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Digitalization of the Letter of Credit Process: Implications for Business Performance in Trade Finance

Case Study

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ABSTRACT:
International trade processes remain largely manual and paper-based, leading to delays and additional costs for trading parties. The impact is pronounced in the complex ecosystem of trade finance, where the delivery of a single shipment involves multiple participants and entries. This case study examines the digitalization of the letter of credit process from the perspective of an exporting company, focusing on the impact on business efficiency. The study aims to identify potential solutions, the financial and operational impacts, and key obstacles. The primary data for the study consists of semi-structured interviews with representatives of the case company, banks, and freight forwarders. Secondary data includes the case company's system data and process observations. The data is analyzed using thematic and quantitative text analysis methods. Furthermore, the study utilizes scenario analysis based on Monte Carlo simulations to model the effects of electronic documents on the cost structure of the letter of credit process.

The results show that attitudes toward digitalization vary among stakeholders. According to regression analysis, positive sentiment among banks is strongly associated with discourse on digital adoption. The most promising solution for an exporting company is the adoption of electronic documents, and specifically the electronic bill of lading. These solutions eliminate the delays and additional work caused by physical documents, supporting the smooth flow of information between parties. Scenario analysis indicates that as the letter of credit process accelerates, the key benefit for the exporting company is realized through the earlier collection of accounts receivable. Moreover, internal and external integrations within the organization play a key role in enabling the adoption of various digital solutions and their seamless operation. Integrations foster system interoperability, information exchange between stakeholders, reduce duplication of work, and lay the foundation for broader automation. In the long term, automation and artificial intelligence will enhance operational efficiency in support processes, but their systematic utilization requires data standardization and technological maturity. The study shows that creating broad value in the trade finance ecosystem requires a common legal framework that enables data transfer, the harmonization of business data standards, and the commitment of the entire supply chain to digitalization.

KEYWORDS: letter of credit, trade finance, digitalization, electronic documentation, integration, operational efficiency, cash flow

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TIIVISTELMÄ:
Kansainväliset kauppaprosessit toimivat edelleen suurelta osin manuaalisesti ja paperipohjaisesti, mikä aiheuttaa viiveitä ja lisäkustannuksia kaupankäynnin osapuolille. Vaikutus on korostunut kaupan rahoituksen monimutkaisessa ekosysteemissä, jossa yksittäisen hyödykkeen toimitukseen liittyy useita eri toimijoita ja kirjauksia. Tämä tapaustutkimus tarkastelee remburssiprosessin digitalisaatiota viejäyrityksen näkökulmasta keskittyen liiketoiminnan tehokkuuteen kohdistuviin vaikutuksiin. Tutkimuksen tavoitteena on tunnistaa potentiaaliset ratkaisut, taloudelliset ja operatiiviset vaikutukset, sekä keskeiset esteet. Tutkimuksen ensisijaisena aineistona ovat puolistrukturoidut haastattelut tapausyrityksen, pankkien ja huolitsijoiden edustajien kanssa. Toissijaisena aineistona hyödynnetään tapausyrityksen järjestelmädataa ja havainnointia remburssiprosessin kulusta. Aineisto analysoidaan temaattisen ja kvantitatiivisen tekstianalyysin keinoin. Lisäksi tutkimuksessa hyödynnetään Monte Carlo -simulointeihin pohjautuvaa skenaarioanalyysiä, jonka avulla mallinnetaan sähköisten asiakirjojen vaikutuksia remburssiprosessin kustannusrakenteeseen.

Tulokset osoittavat, että suhtautuminen digitalisaatioon vaihtelee sidosryhmittäin. Regressioanalyysin mukaan pankkien positiivinen sentimentti on vahvasti yhteydessä digitalisaation omaksumiseen liittyvään diskurssiin. Viejäritykselle lupaavin ratkaisu on sähköisten asiakirjojen, ja erityisesti sähköisen konossementin käyttöönotto. Ratkaisut poistavat fyysisten asiakirjojen aiheuttamat viiveet ja ylimääräisen työn sekä tukevat osapuolten välistä sujuvaa tiedonkulkua. Skenaarioanalyysi osoittaa, että remburssiprosessin nopeutuessa keskeisin hyöty viejäritykselle realisoituu myyntisaatavien aikaisemman kotiuttamisen seurauksena. Lisäksi organisaation sisäiset ja ulkoiset integraatiot ovat avainasemassa mahdollistaessaan useiden digitaalisten ratkaisujen käyttöönoton ja sujuvan toiminnan. Integraatiot edistävät järjestelmien yhteensopivuutta, sidosryhmien välistä tiedonvaihtoa, vähentävät päällekkäistä työtä ja luovat perustan automaation laajemmalle hyödyntämiselle. Pitkällä aikavälillä automaatio ja tekoäly lisäävät tukiprosessien operatiivista tehokkuutta, mutta niiden systemaattinen hyödyntäminen edellyttää datan standardointia ja teknologioiden kypsymistä. Tutkimus osoittaa, että laajan arvon luominen kaupan rahoituksen ekosysteemissä vaatii datansiirron mahdollistavan yhteisen oikeudellisen kehyksen, yhtenäiset liiketoimintadatan standardit sekä koko toimitusketjun sitoutumisen digitalisaatioon.

