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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.

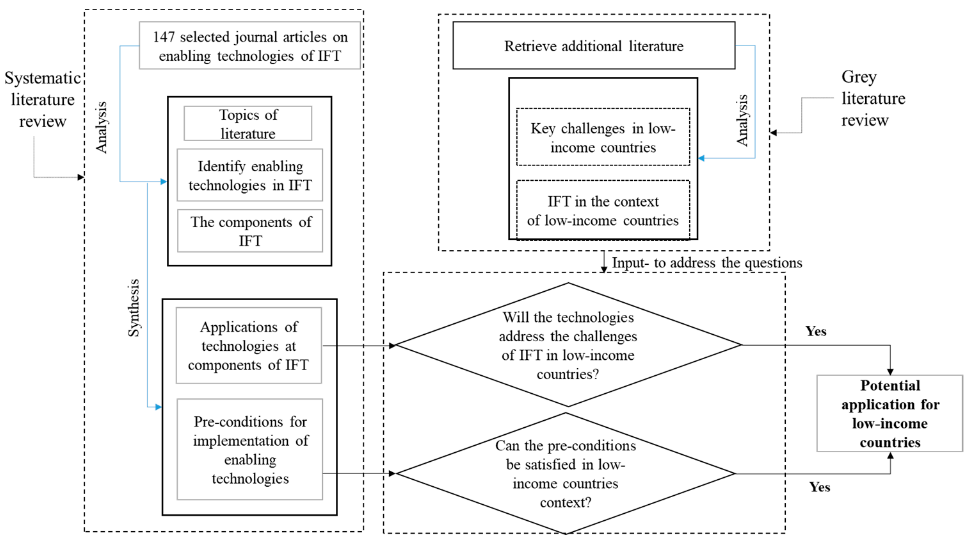

Figure 1. Overall research framework. Source: Authors' own elaboration.

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.

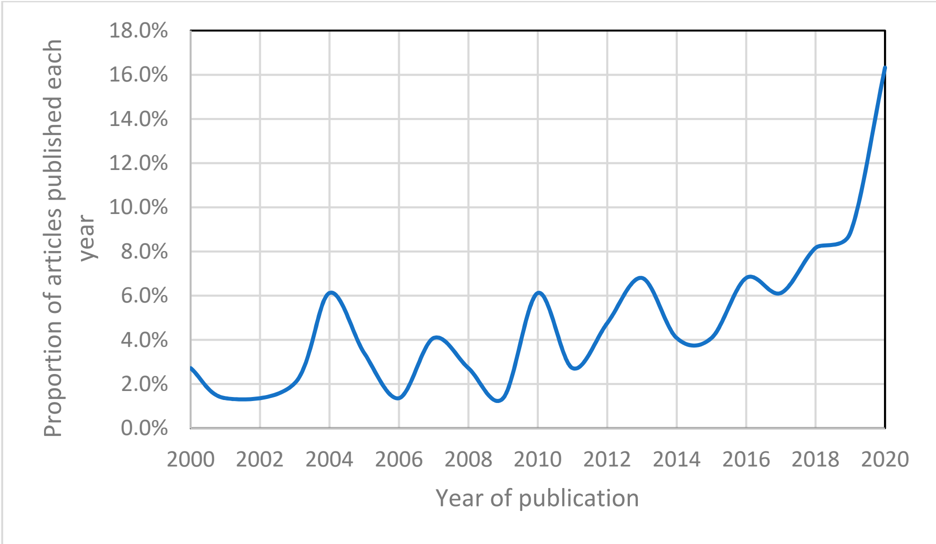

Figure 2. Distribution of articles identified from a systematic literature review over the years 2000–2020.

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

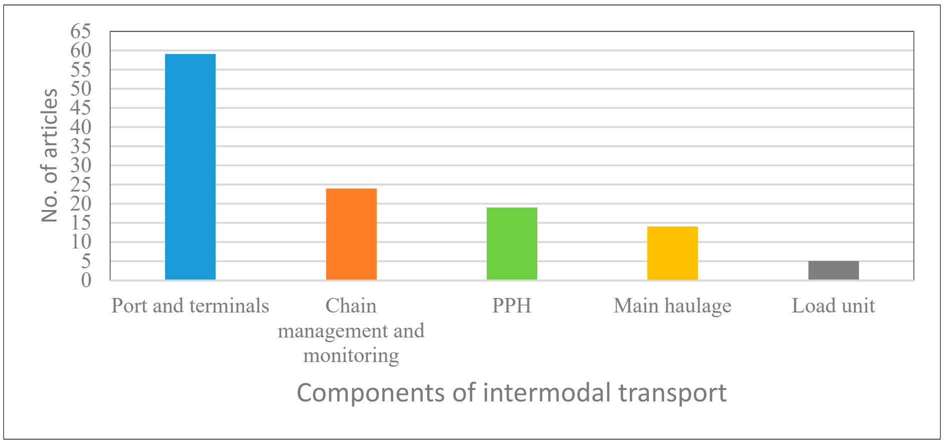

Figure 3. Components of intermodal transport discussed within the articles.

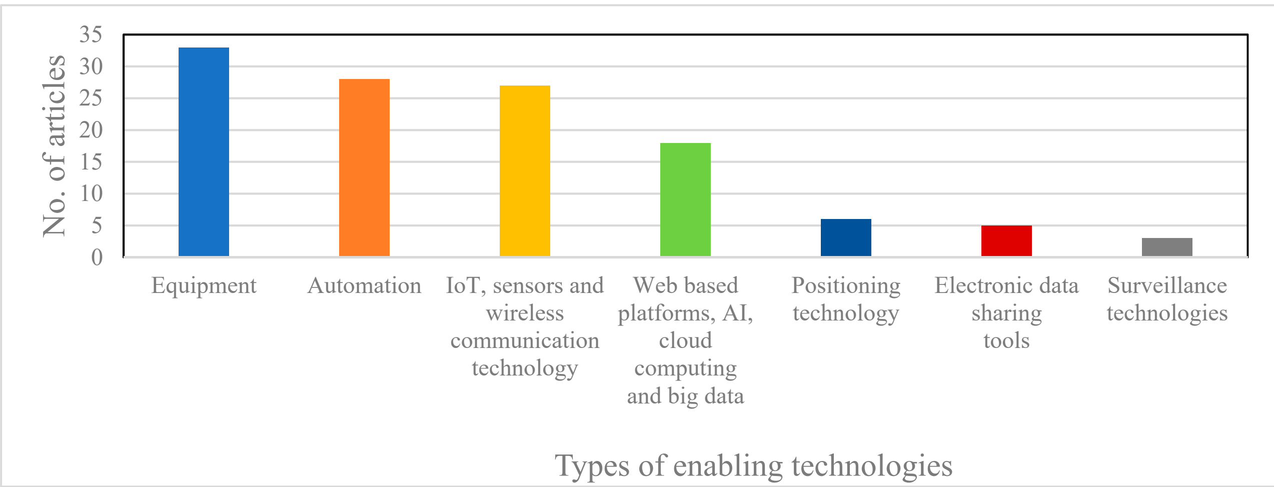

Figure 4. Enabling technologies applied in intermodal freight transport discussed with the articles.

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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