in IFT

The six transport performance indicators shown in Figure 6 were presented and weighted by logistics experts. The results showed that security as the most important value according to the experts, and frequency of accidents the least important criterion. For dry port performance indicators, customers considered turnaround time to be the most important performance indicator, while for service providers it was damage frequency. Cost incurred in dry ports was not of a major importance to service providers, but it was the second most important indicator for service providers. Both customers and service providers gave the lowest weighting to environmental impacts (Fig. 7).

Respondents were asked to list the challenges facing IFT in Ethiopia with regard to transport and dry port services. Old trucks, low truck availability, poor security, poor road infrastructure, lack of standardised tariffs and poor driver behaviour were the primary challenges facing the transport sector. The main challenges observed in dry ports included inadequate technology implementation, long waiting times, and a lack of skilled staff, unfair/inconsistent tax, misplaced containers, corruption, high port fees and bureaucracy.



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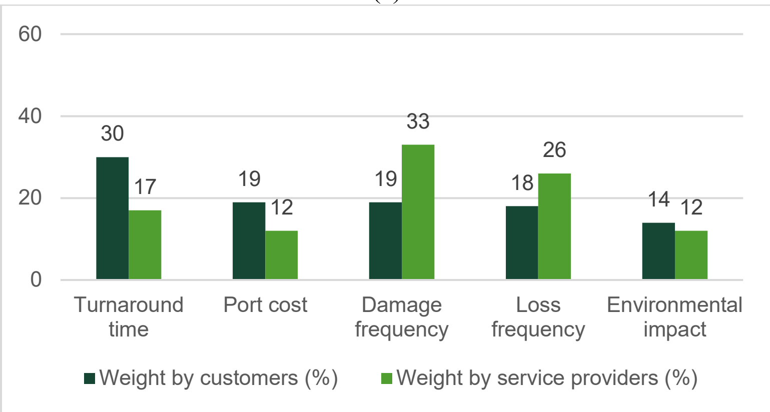

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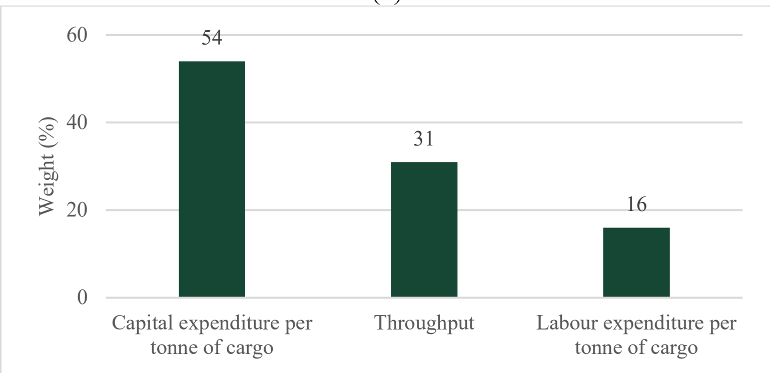


(c)

Figure 7. AHP results of respondents' weighting for a) transport performance b) dry port operational performance c) dry port financial performance

5.3.2 Level of digitalisation in IFT

Road and freight forwarding companies

Adoption of technologies in IFT was considered in terms of Industry 2.0, 3.0 and 4.0. The existence of the earlier technologies significantly affects digitalisation because they provide the building blocks for technological progress (Rousseau and Jovanovic, 2005). All the organisations contacted, including the dry ports, road transport, rail transport and freight forwarders, have access to power and face frequent power outages. Generators are used by 77 % of transport companies and by 95 % of freight forwarding companies, and both the railway company and dry port authority own generators. Table 6 indicates the percentage of road transport and freight forwarding companies using Industry 3.0 technologies. All road transport companies have telephones and computers, while 64 % of them use smartphones and 87 % have internet access. The web-based services and software are the least used technologies in road transport companies. A small proportion of companies have adopted Industry 4.0 technologies, as indicated in Figure 8.

Table 6. Industry 3.0 technologies used by road transport and freight forwarding companies

Industry 3.0 technologies, %	Road transport companies	Freight forwarding companies
Telephone	100	86
Mobile phone	91	84
Smartphone	64	80
Computer	100	100
Software	52	81
Internet access	87	100
Web-based services	32	54

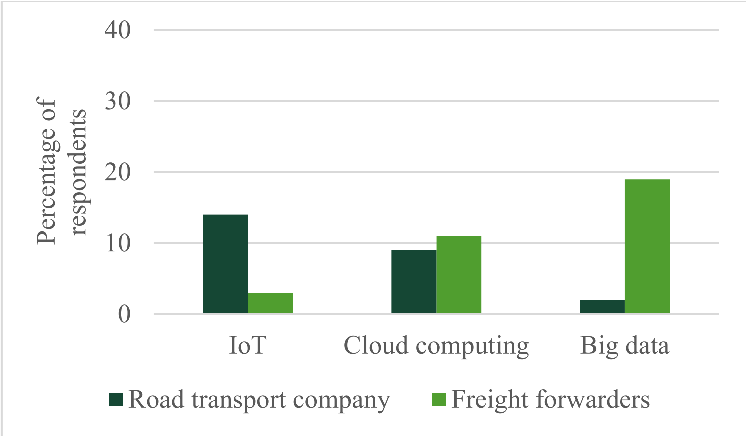
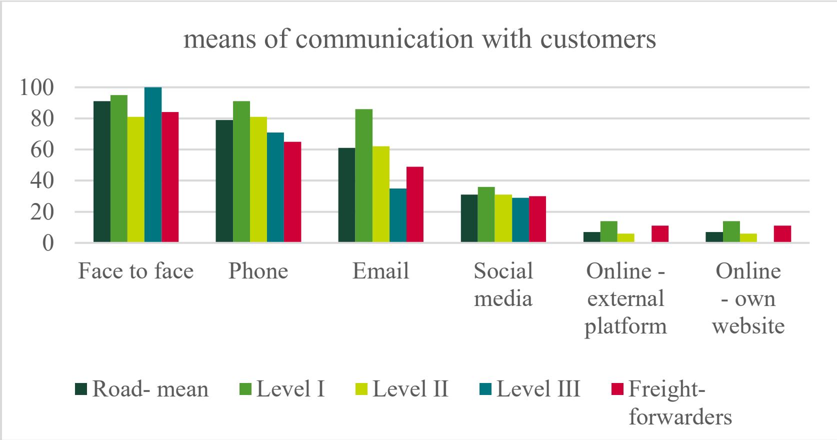


Figure 8. Industry 4.0 technologies adopted in road transport and freight forwarding companies

The application of advanced technologies in business activities, such as communication with customers and payment methods, is low, as indicated in Figure 9. Face-to-face meetings with customers are the primary practice of communication with customers in both road and freight forwarding companies. Cheques and cash are the main payment methods used by the companies (Fig. 9).



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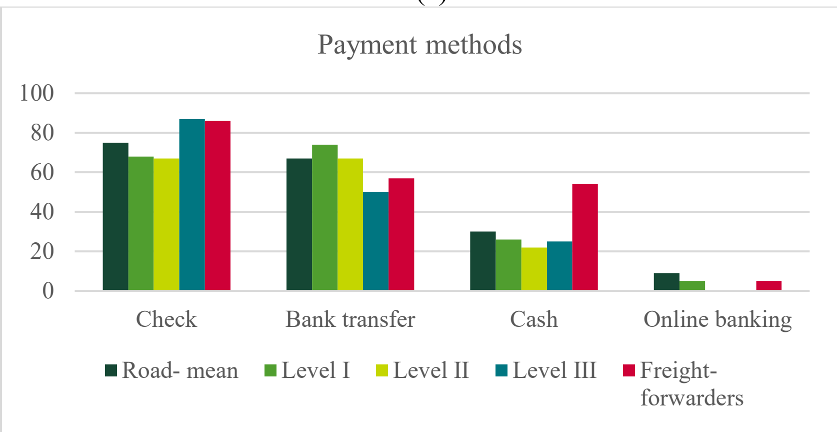


(b)

Figure 9. Application of digital technologies to undertake business activities in road transport and freight-forwarding companies with y-axis indicating percentage of respondents, (a) while communicating with customers and (b) while making payments.

Road transport companies practice in sector-specific tasks, such as communicating with drivers, tracking practices, managing delivery errors and implementing routing and scheduling methods, are shown in Figure 10. There is no real-time tracking of trucks and use of call centres is the primary means of obtaining updates on trucks (Fig. 10b). Manual routing and scheduling methods and paper-based delivery error management are the most commonly used practices in road transport companies.

Figure 10. Digital technologies used by road transport companies considered under the different levels of road transport companies: a) routing and scheduling methods, b) means of communication with driver, c) tracking and tracing practices, and d) means of managing delivery errors. Y-axis shows the percentage of respondents.

Considering the sector specific technology practice in freight forwarding companies, the study found that the status of goods is tracked during shipping and at seaports using a web-based platform provided by the shipping companies. However, once the freight has left the seaport, it becomes difficult to trace the goods. Of the 65 % of forwarding companies that facilitate inland transport services, 32 % replied that they do not know where the goods are until they reach the dry port or the destination point, while the remaining 68 % replied that they use telephone calls. Even when the goods reach dry ports, there is no real-time tracing system. Only 59 % replied that they use a web-based platform to trace goods at dry ports. The respondents complained that the web-based system provided by ESLSE is slow and mostly out of service, so they rarely use it. Furthermore, 40 % reported that they use telephone calls to check on the status of goods in dry ports, while 24 % and 22 % claimed that they go in person to ESLSE or use email respectively. The responses also showed that scheduling and arrangements with transport companies are made by telephone or by contacting them in person. All the respondents use a web-based platform when providing documents to the customs authority. However, documents, such as receipts and invoices, need to be provided for the port authority in person.

Railway and dry port authority

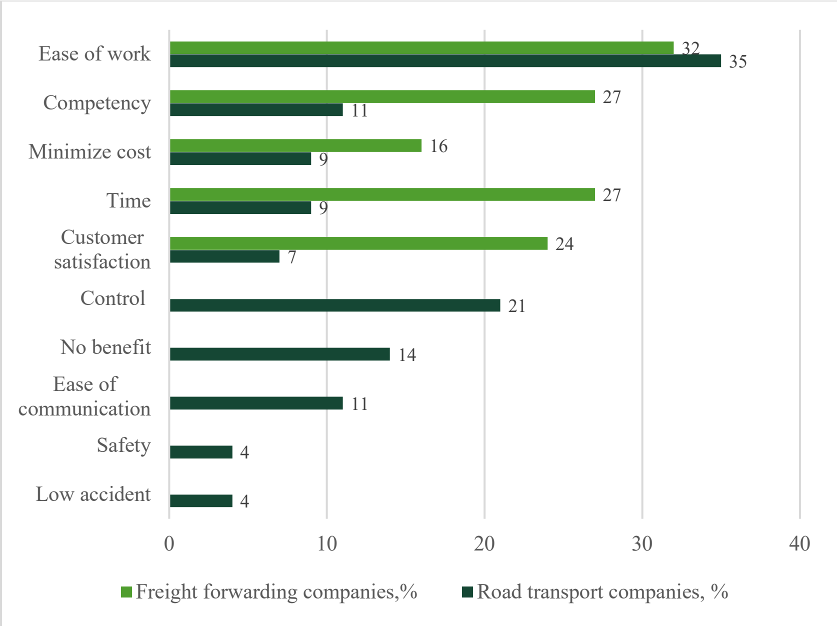
The interviews with the railway and dry port companies showed that both companies have access to electric power as well as to generators at all their sites. Industry 3.0 technologies, including telephones, mobile phones, smartphones, computers and web-based services, are available in both the railway and dry port companies. The railway company's offices uses fibre internet throughout the corridor, while the dry ports use broadband internet. Freight management, maintenance and planning software is used by the railway company. An enterprise resource planning (ERP) system is adopted in the dry ports. The Industry 4.0 technologies of cloud computing and IoT are adopted by railway company and dry ports. Both the railway and dry port companies communicate with their customers mainly face to face. Email is the other method used by the railway company. Both companies use cheques for payments.