AVAINSANAT: remburssi, kaupan rahoitus, digitalisaatio, sähköiset asiakirjat, integraatio, operatiivinen tehokkuus, kassavirta

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Abbreviations

ADE	Automated Document Examination
AI	Artificial Intelligence
API	Application Programming Interface
B/L	Bill of Lading
CIA	Cash-in-Advance
DC	Documentary Collection
DID	Decentralized Identifier
DLT	Distributed Ledger Technology
eB/L	Electronic Bill of Lading
eDocs	Electronic Documentation
eFTI	Electronic Freight Transport Information
ETR	Electronic Transferable Record
eUCP	Electronic Uniform Customs and Practice for Documentary Credits
FinTech	Financial Technology
ICC	International Chamber of Commerce
IoT	Internet of Things
KYC	Know-Your-Customer
L/C	Letter of Credit
MLETR	Model Law on Electronic Transferable Records
OA	Open Account
OCR	Optical Character Recognition
RPA	Robotic Process Automation
SME	Small and Medium-Sized Enterprises
TCT	Transaction Cost Theory
UCP	Uniform Customs and Practice for Documentary Credits
VC	Verifiable Credential
vLEI	Verifiable Legal Entity Identifier

1 Introduction

International trade accounts for a significant share of global gross domestic product and acts as a key indicator of economic performance. However, global trade contains inherently risky features related to the divergent objectives of importers and exporters. Trade finance aims to reconcile these interests, supporting 80-90% of world trade, according to WTO estimates (Hallaert, 2011). Despite the increased share of intra-firm transactions reducing this figure to some extent, trade finance remains a crucial component of global trade in today's markets.

The recent geopolitical tensions and financial stress have increased economic uncertainty, transaction costs, and limited access in trade finance (Demir & Javorcik, 2020). The Covid-19 pandemic further exposed structural issues by disrupting supply chains, reducing the availability of foreign trade instruments, and highlighting the vulnerability of paper-based instruments such as letters of credit (L/Cs) (Auboin, 2021). Traditional practices embedded in the instruments constitute significant inefficiencies, increasing the resources committed to a company's trade finance. From the exporter's perspective, the existing L/C process is intensive and slow, complicating effective cash management.

Digitalization has long been a priority in trade finance, yet little progress has been made due to technological limitations, lack of expertise, and insufficient legal frameworks and standardization. However, rapid technological advances combined with the recent disruptions have made digitalization more relevant than ever. Beyond providing companies with efficiency and improved working capital management, the shift to digital tools fosters transparency and compliance across supply chains, thus supporting corporate governance and sustainability objectives (Kim et al., 2022).

1.1 Background and Motivation

Trade finance comprises the instruments and financial services that facilitate and secure the global flow of commodities. As previously discussed, it plays an indispensable role as an enabler of global trade. Documentary trade, such as L/Cs, relies heavily on paper-based documentation and manual processes. It is evident that as trade volumes grow and supply chains become more complex, documentary-based trade finance will increasingly face constraints and delays that hamper the existing processes.

The typical challenges of bank-intermediated traditional trade finance arise particularly from inefficient processes. Manual and paper-based practices increase cost intensity by extending lead times and binding labor (ICC, 2020). Moreover, such processes increase risks, as the supply chain is not integrated or transparent, which exposes it to potential fraud. Another key challenge is information asymmetry, which causes financial friction and increases costs due to the trade finance premium driven by bank screening measures (Ahn, 2011). Other relevant challenges are related to the exposure to external value chain disruptions and the difficulty for small and medium-sized enterprises to participate in trade finance (ICC, 2020).

In response, several companies, financial institutions, and working groups have made efforts to promote a digital environment. The idea of paperless trade has been around for a long time, but it appears that recent events, innovations, and initiatives have brought the industry to the forefront of emerging opportunities. However, the end-to-end digitalization will require a considerable amount of standardization, resources, and commitment from various stakeholders (McKinsey & Company, 2021).

The case company for this commissioned thesis is a global manufacturer and exporter of industrial and technological products. The company's business is based on complex and valuable supply chains, where trade finance is an enabling component. The global dimension of operations underlines the need to manage trade fluidity and efficiency. Going forward, digitalization is a key consideration for a company whose activities and

operating environment rely heavily on efficient financing solutions. Hence, it is logical to examine the L/C process optimization from a digitalization perspective, particularly given the existing trade finance framework.

As stated, creating value broadly through digital tools in the trade finance ecosystem requires the commitment of most stakeholders. Consequently, the pursuit of holistic transition remains a relatively theoretical and unattainable objective from an individual company's perspective. However, it is significant to consider how and to what extent an individual company can contribute to digitalization incrementally, focusing on the implications of modernizing a given instrument or process. This approach and early adoption efforts will not only prepare the company for future opportunities but could yield direct operational gains in the present business environment.

Despite the recent advances in trade finance digitalization, there remain considerable research gaps in the body of literature. Most existing studies tend to focus on the phenomenon at the ecosystem level. Hence, the implications for an individual company are limited. Furthermore, the previous literature discusses individual technologies and discrete digital platforms, excluding most of the potential synergies and practical implications from the analysis. As such, there is a need for research that draws together key solutions, compares their feasibility and implications, and offers concrete insights into leveraging digitalization in export trade finance.

To address the research gap, practical guidelines are required to complement the existing theory and to evaluate the feasibility of digital tools at the company level. This study focuses on the L/C process due to its central role in global commerce. Moreover, the process involves multiple stages, stakeholders, and traditional practices, making it an ideal subject for examination in the context of digitalization. Dismantling the process into its subcomponents allows the identification of where digitalization can yield efficiency gains and how they are reflected in the exporter's operational activities.

1.2 Purpose of the Study

This study aims to investigate how the L/C process digitalization affects the business performance of the case company. The focus is on assessing the magnitude and the mechanisms by which digitalization affects process efficiency. This study recognizes the prerequisites and challenges of end-to-end digitalization, which is why partial process digitalization is a key consideration. By assessing the existing process, potential digital solutions, and the feasibility of implementation, the study seeks to provide insights that support managerial decision-making. In doing so, the study establishes both a company-specific perspective and a wider understanding of the transition towards digitalization.

Evaluating the current state of the case company's L/C process is essential for identifying opportunities for improvement. Typically, the process is cumbersome and can result in inefficiencies for a variety of reasons. First, the process involves multiple parties and interfaces, which often impede the seamless information flow. Second, the process is partially manual and paper-based, which prevents the seamless information flow between parties. Thirdly, reviewing terms and documentation is time-consuming, both for the counterparties and for the banks intermediating the transaction. Together, these factors contribute to additional costs and information asymmetry. An analysis of the current state will indicate which process components are acting as bottlenecks or are the most cost intensive. Identifying the challenges is key to the efficient allocation of resources. Hence, the first research question of the study is:

RQ 1: What are the most prominent inefficiencies in the L/C process?

After identifying the key constraints, the available technologies and solutions are analyzed in terms of feasibility and potential. This assessment is based on interviews with trade finance professionals and previous literature. The focus is on discovering both enabling technologies and more concrete, ready-to-implement solutions that can facilitate digitalization in practice. Accordingly, the second research question is:

RQ 2: What are the most potential digital solutions to address the identified process inefficiencies?

Since the L/C process digitalization is explored from a company perspective, it is crucial to consider how the implementation of digital tools can enhance overall business performance. In this study, business performance is reflected through operational efficiency and cash flow improvements. The analysis therefore focuses on inputs such as costs and labor, and outputs such as process speed and liquidity effects. Given this background, the third research question is:

RQ 3: To what extent and through which mechanisms can the L/C process digitalization affect business performance?

Besides exploring the feasibility of available digital solutions, this study looks at the barriers to the L/C digitalization. It is widely recognized that trade finance encounters various constraints to process and instrument innovation. Some of the challenges are based on established policies and some are due to external factors such as jurisdiction or technology scalability (ICC, 2024). Thus, this study attempts to identify the main challenges facing the exporting company in the digital transition and whether the company can contribute to alleviating them. This is addressed through the following research question:

RQ 4: What are the main obstacles and limitations to digitalization?

Through the research questions, this study aims to provide insights into the digitalization of corporate trade finance. Although the topic is highly relevant for global commerce, relatively little research is available on the subject due to insufficient data and initiatives. So far, progress has been largely driven by banks and financial technology providers through their investments and innovation in digital trade finance, while businesses have tended to lag (Deutsche Bank, 2024). A key explanation for this lies in uncertainty and the limited scope of existing solutions, which have constrained the adoption.

To conclude, this study aims to capture the key factors that increase costs and disrupt corporate trade finance. Concurrently, the study seeks to understand how, and which digital solutions can enhance a company's operational efficiency. By addressing the existing research gap, this study aims to provide an overview of the L/C process digitalization and further analyze the achievable benefits. Moreover, this study aspires to produce practical recommendations for the case company. By identifying key technologies that drive cost-effectiveness and compliance, the findings can aid firms in innovating and deploying digital solutions to support their trade finance functions.

This study consists of eight main chapters. The introduction is followed by a theoretical framework that discusses the role, structure, and theory of trade finance. The literature review in chapter three complements the theoretical framework and identifies the research gap. The subsequent data section describes the research data, which consists of twelve semi-structured interviews. Chapter five outlines the methodology, covering the research design, the mixed-methods approach, and the reliability and validity of this study. Chapter six presents the results of the study, and the discussion in chapter seven interprets the key findings in relation to previous literature. Finally, the conclusion summarizes the key findings, managerial implications, and opportunities for further research.

2 Theoretical Framework

This theoretical framework outlines the fundamental characteristics, structure, and underpinning theories of trade finance. It discusses trade finance's function as an enabler of global trade. The focus of the review is on key theories that underpin trade finance concepts and trade-offs. Moreover, the section aims to reflect on the objectives and challenges of trade finance, which this study seeks to address through digitalization.

2.1 Structure of Trade Finance

International trade refers to the exchange of goods or services across borders. As suggested by the model of comparative advantage, it is a key driver of global economic growth. However, it involves risks and costs arising from the risk allocation dilemma (Schmidt-Eisenlohr, 2013). Exporters face the possibility of non-payment, while importers must account for delivery disruptions. These concerns mainly arise from information asymmetry, currency risk, country risk, and transport risk. Exchanging parties must negotiate the trade-off between financing costs and contractual environments to effectively finance trade through available payment contracts. For exporters, the time gap from production to payment creates working capital challenges, making trade finance crucial to secure liquidity and counterparty commitment (Hoefele et al., 2013).