The railway system uses up-to-date digital technologies for transport-related communication. Trains are fully computerised and a direct web-based PC-to-PC link is used to track them. Radio networks are used to communicate with drivers at any time. A real-time method using computers in trains is used for scheduling. Proof of delivery takes the form of a paper-based signature. Email and telephone calls to the depot are used to resolve delivery errors. From the visit and interviews in dry ports, it was established that internal communication in ports with crane operators, drivers and gate controllers is done via a radio system in dry ports, while email is used to communicate with transport companies, freight forwarders and customs.. The planning/organisation of stacking of containers takes place manually, while the tracking of their location is managed using radio frequency identification (RFID). An electronic data interchange (EDI) system is used to manage port documents.

Benefits of and barriers to adopting digital technologies

With respect to the main benefits, the highest percentage of respondents from both the road transport and freight-forwarding companies, 35 % and 32 % respectively, stated that adopting digital technologies would make their work easier. The next highest percentage of responses (27 %) from freight forwarders was that technologies help them to stay competent in the market and save time. In road transport companies, staying competent in the market received a low proportion of responses. The advantage of having control over trucks and drivers received the second highest response for road transport companies. Increasing safety and reducing accidents were advantages mentioned by lowest proportion of road transport companies (Fig. 11).

Despite the respondents' agreement on the various benefits of ICT for their organisations, they mentioned several constraints to the adoption of technologies, which are given in Figure 9. The lack of ICT infrastructure in the country is considered to be the greatest barrier to the adoption of technology by both road transport and freight-forwarding companies. High investment costs, a lack of well-equipped IT experts and a lack of IT skills in companies are the major barriers highlighted by both road transport and freight-forwarding companies. Information security concerns is the least mentioned barrier.



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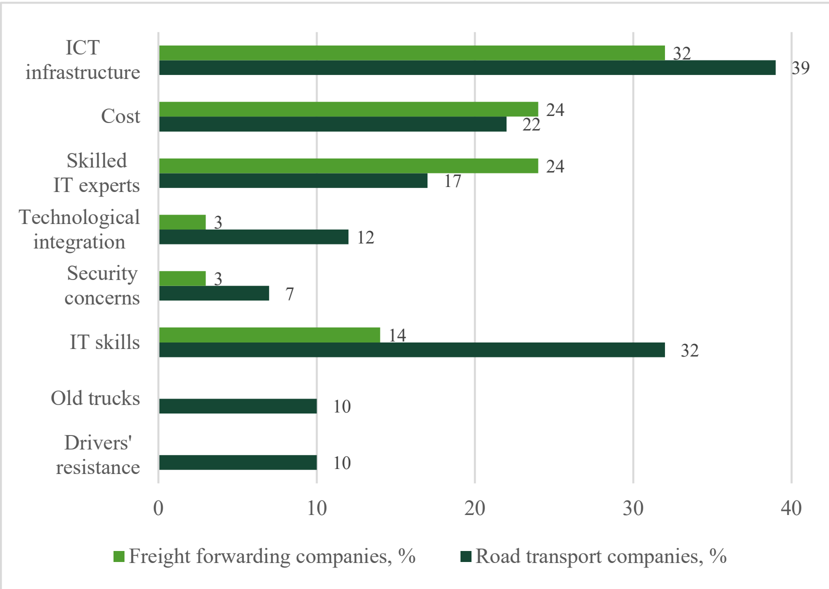

(b)

Figure 11. Benefits of (a) and barriers to (b) adopting digital technologies in road transport and freight-forwarding companies. Some responses were relevant for road transport companies only.

5.4 Studies on dry port

5.4.1 Optimum dry port location analysis

Weighing of the dry port location selection criteria

Table 7 summarises the criteria used to determine the location of dry ports and the results of the weighting analysis. The weightings from respondents show that distances from road and railway are the most important criteria, with a weighting of 0.2 and 0.18 respectively. The next important factor is proximity to the production base, with value 0.15. Then follow weights of slope, proximity to the marketing area and distance from urban area in their order of list. Distance from seaport is the least important criteria with a value of 0.09 (Table 7). The sub-classifications in Table 7 show the categorisation of land based on the criteria considered, with higher values given to the most suitable classes and vice versa.

Table 7. Criteria weightings used in identifying the optimal locations of dry ports in Ethiopia

Criterion	Weight	Sub-classification	Value
Distance from road	0.20	0-5 km	5
		6-10 km	4
		11-20 km	3
		21-30 km	2
		>30 km	1
Distance from railway	0.18	0-5 km	5
		6-10 km	4
		11-15 km	3
		16-20 km	2
		>20 km	1
Proximity to production	0.15	0-15 km	5
		16-30 km	4
		31-45 km	3
		46-60 km	2
		>60 km	1
Slope	0.14	0-8 %	5
		9-15 %	4
		16-25 %	3
		26-45 %	2
		> 45 %	1
Proximity to potential marketing area	0.13	0-15 km	5
		16-30 km	4
		31-45 km	3
		46-60 km	2
		>60 km	1
Distance from urban areas	0.11	Rural	3
		Sub-urban	2
		Urban	1
Distance from seaport	0.09	150-175 km	5
		176-200 km	4
		201-250 km	3
		251-300 km	2
		>300 km	1

Suitability of dry port locations

Map showing areas in Ethiopia ranked with the level of suitability for dry port location is shown in Figure 12. As indicated in the figure, a significantly small proportion of the region falls under the highly suitable and unsuitable categories, comprising 4 % and 1 % of the land, respectively. The highest proportion of the land (82 %) falls under marginally and moderately suitable areas. The areas marked in blue indicate water bodies that restrict dry port construction. The third highest proportion of land is in the least suitable category, primarily concentrated in the south-eastern regions.

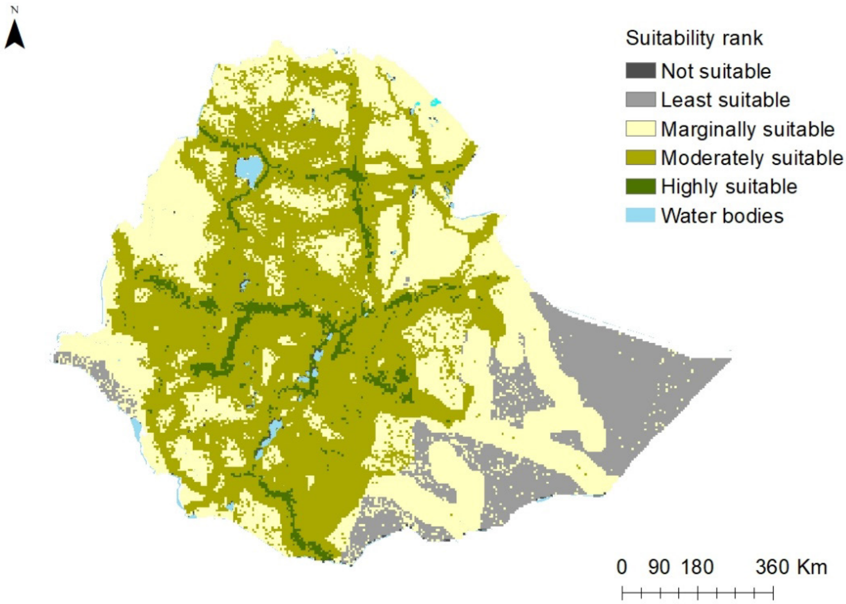

Figure 12. Suitability map of dry port locations in Ethiopia

Location suitability and sustainability of existing dry ports

The study evaluated the suitability of existing dry port locations by overlaying them on the suitability map depicted in Figure 12 and analysing their placement. Figure 13 shows that five of the eight dry ports are situated within highly suitable areas. There are two dry ports in a moderately suitable area and one (Kality dry port) in a marginally suitable area. Unlike the distribution shown on the suitability map, most of the existing dry ports fall in the highly suitable category.

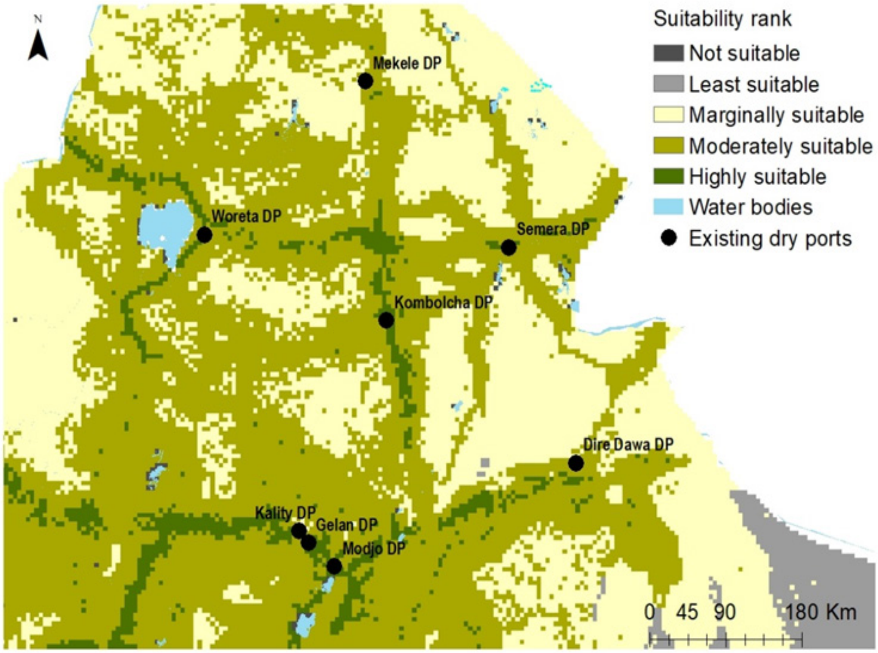

Figure 13. Location of existing dry ports in Ethiopia relative to the categories in the suitability map.

The future environmental implications of the existing dry ports were assessed by checking whether they are located within a city or an urban buffer zone. For this, a map of nearby cities, each with a buffer zone of two kilometres, was prepared and overlaid with the suitability map and the location of existing dry port sites. Figure 14 shows that the three dry ports of Kality, Kombolcha and Mekele are located within cities and therefore this may contribute to a lower ranking in terms of environmental value.