The trade finance market can be divided into bank-intermediated and interfirm trade credit markets (ADB, 2019). Bank-intermediated trade finance refers to commerce in which banks facilitate the transaction. Conversely, in trade credit transactions, exporters and importers extend credit to each other, with payments being made either in advance or after delivery of the goods. The trading participants are free to negotiate payment terms that subsequently affect how the risk is allocated between them. In international trade, this trade-off is crucial as beyond company attributes, the differing financial and legal environments have a significant impact on the payment contract choice and the implications of the underlying trade (Hoefele et al., 2013).

Trade finance payment methods can be classified into four categories. Trade credit transactions include open account (OA) and cash-in-advance (CIA), while bank-intermediated trade finance includes letter of credit (L/C) and documentary collection (DC) (Niepmann & Schmidt-Eisenlohr, 2017). L/C is the most standardized form of bank-intermediated trade finance (ADB, 2019; Garralda & Vasishtha, 2019). L/C is based on the issuing bank guaranteeing an agreed payment to the exporter upon delivery of the goods. The parties negotiate the terms and content, whereupon the importer initiates the process by requesting its bank to issue the L/C (Niepmann & Schmidt-Eisenlohr, 2017). The issuing bank sends the L/C to the confirming bank, who advises it to the exporter. Once the goods are shipped, the exporter presents the required documents to its bank, which forwards them to the issuing bank for examination. Provided the documents are compliant, the issuing bank hands them over to the importer and makes payment to the exporter, allowing the importer to claim the ownership of the goods against the documentation.

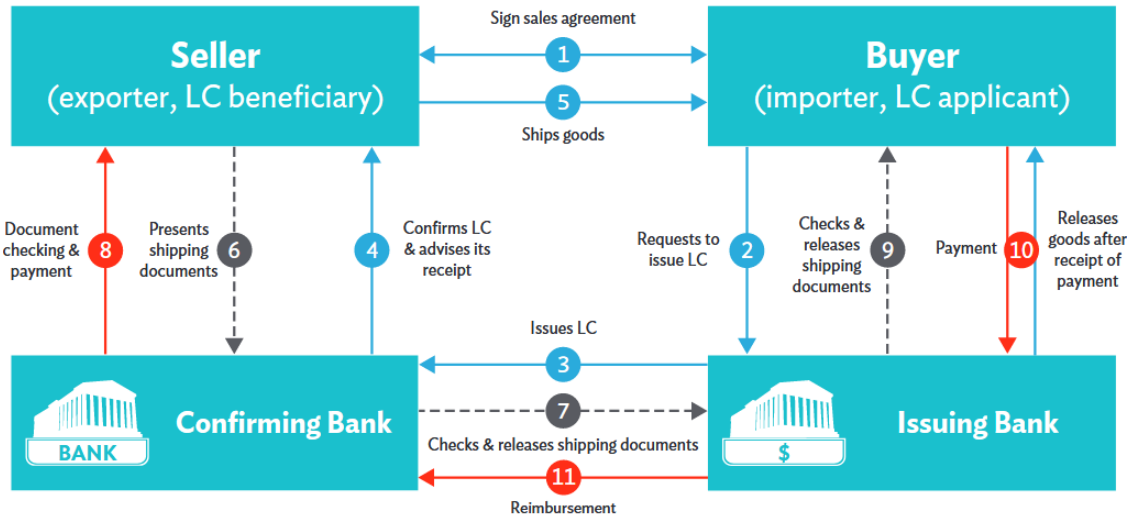

Figure 1. Confirmed L/C process (ADB, 2019).

However, should the supplier consider the risk of non-payment, it can request its bank to confirm the L/C. Under this arrangement, the confirming bank guarantees payment to the supplier if the issuing bank defaults (Ahn, 2011). Confirming the L/C reduces the

risk for the supplier, although it increases costs (Niepmann & Schmidt-Eisenlohr, 2017). Typically, confirmation is considered when the issuing bank's credit rating is not high or the country's political or economic environment is unstable. Although an unconfirmed L/C is a secure instrument, external factors can jeopardize the payment.

Due to the asymmetry of the screening tests banks perform, L/Cs are exclusively employed in global commerce (Ahn, 2011). Moreover, L/Cs are predominantly used in large transactions, where their capacity to mitigate payment risk justifies the relatively high fixed costs associated with their use (Niepmann & Eisenlohr, 2017). L/C balances the transaction risk between partners, while OA and CIA tilt the risk distribution towards the other party. The selection of the payment contract is influenced by the degree to which the contract can be enforced effectively in the buyer's country (Niepmann & Schmidt-Eisenlohr, 2017). L/Cs are typically employed in countries where contract enforcement is moderate given the country's legal system and economic environment. When contract enforcement in the destination country is strong and the perceived overall risk is low, L/Cs create unnecessary costs where the exporter could bear the risk.

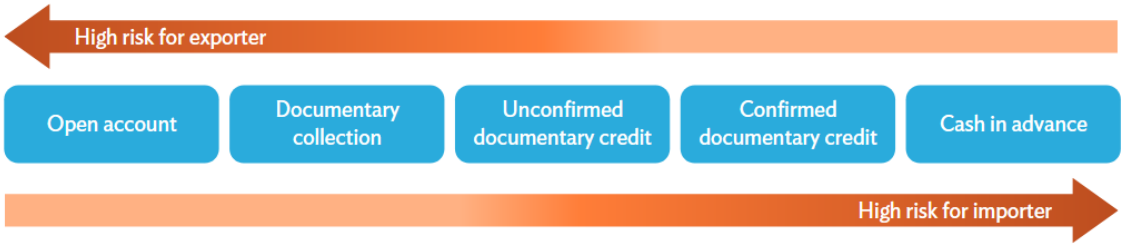

Figure 2. Distribution of risk by transaction type (ADB, 2019).

Typical problem in the trade finance market is the under-supply of solutions, especially in the lower market segment (Auboin & DiCaprio, 2017). Small and medium-sized enterprises (SMEs) have difficulty accessing trade finance due to a mismatch between market supply and demand. SMEs experience an undersupply specifically due to banks' costly interest rates and screening (Stiglitz & Weiss, 1981). The issue is more pronounced in emerging markets with scarce liquidity. Kim et al. (2021) argue that under traditional

banking arrangements, SMEs are often required to provide additional collateral to access trade finance. They find that SMEs face up to 40% of trade finance rejections. This reflects the need to modernize trade finance processes to create a more efficient and symmetric market. Today, it is very challenging for liquidity-constrained firms to benefit from the synergies of global supply chains (Auboin & DiCaprio, 2017).

The trade finance participants can be divided into providers and users. Since these parties tend to have different objectives, trade-offs are negotiated to determine the optimal payment contract (Malaket, 2014). To improve liquidity, the exporter prefers to receive payment promptly, while the importer prefers to delay its obligation. The providers facilitate international trade by providing credit and reducing risks. Beyond facilitating trade, the primary objective of banks is to generate returns from their lending activities and related services. Ahn (2011) suggests that banks perform costly screening tests to assess counterparty default risk. In the presence of asymmetric information, screening introduces a trade finance premium, which makes foreign trade relatively costly. The main challenges for global banks in extending credit and serving trade finance needs relate to anti-money laundering (AML) and know-your-customer (KYC) due diligence requirements (Kim et al., 2022; ICC, 2017). Strict regulation increases the intensity and complexity of screening activities, leading to higher transaction costs (Kim et al., 2022).

The ecosystem also involves middlemen such as freight forwarders and insurance companies (Bhogal & Trivedi, 2019). A forwarder is a logistics operator who is responsible for organizing the transportation of goods. Furthermore, a domestic firm's export business can be assisted by an export credit agency (ECA), which is a government-backed financial institution providing a wide range of financial and insurance solutions to support export operations (Malaket, 2014). Beyond the actual participants, trade finance relies on regulatory bodies and working groups that define the guidelines and standards. Moreover, the ecosystem encompasses a wide range of other players, including logistics providers, customs, and government agents (ICC, 2024).

Furthermore, trade finance revolves around documentation (Deutsche Bank, 2024). Documentation enables the flow of foreign trade by defining and securing the juridical positions of the parties involved. Some documents guarantee payment or contractual obligations, while others specify delivery terms or verify the delivery of goods. In an L/C transaction, the payment obligation is based exclusively on the L/C conditions, irrespective of the underlying sales contract (Crozet et al., 2022). In practice, the bank is obligated to pay once the presented documents comply with the L/C conditions and has no duty to examine the goods or contractual arrangements.

The documentation can be classified into four categories: commercial, transport, regulatory, and financial process documentation (ICC, 2024; UNECE, 2019). The standard documents are the invoice, transport document, packing list, insurance certificate, and certificate of origin. Traditionally, various documents are presented in original, paper form (Barnes & Byrne, 2001). This is due to entrenched practices, slowly evolving regulation, and the difficulty of ensuring interoperability of global interfaces (ICC, 2024). Paper-based processes are slow, costly, and prone to errors (Deutsche Bank, 2024). The Covid-19 pandemic reflected the issues of existing procedures by disrupting the transfer of documents (Auboin, 2021). However, ICC (2024) notes that many key trade documents already have electronic versions available or under development, but widespread adoption requires progress in interoperability, regulation, and industry engagement.

Finally, trade finance operates under legal frameworks and international rules ensuring legal certainty and cross-jurisdictional interoperability. The ICC's Uniform Customs and Practice for Documentary Credits (UCP) governs the global use of L/Cs, applying whenever explicitly incorporated into the credit. In recent years, legislation has become increasingly important in enabling electronic documentation. The UNCITRAL Model Law on Electronic Transferable Records (MLETR) provides the legal basis for using electronic transferable records (ETRs) in domestic and cross-border trade (UNCITRAL, 2018). ETRs are digital equivalents of transferable documents such as bills of lading (B/Ls) and promissory notes. Similarly, the European Union's electronic freight transport information

(eFTI) regulation harmonizes the management of electronic transport information in member states, aiming to strengthen interoperability digital commerce (European Parliament & Council, 2020). Moreover, the ICC has published an electronic version of the UCP (eUCP), to adapt the rules to digital trade (ICC, 2023c).