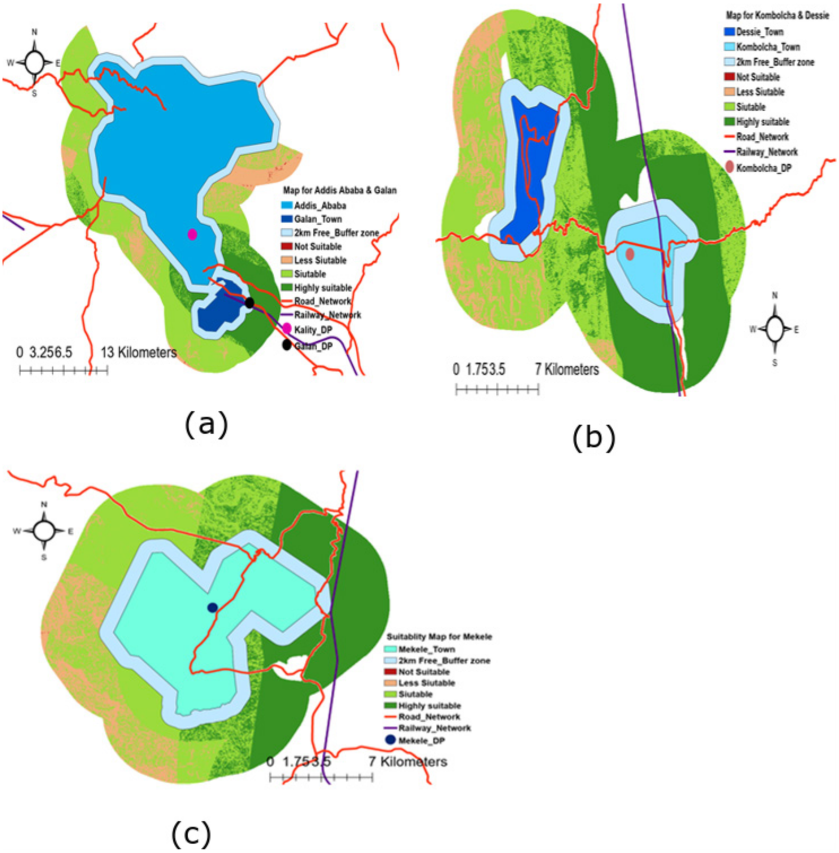

Figure 14. Sustainability of existing dry ports considering their distance from major cities around dry port (DP) area in Ethiopia: (a) Kality DP (b) Kombolcha DP and (C) Mekele DP

5.4.2 Impact of digital technologies on port operations

Mapping of dry port processes

The business flow of the dry port process was plotted using BPMN, as shown in Figure 15. Time components were classified into service time and inter-service time. The time spent while services are being provided by personnel from the dry port or customs is the service time. The time components are represented by boxes in the chart and the names given to them are coded in blue. Inter-service time was classified into waiting time, standard and extended inter-service time, represented by arrows and coded in green, black and red, respectively, in the chart (Fig. 15).

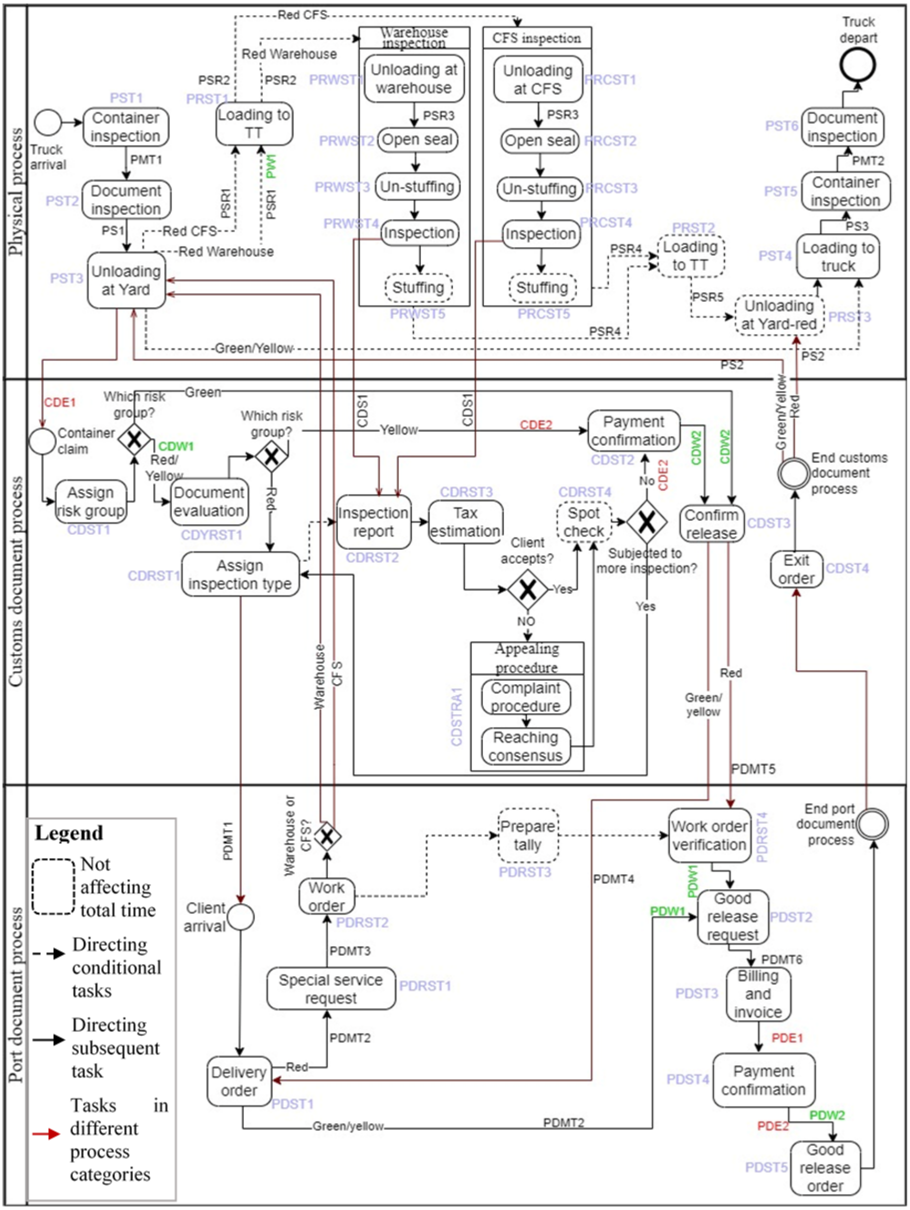

Figure 15. Dry port operations with dedicated codes for the time consumed by each process

Dry port process time

Figure 16 compares the total time along the four process flows cumulatively, based on data from the survey results. The time components that follow each other are all summed up to obtain the total time in the dry port (Fig. 18). In the existing situation (SC1), the maximum process time is for BPF2 and averages 9 days, 17 hours and 19 minutes spent in dry ports. Of this, the shares of physical process, customs-side document process, and port-side document process are 44 %, 39 % and 17 % respectively. The minimum process time is for BPF3, with an average time of 5 days, 7 hours and 5 minutes, which is similar to BPF4. Of this, the shares of physical process, customs-side document process and port-side document process are 1 %, 67 % and 32 % respectively. Figure 17 shows the time improvements with scenario of online platform use (SC2) and online platform and payment use (SC3).

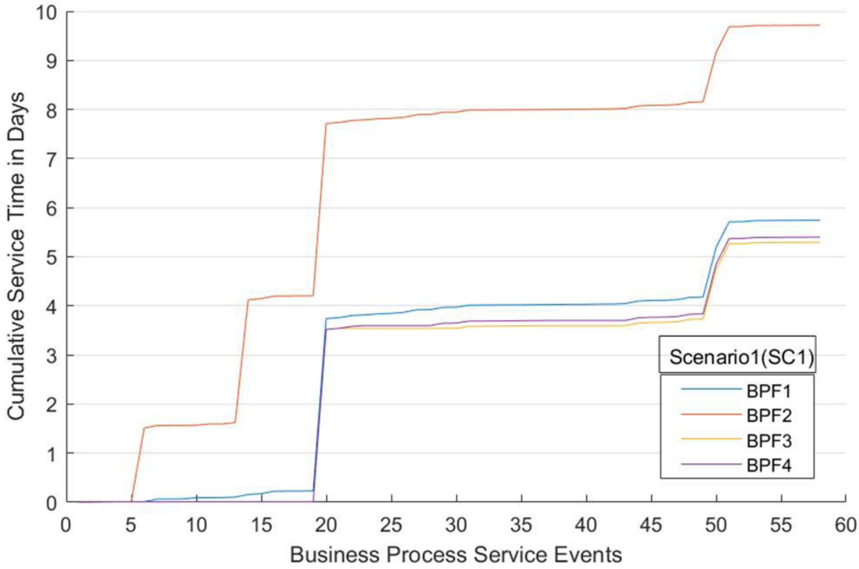

Figure 16. Cumulative time calculated along different business processes

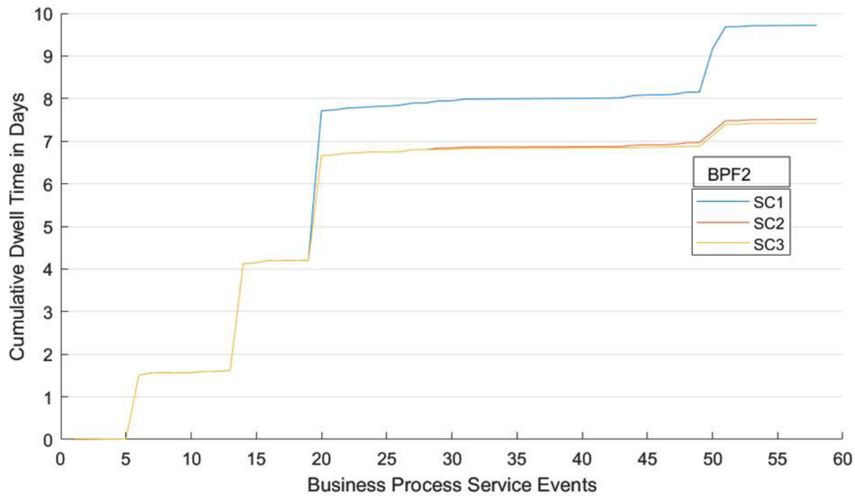

Figure 17. Comparison of scenarios in the case of BPF2, i.e. the case of the red risk group following warehouse inspection

Impact of digital technologies on dry port process time

The average times calculated from the scenario analysis and their comparisons with the original values (SC1) are shown in Figure 18. The physical flow in the dry port does not show a significant improvement with the use of an online platform or payment methods. However, in SC2, a major improvement, up to 64 %, was observed in the port document process time, while a 30 % improvement was observed in the customs document process time. This is due to the numerous document processes on the port side that require the physical presence of clients between each process. In addition, the massive amount of paperwork, including printing and validation, involved in the process takes a significant amount of time.

In SC3, an improvement of up to 67 % was observed in the port document process time, while an improvement of up to 31 % was observed in the customs document process time. Considering the total time values along the four BPFs, improvements of up to 5 % (SC2) and 42 % (SC3) can be achieved.

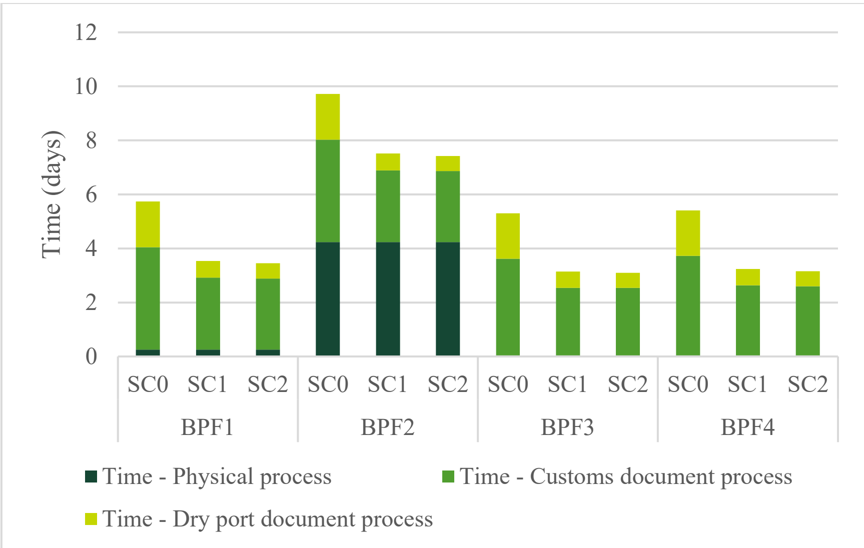

Figure 18. Time spent for business process flows, including results from the scenario analyses.

6. Discussion

Digital technology have numerous applications in IFT and the potential to enhance systems performance. The findings of this study regarding digital technology adoption in IFT and its impact on performance within a low-income country context are discussed in four sub-sections. The first sub-section discusses key performance indicators in IFT and the second discusses current technological practices in IFT. Third, the application of digital technologies in dry port location decision and dry port operation is discussed. Finally, the discussion on implications of digital technology use on IFT performance follows.

6.1 Performance indicators in intermodal freight transport

According to the survey results from customers, turnaround time is the most important dry port performance indicator. At the same time this is the indicator that poses challenges in ports of other developing economies (Shibasaki et al., 2017 and Kine et al., 2022). Martin et al. (2017) and Arvis et al. (2018) also agree that turnaround time is a critical factor affecting logistics performance in landlocked countries. Turnaround time is important for clients as it affects total time they spend in terminal (Carboni & Deflorio, 2018). Incorporating digital technologies that reduce paperwork, eliminate repetitive procedures and in-person meetings with clients could improve turnaround time (Ricci et al., 2016). In Paper V, the investigation into the use of digital technologies for dry port time efficiency revealed a potential improvement in process time of dry port.

Service providers gave the highest weighting to damage and loss frequency, with a value of 33 and 26 % for dry port operations (Fig. 6). 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 (Arvis et al., 2018) and thus help improve customer satisfaction. This, in turn, would probably result in more customers using port services, thereby increasing throughput in the port. Hence, port operations in low-income countries may improve the quality of their service to achieve greater reliability (Celebi, 2019).

From the financial dry port PIs, service providers gave the highest weighting to capital expenditure per tonne of cargo, with a value of 54 % (Fig. 6). This shows that service providers prioritize reducing the expenditure that results from investing in port equipment. However, investing in technological advancement and increasing the number of cranes can improve throughput in the dry port and increase its efficiency and profitability. 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. This could imply that technologies replacing people may not appear attractive for port operators.

For both customers and service providers, environmental impact was given the lowest weighting, with values of 14 % and 11 % respectively (Fig. 6). Although there have been some initiatives in Ethiopia to reduce the climate change (FDRE, 2021), the results of the survey showed that this issue has not gained much traction in dry port operations.

From the transport PIs, customers gave the highest weighting to security, with a weighting of 24 % (Fig. 6). 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 (Wheat et al., 2019, Ansah et al., 2020). Security threats due to political instability might cause loaded trucks to be delayed either in the dry port or along the corridor, while increasing risk of theft. The limited implementation of tracking technologies by road transport companies in Ethiopia’s IFT corridor (Kine et al., 2023) is linked to this indicator. Therefore, implementing of tracking technology could be highly valuable in improving IFT performance in this regard. Availability of transport is the second most important transport performance indicator. The use of online platform could contribute to availability by providing real-time truck information different stakeholders in IFT. Online platform was investigated in Paper V, with a focus on improving dry port process time and future study could consider the aforementioned aspect. Transport time and costs have been found to be the most important indicators in a European context (Islam et al., 2013), but these were ranked third and fifth respectively in the present study. This study did not incorporate sub-indicators within the identified performance indicator, which may limit a comprehensive understanding of the specific dimensions contributing to a particular key performance indicator.

6.2 Current technological practice in IFT and implications

Adoption of general purpose technologies could significantly affect digitalization of IFT. The results from Paper III indicate that the road transport companies, freight forwarders, dry port authorities and railway companies use fundamental ICT with exceptions on adoption of smart phones, industrial and sector specific software, and web-based services particularly in road transport companies. Websites are powerful in digitalising customer services, conducting business activities and disseminating information within companies (World Bank Group, 2016). The emerging digital technologies including IoT, AI, big data and cloud computing have been introduced to a lesser extent in the IFT system. These technologies are not widely prevalent on a global scale either (OECD, 2022). The barriers respondents mentioned including, lack of IT skills of staffs, IT experts, lack of technological integration and resistance from drivers aligns with socio-technical perspective theories of human factors and external environment (Ras et al., 2017; Dalenogare et al., 2018). A comparison of the prevalence of general purpose technologies at a national level with the results in this study showed that there is less resistance among service providers to moving towards digitalisation. However, there will be barriers in end to end transparency and integration of communication especially towards the end users in the chain including importers, exporters, and consumers. Addressing the digital divide in countries is crucial in this regard to insure a seamless end-to-end flow of information and goods, which is evident in low-income countries (Fuchs & Horak, 2008, World Bank Group, 2016).

The technological practices involved in providing services in road transport companies indicated a lack of use of real-time technology to control drivers and goods. Transport performance indicators such as safety which is the most important performance indicator according to Tadesse et al. (2022)

could be improved by digitalising these areas. Specific tasks such as proof of delivery and error management, rely heavily on paper works, implying additional trips required to transfer papers between actors. This introduces inefficiencies in the IFT system.

The technology practice of freight forwarding companies is highly dependent on the technological progression of other stakeholders since their main task is to integrate the actors. Therefore, the digitalization of these organization could highly be impacted by external environments as observed in other studies for different enterprises (Kuan & Chau, 200; Alraja et al., 2020). In this regard, interaction with seaports is done through web-based platforms, which aligns with global practices. Currently, however, once containers leave or before reaching the seaport, the organisation of road transport, tracking during transit and interaction with dry ports by freight forwarders are heavily reliant on telephone calls and in-person meetings. This leads to inefficiencies in the planning and operation of inland section. Collaborative tracking and tracing at dry ports could help mitigate the inefficiencies caused by low visibilities in these situations (Mirzabeiki et al., 2016). Therefore, a closer examination of the application of digital technologies in dry ports was undertaken in Papers IV and V. A trend was observed for road transport companies with higher adoption of general purpose technologies to digitize their services. This aligns with the assumption that integration of foundational technologies affect digitalization of enterprises in Technology Organization and Environment framework (Kuan & Chau, 2001; Alraja & Al-ahmad Malkawi, 2015; Alraja et al., 2020). The sizes of road transport companies showed impact on adoption of technologies. However, the analysis did not consider different sizes of freight forwarders, and therefore its effect on technology adoption is not evident in this study. In addition, the small number of freight forwarders involved in the study could affect generalizability of the results.

6.3 Application of digital technologies in dry ports

6.3.1 Strategic planning of intermodal freight systems

Dry port location selection is an important strategic decision that could benefit from digital data and robust analysis tools. Paper IV attempted to incorporate GIS and MCDM as a sound approach to determining optimal dry port locations. The inclusion of spatial data for location analysis would increase the accuracy and speed of analysis. Web-based platform and GIS were also applied by other studies to analyse policy measures (Stylios et al., 2017; Macharis & Pekin, 2009). GIS was used to support a policy making that will enable use of IFT. The suitability map formulated in this study provides guidance for decision making regarding future dry port construction. This will save unnecessary costs and inefficiencies that may arise from wrong placement of dry ports. However, data on marketing and production places were not available digitally and this represents a huge setback to effective planning. A digital inventory of logistic facilities, major marketing hubs and production areas could be implemented as a short-term improvement to facilitate planning and digitalisation of supply chains. Lack of data is common problem in low-income countries (Borel-Saladin, 2017; Osuteye et al., 2017) which would be a barrier to implement digital solutions effectively. The results indicated that most of the existing dry ports align with the identified most suitable lands in the study, suggesting that low performance of dry ports due to inappropriate site is less probable for the subsequent case study.

6.3.2 Dry port processes

The business process model of dry ports provides insights that enable the identification of alternative business process flows that are more time efficient or where more action is required to improve processes further. In particular, the scenario analysis allows understanding the significance of the implementation of effective digital tools to improve the time efficiency of dry ports and reduce related costs, resource use and environmental impacts while increasing customer satisfaction. Similar empirical studies on digital and communication technologies indicated increased port efficiency (Castellano et al., 2019; Rodrigues et al., 2023). The reduction of process times in dry port can contribute to mitigation of the primary bottlenecks in logistics particularly causing low logistic performances observed in low-income countries. A higher effect is observed when the current digitalization of port is high and for ports moving towards smart ports (Castellano et al., 2019). Furthermore, the method and model developed could be customised and upgraded to increase the scope, analyse more scenarios and consider other dry port performance indicators, such as costs, human resources etc.

However, the assumptions about the effectiveness of digital tools are heavily reliant on ICT infrastructures and skilled IT professionals. In addition, they require the collaboration of stakeholders such as importers/exporters, freight forwarders, transporters, and dry port and customs authorities (Serra & Fancello, 2020). These preconditions necessitate government initiatives to advance ICT infrastructures, as well as efforts from motivated business stakeholders and IT professionals to advance the system.

6.4 Impact of digital technologies on IFT performance

This thesis identified multiple drivers supporting the advancement of digital technologies in IFT. These include the widespread of general-purpose technologies among IFT companies, positive attitudes toward digitalization within these organizations, competition among freight forwarding companies, and government initiatives to promote digitisation. The technological gaps indicated in Paper III and the application areas of digital technologies in IFT in Papers IV and V imply that performance gains related to the KPIs outlined in Paper II could be made. The adoption and application of digital technologies such as web-based platforms considered in paper V have the potential to enhance the dry port key performance indicators. Further automation of information exchange impact turnaround time in seaports (Jacobsson et al., 2020). Accordingly, among the main challenges in IFT of low-income countries identified in Papers I and II, challenges such as long waiting time, high bureaucracy, extensive paper-based services, and lengthy and repetitive customs checks could be mitigated by the use of electronic and online communication systems. Virtual clustering and ICT solutions implemented in other case studies (Golińska, 2013; Corriere et al., 2014) could improve the key performance indicator availability (Tadesse et al., 2022) of transport services. Truck capacities could be recorded on these platforms, helping to address the challenge of finding the right truck capacity by service users. GPS and route optimization tools could influence the other important transport performance indicator travel time. The most important performance indicator identified in paper II, security, could also be improved by implementing GPS and telematics that insure the real-time control of containers during transportation. This will contribute to drivers' safety and provide improved oversight.

The identified barriers such as poor internet network and system failures could affect successful implementation of digital tools. In addition, the adoptions of technologies could be influenced by accessibility, affordability and skills (UN-OHRLLS, 2018) could contribute to the successful adoption of the digital technologies. By considering the existing technological gaps found in this paper the recommendation is to utilize the already adopted ICT technologies to digitalize services. This approach could enhance labour skills, human resource capabilities, and the adaptability of processes to technology, as well as strengthen collaboration efforts (Wagner, 2008; Fuchs & Horak, 2008). These improvements may support the successful integration and implementation of emerging digital technologies.

7. Conclusions

This thesis has assessed the state of the art of digital technologies in intermodal freight transport (IFT). The existing intermodal freight transport was explored considering the performance indicators, challenges and level of digital technology adoption in Ethiopia. The optimal locations of dry ports were mapped, with such approaches required in dry port planning. Dry port business process flows has been modelled and the total process time was calculated. The potential benefits of digital technologies in optimising operations in dry ports were also investigated.

Security and availability were highly ranked performance indicators for transport, while turnaround time and damage frequency were highly ranked for dry ports. The low performance of IFT in low-income countries in this aspect could be attributed to time-consuming port and customs procedures, inefficient resource utilization, labour-intensive document and information exchange, and fragmented inland transport. These indicators call for policy and technological interventions in developing economies.

The primary technological gaps identified in this thesis were the low traceability of containers in inland transport, low utilization of technology in road transport companies, the lack of system integrating different actors and reliance on manual payments. Recommended digital technologies to address these gaps are electronic data interchange, single-window services, web-based platforms, and global positioning system for tracking.

There is an opportunity to utilize general-purpose technologies in freight forwarding companies to a greater extent than it is in current use, while road transport companies there is a need to introduce these general purpose technologies to digitalize their services. This would require freight forwarders to collaborate effectively with other stakeholders, while competitive pressure could be the main drive to adopt technology for road transport companies.

The application of geographic information systems and use of spatial data in dry port location planning and analysis could enhance decision-making with regard to the optimal location of dry ports. The availability of digital data is crucial in this context, and gaps in data recording and management could hinder the digitalization path.