Over the past decades, financial sector reforms have indirectly influenced the availability of trade finance. The Basel III framework, introduced in response to the 2008 financial crisis, established stricter capital and liquidity requirements to strengthen risk management, regulatory coherence, and financial stability (Auboin & Blengini, 2014). Given the sensitivity of trade finance to financial fluctuations, these reforms were beneficial in enhancing stability and risk management (Kim et al., 2021). However, Auboin and Blengini (2014) suggest that the reformed leverage ratio may have reduced the availability of trade finance. The leverage ratio does not reflect the risk weighting of the loans but requires banks to hold a certain amount of assets relative to total assets, which could limit the incentive for banks to utilize L/C financing.

2.2 Theory of Trade Finance

This section discusses the key theories that underlie the fundamental nature of trade finance. The section addresses topics including the incurrence and allocation of costs relative to risk, the unequal distribution of information, and the diffusion of technological innovation across the market. Together, these themes seek to identify the factors that drive trade-offs and the application of L/Cs in trade finance. Ultimately, the given theories provide a foundation for this thesis to analyze the potential of digital technologies within the L/C process framework.

2.2.1 Transaction Cost Theory

Trade finance premium largely consists of perceived risks and transaction costs (Ahn, 2011). Transaction cost theory (TCT) predicts that organizations select governance structures to maximize transaction performance and minimize costs (Cuypers et al., 2021). TCT implies that transactions always incur costs. In this study, the theory helps to conceptualize the cost structure of the L/C process. TCT is grounded in bounded rationality and opportunism, implying that firms face limited information and actors pursuing self-interest (Cuypers et al., 2021). The theory suggests that transactions are organized primarily based on asset specificity, frequency, and uncertainty. Asset specificity states that the more specifically the resources are designed for a particular transaction, the more problematic their use in a different context will be. Frequency refers to the recurrence of a transaction. Frequently repeated transactions result in higher costs, and vice versa. Uncertainty refers to a lack of trust between the parties, which increases expenses.

The above factors indicate the governance mechanisms to which transactions are allocated. Governance mechanisms are how firms manage their transactions. According to Williamson's (1979) TCT framework, there are three governance mechanisms: markets, hierarchies, and hybrids. Market governance is the main mechanism for non-specific transactions in which the parties act independently and under market conditions. If the exchange is linear and does not involve significant uncertainty, the market structure is an efficient way to operate. Hierarchy is a mechanism in which the authority firm controls the flow of the value chain (Cuypers et al., 2021). The hierarchy allows the company to manage risk more effectively and is also the most cost-effective solution for specific transactions. A hybrid is a mechanism that combines features of a market and a hierarchy mechanism (Williamson, 1979; Cuypers et al., 2021). In cases where resources are partially specific, the hybrid mechanism mitigates opportunism through contracts and cooperation. L/C is a hybrid mechanism transaction where financial institutions act as intermediaries, reducing the riskiness of the transaction.

L/C preparation requires specific investments. Due to the specificity of the costs, the company cannot rely solely on a market-based transaction mechanism but seeks to ensure the flow of the transaction through contracting, alliances, and third parties (Cuypers et al., 2021). The process incurs costs specifically in terms of manual work, document verification, and bank charges (Ahn, 2011). Moreover, the parties to foreign trade are exposed to uncertainties, which contributes to it being governed by a hybrid mechanism specifically in intermediate-risk countries (Niepmann & Schmidt-Eisenlohr, 2017). L/Cs are typically employed in relatively less frequent transactions, where sufficient trust in the counterparty is absent. Thus, the optimal choice for firms is to use the bank's contractual environment to execute the transaction (Ahn, 2011). Although this approach incurs costs, it tends to be a necessary trade-off to secure the underlying contract.

Within the TCT framework, three factors have the potential to reshape the current structure. First, electronic systems can make data exchange and resource allocation more cost-efficient (Egelund-Müller et al., 2017). Second, digital platforms and solutions can contribute to reducing opportunism by increasing information symmetry, trust, and transparency (Kowalski et al., 2021). Finally, Cai (2018) suggests that digitalization can shift the L/C process towards a more market-based one, as technologies reshape the intermediary role of financial institutions. She argues that disintermediation could be possible in some areas of finance, although it is unlikely that emerging technologies will entirely displace traditional intermediaries.

2.2.2 Information Asymmetry

In international markets, information asymmetry refers to a situation where sellers have more information than buyers about the quality of products (Potoski & Prakash, 2009). This hinders trade, as buyers' transaction costs increase when assessing the quality of suppliers. Akerlof (1970) refers to this phenomenon as the lemons market. He argues that information asymmetry creates a contradiction where the total volume of trade decreases as buyers fail to identify the quality of products relative to their price. This

reduces market efficiency by depressing the exchange of quality products and the import opportunities. The characteristics of global commerce impose trade barriers that limit the ability of producers to signal product quality (Potoski & Prakash, 2009). This dilemma is pronounced in developing countries, where the country-of-origin stigma undermines a firm's credibility solely on the grounds of general market assumptions concerning a particular country or continent (Akerlof, 1970).

Lee et al. (2020) address the role of asymmetric information in bank-intermediated trade finance, proposing two forms of information friction. Ex-post information opacity refers to a bank's difficulty in receiving real-time information about the trade process, hampering efficient decision-making and imposing additional costs. By ex-ante information asymmetry, they refer to exporters having more comprehensive information than banks about the transaction, leading to increased trade finance premiums. Lee et al. (2020) suggest that the information gap in trade finance leads to a decline in aggregate trade volume. Without sufficient transparency, a bank may refuse a transaction it perceives as too risky. They suggest that financial technology (FinTech) solutions can ease information friction to a considerable degree. Digitalizing key trade documents accelerates the process lead time, streamlining bank-intermediated trade finance. Furthermore, solutions leveraging artificial intelligence (AI) facilitate information asymmetry through alternative credit systems and improved KYC measures for banking institutions (ADB, 2019).

2.2.3 Technology Diffusion

Technology diffusion is a theory explaining how an innovation eventually reaches the end user (Zhou et al., 2023). The theory describes how and at which rate innovation is spread among users. The process is characterized by a cumulative S-shaped diffusion curve, demonstrating how an innovation is adopted over time. Digital technology diffusion has unique characteristics, and the process is more complex than for traditional technologies (Nicoletti et al., 2020). Consequently, the adoption of novel technologies requires deeper knowledge and policy adaptation to intangible modes of production.

Rogers (2003) identifies five categories of technology adopters, shown in Figure 3. He suggests that innovators and early adopters can gain a competitive advantage by being first to market. Early investment enables early technology development and optimization, which contributes to long-term cost savings before the technology diffuses and increases in cost. Conversely, large initial investments and uncertain expected returns disincentivize most companies from adopting technologies at a very early stage. Limited resources, lack of ability, or weak market incentives are determinants of late technology adoption in a firm (Rogers, 2003; Nicoletti et al., 2020). By being a late adopter, a firm can effectively lower initial investment costs, technical difficulties, and legal hurdles.

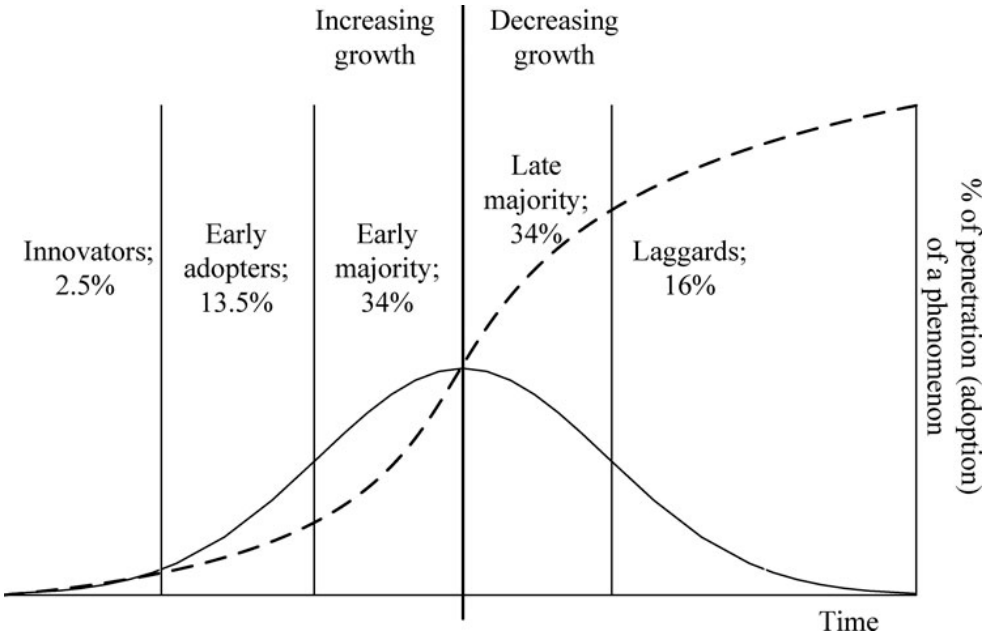

Figure 3. Technology diffusion over time (Dolnicar et al., 2014, based on Rogers, 2003).

The diffusion of digital technologies is not restricted to specific technology but rather relies on cross-industry technology synergies (Zhou et al., 2023). Digital technology diffusion holds the potential to reshape business models and create value through new means in global supply chains. However, implementing new technologies requires firms to invest increasingly in intangible capital such as management and information technology (IT) skills to ensure an efficient transition (Nicoletti et al., 2020).

Larger firms have a better ability to adopt digital technologies, as they have more cumulative knowledge and stronger capabilities (Cho et al., 2023). Moreover, a firm's R&D effort positively correlates with adopting emerging technologies. There is evidence that foreign-owned firms tend to exploit technology more effectively due to the spillover effects, allowing them to leverage cumulative knowledge across the organization. Nicoletti et al. (2020) indicate that establishing a framework to support the diffusion is not sufficient where market incentives or opportunities are limited. They suggest that technology diffusion is successful when markets do not constrain firms' participation, competition is sufficient, and firms have access to private equity.

2.3 Foundations for Digital Trade Finance

Trade finance has lagged behind digital developments due to traditional practices and limited standardization (Kim et al., 2022). According to the ICC (2020), 61% of banks consider internal technical or financial capabilities as a critical barrier to digitalization, while 51% agree that both regulatory and customer needs are the main barriers to implementing new technologies. For businesses, the main barriers are the multiplicity of platforms, insufficient information, and a lack of technical expertise (Kim et al., 2021). However, the industry's broader outlook reflects a growing interest and need to digitalize, particularly motivated by the aftermath of the Covid-19 pandemic. Banks, FinTechs, and large multinational organizations have allocated resources to digitalization, giving rise to numerous new initiatives (ICC, 2023a; ADB, 2019). Moreover, advances in the regulatory environment have supported the transition. In particular, the implementation of the MLETR accelerates the adoption of ETRs domestically and across borders.