For the dry port business processes, the introduction of digital technology in the studied system could significantly reduce the total process time. Implementation of integrated digital platform, information sharing system, online payment, have the potential to improve of the time efficiency for port document processes by up to 67 %.

The thesis concludes that by addressing the identified technological gaps along with the digital technology applications highlighted in this study, digital technologies play a pivotal role to improve IFT performance. The performance indicators identified from literature and survey could be adopted by other low-income countries to improve the performance of their dry port operation and transportation taking local conditions into account.

Addressing organizational, infrastructural and human resource constraints in low-income countries could exploit the potential benefit of digital technologies and enhance key performance indicators in the IFT. However, the implementation of digital technologies in IFT is a broad discipline, and more studies tailored to the specific conditions of low-income countries are required given today's rapidly changing digital landscape.

8. Further research

The current lack of a quantitative index measuring digitisation in IFT is a gap identified in this study. Developing such a framework would advance the planning and impact of future technology interventions.

The coupled MCDM and GIS method was used to identify general land areas suitable for dry port location analysis. Location analysis that takes the flow of goods into consideration would improve the output further.

The dry port component of IFT was given a greater emphasis in order to study the impact of digital technologies on performance. Studies that consider the whole IFT chain and the effect of each component would be of interest.

The benefits of adopting digital technologies was analysed in the study in relation to reducing dry port process time. However, incorporating the benefits regarding human resource utilisation, economic gains and service quality that the technologies would bring to importers/exporters, freight forwarders, transport companies and dry port authorities would allow a more holistic insight.

More research on methods to select appropriate digital technologies that will address IFT challenges in low-income countries, determining the success rates of technological measures, is another important study area for further exploration.

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Popular science summary

Intermodal freight transport is the use of multiple means of transport to move goods within a single shipment and billing from the point of origin to a destination. It maintains an especially important role in international maritime transport. With growing international trade and globalization, high efficiency of intermodal freight transport is required. One of the main constraints in the system is the management of the massive flow of information and documents between the various actors involved. Digital technologies play an important role in such systems, since they could improve the performance of the system. Nevertheless, there is still limited adoption of digital technologies in low-income countries. It is therefore important to investigate the potential of digital technologies to enhance currently under-performing intermodal freight transport in low-income countries.

This thesis aimed to examine the potential benefits of digital technologies on intermodal freight transport of low-income countries. To do this, the existing system was explored considering identification of important performance indicators and the current practice of digital technologies. Thereafter, applications in optimal dry port location analysis and dry port process restructuring were studied. These approaches enabled a broader discussion of the roles digital technologies play in intermodal freight transport performance.

The adoption of basic technologies together with the identified technological gaps indicate the opportunity of further adoption of digital technologies in intermodal freight transport. Emerging technologies like internet of things, artificial intelligence and big data are almost non-existing in the studied systems despite being introduced worldwide. The use of geographic information systems in dry port location analysis shows the role spatial data and digital tools could have in intermodal freight transport planning. Furthermore, digital technologies have opportunities for applications and impacts at the operational level, as demonstrated in this study's findings on the improvement of dry port processing times. Therefore, it is important to unlock the potentials of digital technology and leverage them in intermodal freight transport, particularly in low-income countries. Parallel development in organizational structures, infrastructural and workforce would further facilitate positive outcomes.

Populärvetenskaplig sammanfattning

Intermodal godstransport innebär användning av flera transportmedel för att förflytta och fakturera varor och i en och samma försändelse från sin ursprungspunkt till en destination. Den spelar en särskilt viktig roll inom internationella sjötransporter. Med växande internationell handel och globalisering krävs hög effektivitet i intermodala godstransporter. En av de främsta begränsningarna i systemet är hanteringen av det massiva flödet av information och dokument mellan de olika inblandade aktörerna. Digital teknik spelar en viktig roll i sådana system, eftersom den kan förbättra systemets prestanda. Användningen av digital teknik är dock fortfarande begränsad i låginkomstländer. Det är därför viktigt att undersöka potentialen hos digital teknik för att förbättra de för närvarande underpresterande intermodala godstransportsystemen i låginkomstländer.

Denna avhandling syftade till att undersöka de potentiella fördelarna med digital teknik för intermodala godstransporter i låginkomstländer. För att göra detta undersöktes det befintliga systemet med fokus på att identifiera viktiga prestandaindikatorer och tillämpning av digital teknik i befintliga system. Därefter studerades hur lokaliseringsanalys kan tillämpas för optimal placering av torrhamnar och hur deras processer kan omstruktureras. Dessa tillvägagångssätt möjliggjorde en bredare diskussion om den roll digital teknik kan spela för de intermodala godstransporternas prestanda.

Användningen av grundläggande teknologier tillsammans med de identifierade luckorna i dess införande visar på ytterligare möjligheter för införande av digital teknik inom intermodal godstransport. Framväxande teknologier som Internet of Things, artificiell intelligens och Big data är nästintill obefintliga i de studerade systemen trots att de nu introduceras över hela världen. Användningen av geografiska informationssystem inom lokaliseringsanalys för torrhamnar visar vilken roll spatial data och digitala verktyg kan spela i planering av intermodala godstransporter. Dessutom innebär digital teknik möjligheter till tillämpningar med effekter på operativ nivå, vilket även det demonstrerats i denna studies resultat där torrhamnars processtider kan förbättras.

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future transportation

Review

Digitalization and Automation in Intermodal Freight Transport and Their Potential Application for Low-Income Countries

Helen Zewdie Kine [1,*], Girma Gebresenbet [1], Lorent Tavasszy [2] and David Ljungberg [1]

1 Department of Energy and Technology, Swedish University of Agricultural Science (SLU), 750 07 Uppsala, Sweden; Girma.Gebresenbet@slu.se (G.G.); David.Ljungberg@slu.se (D.L.)
2 Faculty of Technology, Policy and Management, University of Delft, 2628BX Delft, The Netherlands; L.A.Tavasszy@tudelft.nl
* Correspondence: helen.zewdie.kine@slu.se

Abstract: This paper presents an assessment of enabling technologies in intermodal freight transport. It first identifies the technologies used in intermodal freight transport globally using a systematic literature review. Then, it characterizes intermodal freight transport in the context of low-income countries to assess the potential application of digitalization and automation for the countries. Countries with a per capita gross national income (GNI) lower than $1025 are categorized as low-income countries. To achieve the objectives, a review was undertaken of 147 published articles from Scopus, Web of Science, and Transport Research International Documentation (TRID). Furthermore, distinctions of intermodal transport in low-income countries were also characterized using gray literature. A number of enabling technologies applied at components of intermodal transport were identified. The results demonstrated that several enabling technologies such as wireless communication technology, sensors, positioning technology, and web-based platforms are highly utilized in intermodal freight transport globally. In contrast, electronic data interchange (EDI), wireless communication technologies, and web-based platforms also have potential applications in low-income countries, and their adoption should be studied further.

Keywords: intermodal freight transport; ICT; digitalization; automation; low-income countries

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1. Introduction

Intermodal freight transport (IFT) refers to the transportation of goods using more than one means of transport without changing load units during transportation and incorporating the concept of integration, door-to-door service, and the use of a single bill of lading [1–3]. Intermodal transport involves several stakeholders and components and thus requires an intensive flow of information, which causes the system to be complex and require technological innovations [4–9]. The efficient application of available and emerging digitalization and automation technologies allows the seamless and timely flow of information and goods in IFT. Information and communication technologies (ICT) in intermodal transport include networking and communication technologies, sensors, satellite technologies, cloud computing, web-based platforms, and automation. These technologies are implemented in decision making, port planning and management, chain management, and monitoring. Several studies have shown the adoption of enabling technologies to improve IFT performance [10–12].

The digitalization and automation of IFT in low-income countries are in their infancy. The traditional paper-based exchange of information and documents among stakeholders still prevails [13–15]. Real-time information and traceability of goods are not widely implemented. Port operations are not automated and remain heavily dependent on manual procedures and labor. By adapting enabling technologies, low-income countries can enhance IFT. A study by Yanocha et al. [16] examined the adoption of integrating technology in low-income countries and discussed the barriers to and potential opportunities of technology adoption, but the focus was on public transport.

Literature reviews by Bontekoning and Priemus [5], and Van Binsbergen et al. [9] identified studies on the implementation of ICT in IFT and logistics, mainly focusing on its adoption. However, these studies focused on a single technology and single components of IFT. Comprehensive reviews considering all components and enabling technologies are almost non-existent in the literature. Only the report of Harris et al. [7] on recent ICT discoveries and their adoption in intermodal transport considered all the components, but they focused just on European countries. There is a shortage of such studies relating to low-income economies.

The objective of this paper was to identify the main technologies in IFT globally and their applications by means of a systematic literature review (SLR). The aim was also to characterize IFT in low and high-income countries in order to assess the potential applications of digitalization and automation in low-income countries. Questions as to whether the technologies address prominent challenges of IFT in low-income countries and are suitable for existing conditions are considered when discussing potential applications. Section 2 below outlines the methodology used in the study. Results including from SLR the technologies and their application in IFT are reviewed in Section 3. Section 4 discusses the potential applications of these technologies in low-income countries, and finally, the conclusions are presented in Section 5.

2. Materials and Methods

To implement the objective of the current paper, two approaches were employed, as indicated in Figure 1. First, a systematic literature review (SLR) was undertaken to describe the state-of-the-art and applications of enabling technologies in IFT. From this analysis, the application of technologies that are components of IFT and their pre-conditions were synthesized. Additional gray literature was reviewed to characterize IFT in low and high-income economies. The outcomes of the characterization were the identification of IFT and key challenges in low-income countries. Then, these outcomes were used as an input for selecting the potential applications of technologies in these countries. The technological applications were assessed as to whether or not they address the key challenges in low-income countries. Then, their characteristics and pre-conditions were checked to establish whether they fit with IFT in the context of low-income countries.

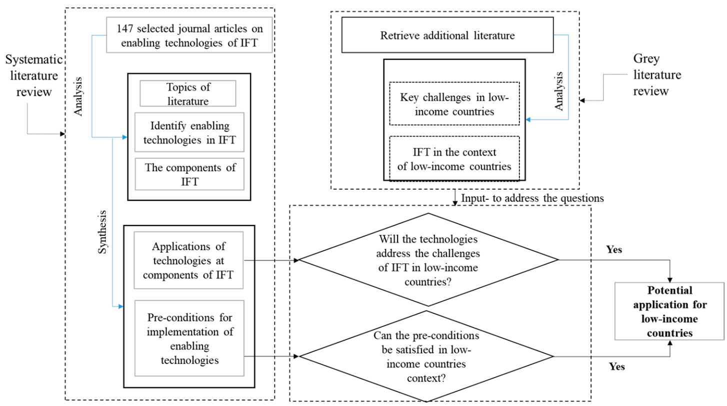

Figure 1. Overall research framework. Source: Authors' own elaboration.

The SLR followed the steps of Wee and Banister [17]. The first step was scoping, where the questions being addressed in this study were formulated. These included: Which components of IFT are studied? What enabling technologies are used in intermodal transport? What are the applications of these technologies? Then, in the planning, the proposed keywords were ("Inter*modal transport*" OR "multi*modal transport*" OR "Synchro*modal transport*" OR "Co*modal transport*" OR "Combined transport*") AND (digiti*ation OR digitali*ation OR technolog* OR automat* OR robot*). The selected databases were Scopus, Web of Science, and TRID, and the articles searched had been published between 2000 and 2020. The year 2000 was selected as it was the year that marked the start of the boom of technology in transport. In all, 553 articles were identified during the searching stage.

After the collection of these journal articles, the screening stage followed. Papers that were duplicated or outside of the scope of the study were excluded from the search results. Studies performed on public transport were also excluded, since the scope of this paper is freight transport. A few papers that only mentioned technology without investigating a specific technology type were also removed. The next step in the screening took place by reading the title and abstract of these articles. This led to the identification of 147 papers that were found to be relevant. Following the screening came the analysis and synthesis stage. Here, a detailed review was undertaken of the 147 articles selected to retrieve the required information. This included the component of intermodal transport on which the studies focused, the type of technology studied, and the application of the technology. Then, the retrieved articles were categorized on the basis of this information. The answers to the questions initially asked are presented and indicated in the Results section of this paper. The searching and collection of articles started on February 2020. The iterative process of including and excluding articles took place until September 2021. Analysis and synthesis followed afterwards. A second round of searching was carried out in March 2021 to include the latest articles in the study.

No literature about low-income countries was found in the systematic literature review. Therefore, gray literature on projects undertaken in low and high-income countries and international and regional reports were used to characterize IFT in high and low-income economies. The analysis took the components of intermodal transport from the SLR into consideration. From this literature, distinctive features differentiating IFT in low-income countries from that in high-income countries were selected, and the challenges that stood out in low-income countries were identified.

In order to identify enabling technologies that have the potential to be adopted in low-income countries, the outcomes from the SLR and characterization were used. Case studies from the reviewed articles that address the identified issues and have the potential to be implemented in low-income economies were collected.

3. Enabling Technologies and Their Applications in Developed Countries

3.1. Bibliometric Results

Figure 2 shows the number of reviewed papers published between 2000 and 2020. The percentage of articles published show an increasing trend over the years and a maximum number of publications is seen in the year 2020.

Table 1 shows that 78% of the reviewed articles were from Europe, followed by Asia. No research was found for Africa. It is indicated that the topic has been well researched in the context of high-income countries, but no articles were found that related to low-income countries.

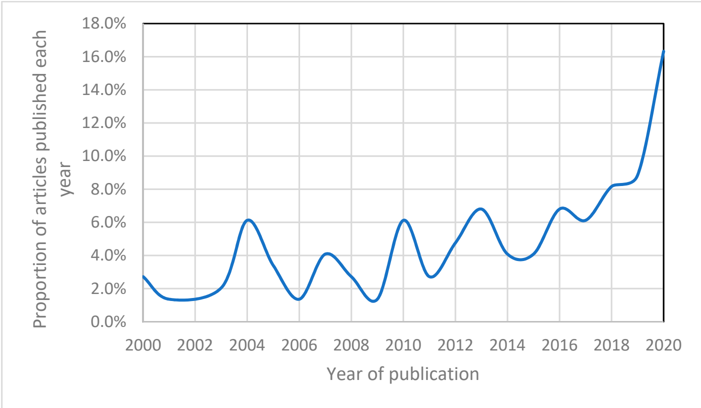

Figure 2. Distribution of articles identified from a systematic literature review over the years 2000–2020.

Table 1. Distribution of reviewed articles by geography and economic class.

Continent	Number (and Percentage) of Reviewed Articles	Economic Group of Countries			
		High-Income	Upper-Middle	Lower-Middle	Low-Income
Europe	104 (71)	87	16	1	-
Asia	15 (10)	5	8	2	-
North America	19 (13)	12	7	-	-
Oceania	9 (6)	4	5	-	-

3.2. Classification of Topics

Based on the main topics addressed, the selected articles were classified into six categories, as shown in Table 2. Most of the papers are in the description category, which is followed by articles evaluating performance.

In view of the classification of components in intermodal transport from the literature, five components were identified: ports and terminals, chain management and monitoring, pre- and post-haulage (PPH), main haulage, and load unit. Ports and terminals refer to the point at which a change in means of transport occurs. The chain management and monitoring component concerns the timely communication of information along the whole chain. PPH covers the movement of goods to/from ports from/to the warehouses of clients. The main haulage is the section that covers the longest portion of transport and is carried out using massive means of transports such as trains, ships, or planes. Load unit is the means of keeping goods in a single unit. Figure 3 shows that most papers focused on ports and terminals, which was followed by chain management and monitoring. Very few papers discussed the load unit component.

Enabling technologies found in the literature included equipment, automation and artificial intelligence (AI), web-based platforms and big data, sensors and wireless communication technology, electronic data-sharing tools, and surveillance technologies. The number of articles discussing the corresponding technologies are shown in Figure 4.

Table 2. Topics about IFT discussed in the identified articles.

Topics	Description	No. of Articles
Performance evaluation	Studies highlighting performance improvement of intermodal transport when technologies under consideration are adopted	41
Modal shift	Studies on how technologies are important for increasing the share of intermodal transport, especially in order to reduce the proportion of road transport	20
Description of technologies	Articles that provide an explanation of the technologies used in IFT	50
Adoption of technologies	Studies that focus on the conditions that hinder or enhance the adoption of technologies	24
Environmental impact	Investigations showing the impact of technologies to minimize the environmental impact of transport	6
Technology selection	Studies on the suitability of certain technologies for adoption in the case studies considered	5

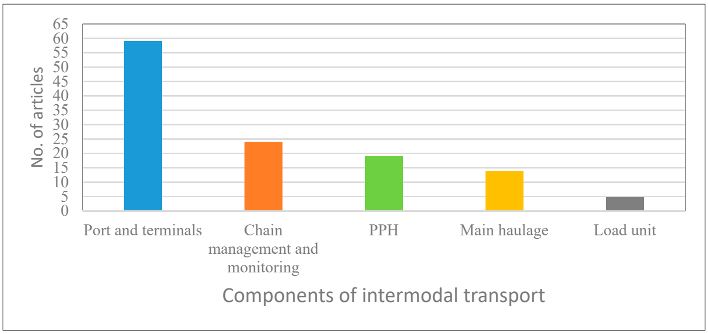

Figure 3. Components of intermodal transport discussed within the articles.

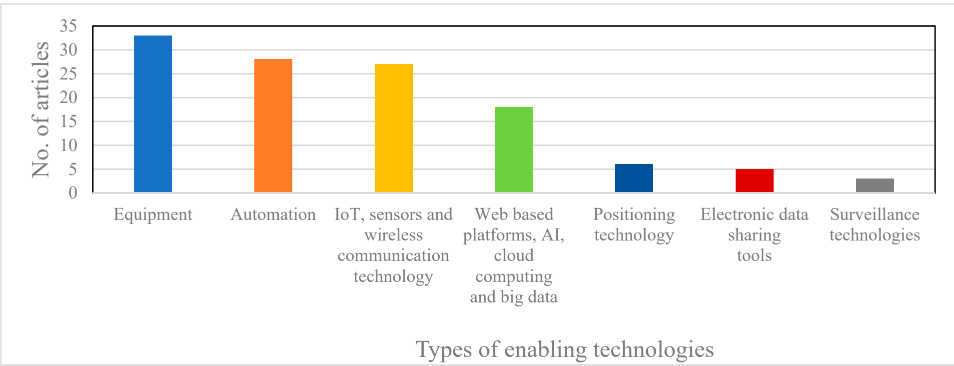

Figure 4. Enabling technologies applied in intermodal freight transport discussed with the articles.

3.3. Applications of Enabling Technologies

Types of enabling technologies identified from the reviewed articles are presented here. Each of the technologies has a particular application in intermodal transport. This is better understood by considering the components of IFT. Table 3 summarizes the application of enabling technologies in different components of intermodal freight transport.

Table 3. Application of technologies on different components of intermodal freight transport.

Enabling Technologies	Components of Intermodal Transport				
	Ports and Terminals	**Chain Management and Monitoring**	**PPH**	**Main Haulage**	**Load Unit**
Automation	Automation of equipment in ports to reduce idle time, increase safety, and ensure efficient cargo handling Accurate port planning and scheduling with automatic information exchange systems Reduce the number of operations required in moving containers	*	Collect automatic data from port operators, logistic providers and carriers for excellent decisions support system Automated trucks and platoon operations work to reduce road congestion, environmental impact and improve safety	Autonomous underground transport and ships providing a fast and reliable service	*
IoT, sensors, and wireless communication technology	Provides automatic identification of units at gates, security of containers and real-time tracking and tracing in ports Optimize port call	Ensure security of cargo by sending signals for risk conditions and safety of perishable products Optimize mode choice using real-time data	Used for efficient port calling process Provide real-time information from trucks to stakeholders	Monitor vibration during transportation and report for anticipated risk	*
Web-based platforms, AI, cloud computing, and big data	Broadcast schedules in port Clear presentation of required information and procedures to stakeholders	Used to select best chain in choosing transport service Enable fast and reliable decision support system Provide visibility of goods in transport	Provide decision support system for logistics providers Establish collaboration between carriers to reduce empty running Online matching between shipping request and service	Easy access to information of the status of long-haul vehicle to stakeholders	Provide centralized and fast container booking system
Positioning technology	Used to locate trucks, containers, and equipment in ports for efficient work planning	Ensures traceability by locating the cargo throughout the chain	Identifies real-time location of trucks Used to determine shortest path routes	Provides real-time location of cargo while in main haulage (e.g., a location where any mishandling of good occur)	*

Table 3. *Cont.*

Enabling Technologies	Components of Intermodal Transport				
	Ports and Terminals	**Chain Management and Monitoring**	**PPH**	**Main Haulage**	**Load Unit**
Electronic data-sharing tools	Provide easy and quick port administration in port calling, customs declaration, clearance notification Port-EDI for a one-stop service (single window)	n/a	Exchange booking and boarding instructions between consignee and freight forwarders	Information about position of ships	n/a
Surveillance technology	Ensures the safety of cargo under port process Identifies plate numbers of trucks entering port	Ensures cargo safety throughout the chain	Controls security of cargo and drivers in inland transport	*	Automatic extraction of container identity code

* No article found. "n/a" not applied.

3.3.1. Equipment

The existence of more than one means of transport in an intermodal system comes with a challenge in terms of integration of means of transport. Transshipment carried out in ports provides an easy transfer of load units from one means of transport to another. Studies that focused on technological advancements in transshipments dealt with creating a seamless transfer of goods between modes. These included innovation in load units that facilitate the easy handling of cargos, the design of wagons and platforms for suitable handling of load units, and energy-efficient and fast cranes and reach stackers. The studies focused mainly on their application in ports and terminals, including electric cranes for a rapid and low environmental impact and maximizing port utilization, and transshipment technologies that are easy to operate for different kinds of cargo. Applications in main haul included railway wagons designed to reduced vibration and barges for easy loading and unloading.

3.3.2. Automation

The automation of activities in intermodal transport received considerable research attention, as shown in Figure 4. One of the applications of automation is the planning of activities at times when an immediate response is required. The automation of equipment used in ports is another application of automation in IFT. Research has also dealt with the automation of vehicles and wagons for the safe and fast transportation of goods. Robots, automated guided vehicles (AGV), and automatic information updating were addressed in the studies.

3.3.3. Web-Based Platforms, Artificial Intelligence (AI), Cloud Computing, and Big Data

Platforms have a wide application in intermodal transport. Previous studies on platform communication technologies included platforms provided by port operators, business personnel, governmental bodies, logistics providers, and external ICT expertise. With web-based platforms, information can be made easily accessible to the different stakeholders involved in intermodal freight transport. Communicating information at the right time among stakeholders increases integration and provides an efficient system. As a whole, creating an integration between stakeholders is the main application of platforms in

IFT. Big data together with AI are applied for the utilization of large amounts of collected and stored data for planning and decision making in intermodal transport. This is related to real-time data acquisition in decision-support systems (DSS) for managing intermodal transport. All these technologies are based on cloud computing technologies. Cloud computing is also used for purchasing and using the software applied in intermodal transport planning and management.

3.3.4. Internet of Things (IoT), Sensors, and Wireless Communication Technologies

The articles in this category studied radio frequency identification (RFID), ultra-high frequency (UHF) radio, optical character recognition (OCR), near-field communication (NFC), optical scanner, IoT, and real-time information communications. Data can be transferred quickly and wirelessly using these technologies. Smart mobile phone applications can be provided using NFC. Notification of arrival at port can easily be made via apps. Micro-electromechanical system (MEMS), radiation, and electronic seal were the sensors covered in the articles to ensure optimum temperature, moisture, vibration, etc. during transportation. Articles also covered smart sensors capable of processing signals and performing pre-defined functions. When summarized from Table 3, these technologies work on increasing the visibility of chains. In addition, safety, security, and ease of planning are the main applications. The three together enable monitoring of intermodal transport along chains.

3.3.5. Positioning Technologies

Positioning technologies, such as global positioning system (GPS), global navigation satellite system (GNSS), differential global positioning system (DGPS), and automatic vehicle identification, have been covered in the literature together with their versatile applications. Deploying satellite technologies on vehicles and port equipment were discussed in the research. These are installed on vehicles and containers to receive updates on the location of goods. When used with sensors, they ensure that the security of cargos is monitored. They are installed on reach stackers to remotely control their work and are used to identify the location of straddle carriers.

3.3.6. Electronic Data-Sharing Tools

A number of documents have to be communicated between IFT agents. This is especially true in the case of international transport. Both port operators and customs require documents that identify the goods transported, their value, and legal requirements. Electronic data interchange (EDI) and the application program interface (API) are some of the tools available. EDI is a system of standardized electronic data transfer from one computer to another. EDI improves the system by minimizing paperwork and the involvement of people in the process, and it is mainly used to reduce the time involved obtaining and processing information. It reduces the time loss that would be incurred with manual communication of information. The EDI/XML interface can also be used for electronic document transfer, minimizing software costs.

3.3.7. Surveillance Technologies

Although there was not a great deal of literature on surveillance technologies identified in the SLR, they have numerous applications in IFT. Areas studied in the literature included automated video surveillance, number plate recognition, and augmented reality (AR).

3.4. Pre-Conditions and Barriers for Implementation of Technologies in IFT

Certain conditions need to be in place for the successful implementation of enabling technologies in IFT. The extent and type of these pre-conditions vary depending on the types of technologies. Networking technologies and the internet are fundamental requirements for the proper functioning of digitalization and automation. Communication in ports and sensors in trucks need networking technologies to function properly [18,19]. These include wireless personal area network (WPAN), global system for mobile communication (GSM), global navigation satellite system (GNSS), and cellular data. Innovative networking systems such as 4G, long-term evolution (LTE), and 5G are required to establish fully automated smart ports.

Software and skilled labor who can operate the software are also requirements for technologies such as EDI and web-based platforms [20]. Another barrier to the adoption of technologies in IFT is the lack of standardization [18,19,21]. Standardization in digitalization devices, load units, trucks, and railway gauges are requirements for the adoption of technologies [19]. The interoperability of technologies is also a requirement for their adoption in IFT. Since intermodal transport mostly involves more than one country, interoperability is an important characteristic. This calls for strong cooperation between countries and the many stakeholders involved in IFT [22]; otherwise, it may block trade partnerships between countries and between large companies and small and medium-sized enterprises (SMEs).

The introduction of technologies such as the automation of trucks and transshipment technologies is very costly. Cost and uncertainty around the financial return from technologies are other barriers to adopting technology [23,24]. The economic and market benefits of transshipment technologies are not well researched, creating uncertainties that prohibit their adoption in ports. There is also a fear of job losses whenever automation is introduced to the system. Freight forwarders also fear that they will lose their jobs if electronic communication and single window systems materialize. However, there is a shortage of skilled labor to operate these technologies.

Satisfaction with how operations are currently carried out is also a barrier that hinders companies from accepting technologies. This is especially true for SMEs, as stakeholders seem to be satisfied with the current paperwork and traditional communications [14].

For information technology solutions, most companies have concerns about sharing information due to trust and security issues [22]. Some information is confidential, and they have a fear that they may lose customers if they provide customer information.

4. Applications of Enabling Technologies in IFT for Low-Income Countries

4.1. Characterization of IFT in Low-Income Countries

It is important to consider the context of IFT in order to understand the potential application of technologies in low-income countries. This section provides an overview of IFT in low-income countries in relation to the preconditions discussed earlier. Standardization of the carriers to be used for intermodal transport, the allowable limit of goods to transport, ease of connectivity between means of transport, and the flexibility of truck selection in terms of size and capacity are all a function of the quality of the infrastructure [25–27]. Low-income countries have limited infrastructures, including low road densities and a limited quality of road infrastructure [28]. Therefore, some technologies cannot be successfully implemented. Road and rail connectivity are also very poor in these countries [9,29,30]. This has resulted in the low utilization of railroad intermodal transport.

A limited variety and old trucks with minimum installed technologies prevail in the context of low-income countries. Internet availability and access are required for digital technologies to work [27]. High-income economies have a widely implemented ICT infrastructure with over 80% of the population in high-income economies using the internet, whereas this number falls to 20% for most low-income countries [31].

Domestic intermodal transport is mainly used in high-income economies, while the concept barely applies to low-income economies [27,32,33] where international intermodal transport features more prominently. The main reason for using intermodal transport in high-income countries is environmental concerns, while in low-income countries, it is the existence of obstacles such as mountains and water bodies and economic factors [19,21].

The interconnectivity between countries in terms of their physical network and regulations plays a major role in the successful implementation of international IFT. In the case of high-income countries such as in Europe, there is multinational cooperation. However, this is not the case in low-income countries [26]. The lack of interconnectivity and cooperation will have an impact on the effectiveness of any technological or structural changes incorporated in the system.

Up to 90% of businesses worldwide are SME, and it is important to connect these enterprises to intermodal transport. In the case of high-income countries, small trucks or non-motorized transport (NMT) are used to bring goods to or from these enterprises to a collection center, while in low-income countries, it is common to walk (in the case of animal transport) with back-loading and pulling by animals in addition to trucks. These enterprises are not economically strong and do not collaborate with one other in low-income countries [34]. Most of the labeling, packaging, and value added of goods are finished at the production point for high-income countries, making the system easy for intermodal transport.

Studies have also identified that IFT in low-income countries faces challenges such as low interconnectivity and coordination, lack of capital, political interference in the system, etc. [35–37]. Some challenges can be addressed by incorporating enabling technologies into the system. Lessons can be learnt from countries that have adopted enabling technologies and tackled similar challenges. Table 4 provides a list of the challenges faced in low-income countries that stood out most from the gray literature reviewed.

Table 4. Key challenges of IFT in low-income countries.

Intermodal Transport Components	Key Challenges in Low-Income Economies	References
Port and terminals	Inefficient port call process and long time spent in port; low application of electronic exchange of information and documents fragmented information flow among stakeholders; poor networking systems in ports leading to inefficient port management; long waiting time at entrance and exit of ports, at yards; equipment shortages; lack of qualified personnel; repetitive and time-consuming customs checking procedure; corruption	[15,35–41]
Chain management and monitoring	Low traceability of goods; lack of real-time communication of information; absence of cooperation between all stakeholders; absence of transparency on locations, capacity, and price	[26,36]
PPH	Lack of quality and availability of road infrastructure; minimum technologies installed on the trucks (prevalence of old trucks), highly fragmented transport organizations, hard to plan and organize trucks giving service to or from ports; high road transportation cost; shortage of trucks; long and volatile transport times; vehicle overloading	[15,30,36,42,43]
Main haulage	Minimum technologies installed on wagons, ships; lack of railway corridors and connectivity; no efficient connection of railways to customers/warehouses; long and volatile transport time; low vessel frequency	[36,38]

4.2. *Enabling Technologies with Potential Applications in Low-Income Countries*

From the applications of enabling technologies identified in the SLR, the ones that address the challenges of IFT in low-income countries while considering the required conditions are discussed here. The discussion is presented on the basis of the components of IFT.

4.2.1. Ports and Terminals

One of the challenges for ports in low-income countries is network unavailability that causes port management to be time-inefficient. A lesson can be taken from a case study from the Humber port region that uses cellular network technology with a lower rate deal from operators [22]. This networking system does not require extra infrastructure or IT experts adept in the likes of wireless fidelity (WiFi), wireless local area network (WLAN), or wireless personal area network (WPAN) technologies; thus, it is an easy and cost-effective solution. The application of EDI is a technological solution to the high prevalence of paperwork and human interaction in exchanging document and information in ports, and extensible markup language/electronic data interchange (XML/EDI) is an even less expensive option for low-income countries [20]. Another way of electronically exchanging information is the application of a single-window system. A single-window system is good practice because it minimizes the waste of time in ports by providing a single electronic gateway that is used to disseminate a single document to several stakeholders at a time [44]. The application of this technology alleviates repetitive and lengthy customs checks.

Inadequate labor skills can be compensated for by the automation of some activities in port. Full automation of ports may not be feasible in low-income countries. Congestion upon arrival and at the departure from gates is a recognized challenge in low-income countries. RFID is applied to optimize port calls and minimize the time spent at gates with digitized truck/driver identification systems [22,44]. However, it requires the installation of tags on containers and readers at gates and the collaboration of numerous stakeholders, which can impose extra costs and is hard to put into practice for low-income countries. One feasible solution from the literature is the use of identification cards distributed to drivers at the gate. Truck arrivals can be registered with a swipe of the card and their departure notified with the same card [22].

4.2.2. Chain Management and Monitoring

As illustrated above, traceability and tracking, real-time information, chain management, and monitoring are all challenges in low-income countries [16,45]. With the application of RFID and networking technologies, traceability can be achieved. However, RFID readers are required at segments of the intermodal transport chain. This involves additional infrastructure costs and could be a problem, especially in landlocked countries, because the decision will require the willingness of the neighboring country. However, multinational cooperation between countries, as in the case of European countries, should be promoted to make this effective in issues concerning cross-border transport. GPS installation is another technology that can be used to track the location of trucks in the PPH sections instead of RFID, and it is also applied for route optimization [19].

Web-based platforms improve coordination between stakeholders for the better management and monitoring of goods flows, and this technology should be promoted to overcome poor coordination between stakeholders is low-income countries. The adoption of tracking and tracing technology will also minimize the time spent in ports by helping plan the arrival of containers.

4.2.3. Pre and Post-Haulage

Cooperation among transport operators is important in IFT [4]. Empty haulage is significantly reduced when the planning and scheduling of transport service is carried out with cooperation between carriers [27]. Web-based platforms are good practices to increase this coordination. The implementation of these technologies will significantly minimize fragmented PPH transport in low-income countries. The use of sensor technologies (weight sensors) on vehicles can regulate the overloading issues prevalent with most post-haulage of IFT.

4.2.4. Main Haulage

The main haulage of IFT in low-income countries is mainly carried out by vessel [30,37]. Therefore, vessel efficiency is an important aspect of the system. Implementation of the automated port call system will enable the efficient use of vessels. Real-time communication between vessels and ports will enhance the timely facilitation of space and equipment for the loading and unloading of containers by ports [14,39]. This practice will reduce the turnaround time of ships and results in better utilization of the already scarce vessels in the context of low-income countries. The integration will also address the problem of long lead time in IFT of low-income countries.

In summary, ICT infrastructure in low-income countries is growing though coverage, and quality is behind the state of the art [31]. Implementing a fully automated IFT system in the current condition is challenging. Nevertheless, digital technologies, as discussed above, related to document exchanging and communication at firm levels have potential application. These technologies are also required to be less capital intensive. One aspect related to cost is selecting technologies that integrate with the available infrastructures [5,26]. Advanced digital technologies such as AI, cloud computing, and IoT will need adept IT experts for successful implementation. In low-income economies where digital technologies are yet growing, a lack of experienced IT expertise will impose a challenge in implementing these technologies. Training skilled manpower should go hand in hand with implementing technologies. For a successful acceptance of technologies in low-income countries, awareness of the advantages of technologies needs to be created within SMEs. Integration with ports and other big enterprises is made easy through creating the awareness [46].

5. Conclusions

Enabling technologies in IFT and their applications were identified in a systematic review of 147 journal articles published between 2000 and 2020. This study also reviewed gray literature to characterize IFT in the context of high and low-income countries and identified the key challenges of IFT in low-income countries. Enabling technologies from the SLR that address these challenges are recommended as having a potential application in low-income countries.

Although reviews in this field have previously been conducted, this study provides the detailed application of enabling technologies in intermodal transport considering all its components. Furthermore, by considering the context of low-income countries and providing recommendations, this paper fills the gap left by the very small number of studies undertaken on low-income countries. This review found that many studies focused on the port and terminal components of IFT. Enabling technologies have applications for activities carried out in ports and terminals, including port call, planning and management in ports, gate control, and container location. The safety and traceability of cargo are also ensured using ICT. Studies revealed that automation in port planning and operation has led to environmentally friendly, more reliable, and fast port operations.

The applications of technologies identified from the literature also have the potential to overcome challenges in low-income countries. Key challenges including time-consuming port procedures, inefficient resource utilization, labor intensive document and information exchanges, and fragmented inland transports will be addressed using enabling technologies. Simple, affordable, and compatible technologies will address these issues. Technologies, such as document exchange using EDI, single-window services, and GPS tracking for container location, are potential applications of the technologies in ports in low-income countries. Web-based platforms that allow truck coordination and route planning will solve the key challenges observed in the PPH of low-income countries.

Further research needs to be undertaken that examines the adoption of these technologies in low-income countries. These should investigate theories such as technology acceptance models (TAM), a technology organization environment (TOE) framework, diffusion of innovation theory (DOI), the theory of reasoned action (TRA), etc. to examine barriers to and opportunities presented for their adoption.

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

Mahlet Demere Tadesse [1,*], Helen Zewdie Kine [1,*], Girma Gebresenbet [1], Lóránt Tavasszy [2] and David Ljungberg [1]

[1] Department of Energy and Technology, Swedish University of Agricultural Science (SLU), 750 07 Uppsala, Sweden

[2] Faculty of Technology, Policy and Management (TPM), Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands

* Correspondence: mahlet.demere.tadesse@slu.se (M.D.T.); helen.zewdie.kine@slu.se (H.Z.K.)

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.

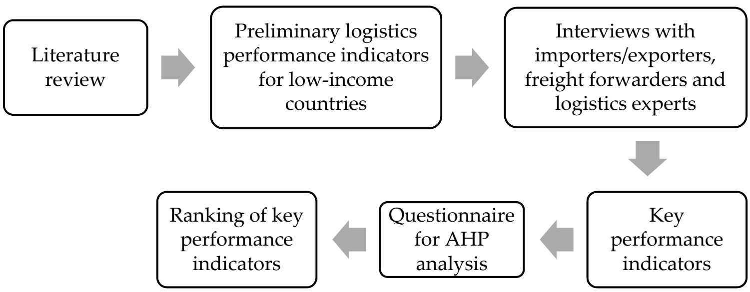

Figure 1. Methodology followed in this study.

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].

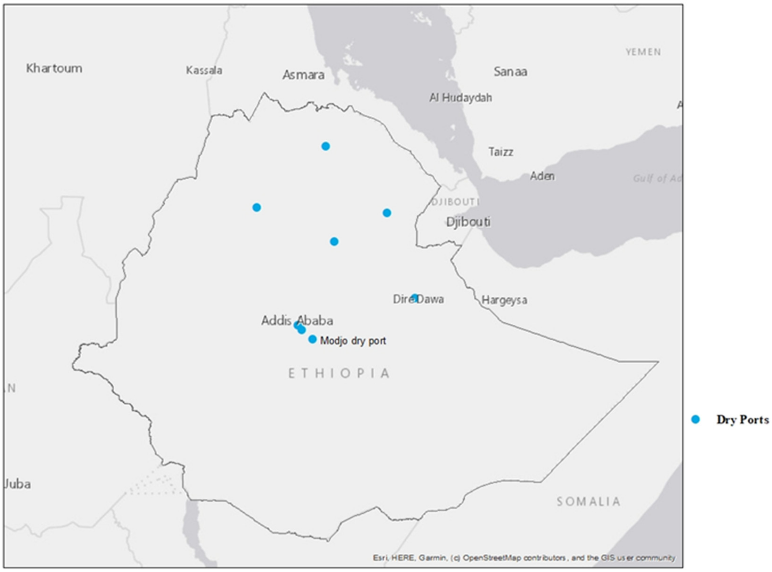

Figure 2. Location of the eight dry ports in Ethiopia.

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

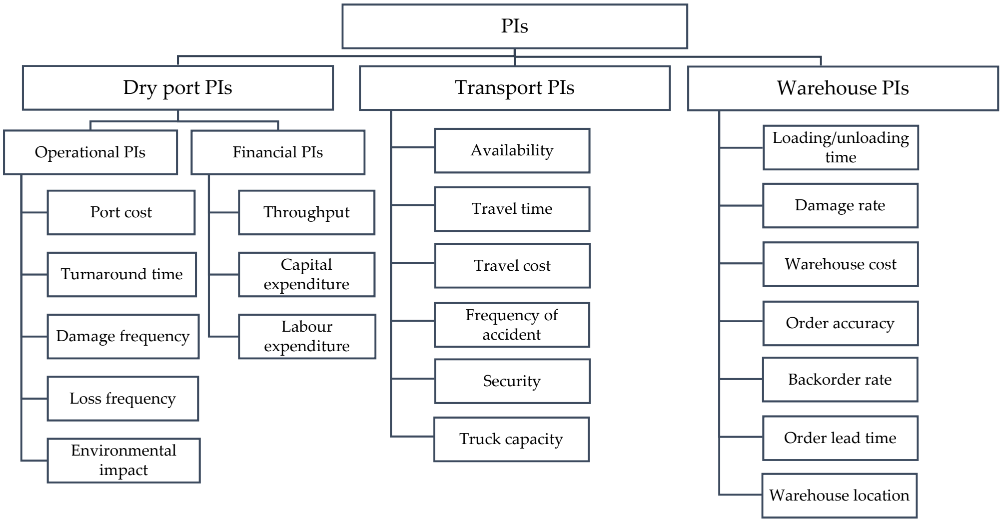

Figure 3. Final list of PIs presented to experts for pairwise comparisons.

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.

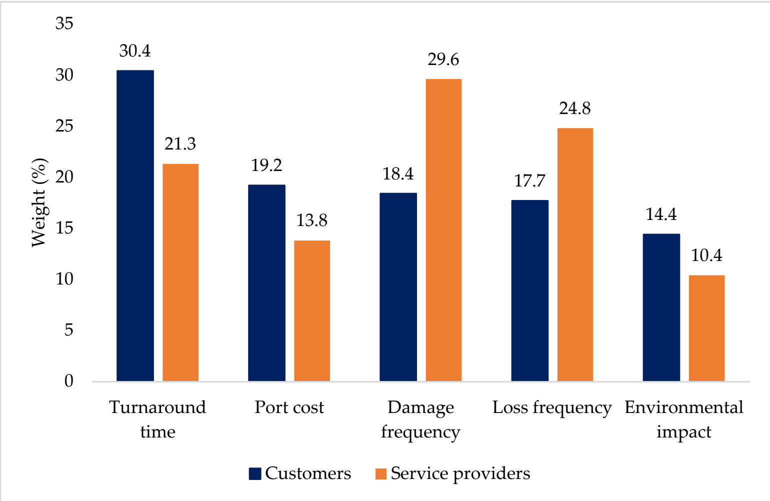

Figure 4. Weightings given by experts for operational dry port performance.

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.

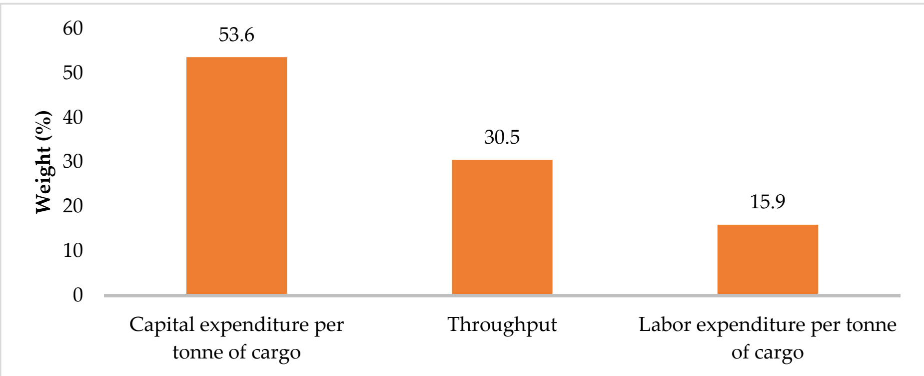

Figure 5. Weightings given by service providers for financial dry port performance.

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.

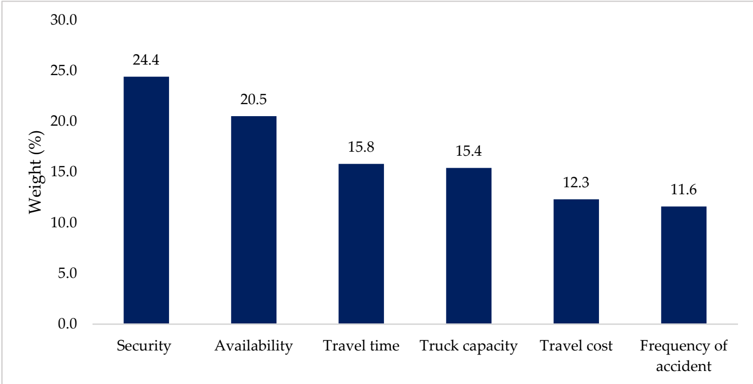

Figure 6. Weightings given by experts for transport performance.

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.

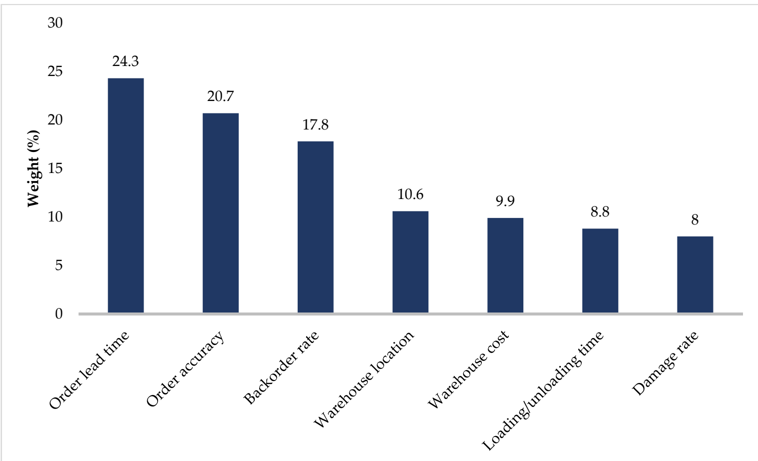

Figure 7. Weightings given by experts for warehouse performance.

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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The application of digital technologies in intermodal freight transport is growing in today's digital world. However, digitalization is slow in low-income countries. Through qualitative and quantitative studies, this thesis explored the potential benefits of digital technologies on intermodal freight transport (IFT) performance in Ethiopia. The empirical studies indicated that there are opportunities to leverage digital technologies to enhance the performance of intermodal freight transport. These insights may also be applicable to other low-income countries having similar IFT and technology contexts.

Helen Zewdie Kine received her graduate education from department of energy and technology at Swedish University of Agricultural Science. She holds a Master's of Science degree in Road and Transport engineering from Addis Ababa Institute of Technology, Ethiopia.

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