2.3.1 Digital Trust

As supply chains become more digital, companies face the challenge of verifying the counterparty's identity in the digital environment. A digital identity is an electronic representation of information about a specific object (WTO, 2022). It enables automated and secure authentication, forming the foundation for many emerging solutions. ICC (2023b) argues that in the future, each transaction should be verifiable, traceable, and auditable. Digital identity provides a foundation for interoperability by enabling reliable authentication and authorization in an electronic environment. Digital identities are expected to replace traditional methods of signing contracts and verifying data. One key enabler is the digital signature, which is an electronic authentication tool ensuring message integrity and sender authenticity (WTO, 2022). Alsheyab (2025) argues that digital signatures are the primary method for authenticating ETRs and securing documents.

To promote adoption of digital identity, the World Wide Web Consortium (W3C) has introduced Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs), which enable the electronic validation of any subject's identity (WTO, 2022). A key feature of this technology is selective disclosure, enabling credential holders to share only specific parts of their data with different parties. DIDs enable cryptographically secured identities without a centralized entity, allowing holders to verify credentials autonomously (ICC, 2023b).

Moreover, the Global Legal Entity Identifier Foundation (GLEIF) has developed the Verifiable Legal Entity Identifier (vLEI), to digitally identify organizations by their legal identity and connect them to the VC system (Wolf, 2023). The vLEI is based on the traditional LEI while providing a cryptographic layer that enables secure and efficient verification of corporate identity and credentials. It can be linked to a DID, allowing companies to use it without relying on central authority. This enhances decision-making and facilitates more effective risk management in trade (Rowley, 2024). According to Wolf (2023), vLEIs can be widely applied to a company's digital processes where identity validation is required. Within the L/C process, vLEI enables a standardized approach to digitally identify stakeholders, resulting in accelerated data flow and secure verification processes.

2.3.2 Key Enabling Technologies and Specific Solutions

Building on Patel and Ganne's (2021) approach, the enabling technologies are categorized by function into infrastructure, data input, connectivity, and analytical technologies. As illustrated in Table 1, each category corresponds to a specific layer within the technological stack, where the lower layers provide a technical foundation for those above. This framework clarifies the role and interdependence of these technologies in the L/C process digitalization, emphasizing their synergies within the ecosystem. The following literature review will further discuss practical applications and empirical findings.

Layer	**Key Enabling Technologies**	
Analyticity	AI	Big Data Analytics
Connectivity	API	DLT
Data Input	IoT	
Infrastructure	Cloud Computing	

Table 1. Layers of enabling technologies (adapted from Patel & Ganne, 2021).

From an organizational perspective, cloud computing offers a scalable digital infrastructure, providing access to flexible IT resources such as applications, servers, or storage, over the internet (Gangwar & Date, 2016). These services are powered by third-party infrastructure that companies can lease to facilitate their business activities. On the data input layer, the Internet of Things (IoT) is a key technology for digitalizing the L/C and supply chains. It is a global network of devices where physical objects, such as sensors, collect data, enabling the devices to interact with each other independently (Lee & Lee, 2015). IoT yields its greatest value when intercommunicating devices are embedded into business intelligence and inventory systems. As shown in Table 1, cloud computing is a core supporting technology that enables the seamless operation of IoT by delivering agility, infrastructure, and cost efficiency (Sousa, 2018).

According to Larson (2018), IoT is a key enabler in transforming the L/C process into a trustless system operating on predefined conditions. Moreover, AI and distributed ledger technology (DLT) are frequently highlighted in connection with IoT, given their potential synergies (WTO, 2022). Enabling technologies typically require mutual interaction to harness their true value in supply chains. This holds particularly true for IoT, as the data it generates requires sufficient digital infrastructure and further refinement to enable the information to guide organizational decision-making.

Application programming interfaces (APIs) enable digital communication between software systems across a network (Wang, 2023). They can be used to integrate an organization's systems and data flows or to connect business partners and harmonize supply chain information (Zachariadis & Ozcan, 2017). APIs are typically categorized as open or private. Private interfaces facilitate an organization's workflow by increasing productivity and transparency of data flow. In contrast, open APIs share a limited amount of data but are accessible to external stakeholders (Wang, 2023; Carr & Ramezani, 2022). A key incentive for adopting open APIs lies in the added value created by third parties, who can develop complementary components that enhance processes across the supply chain.

Another connectivity component is DLT, which is a distributed logbook where information is stored and available to all participants (Egelund-Müller et al., 2017). Operating without central control, it uses cryptographic protocols to add data in immutable chains, which ensures that records cannot be altered without the approval of all network participants. DLT enables transparent consensus among stakeholders without requiring prior mutual trust. Blockchain technology is the most well-known application of DLT. It cryptographically stores transactions in time-stamped blocks (Chang et al., 2019a). Each block contains database information used to validate transactions and create the following blocks. This structure makes the blockchain explicitly immutable. The database information is distributed among all nodes through consensus mechanisms such as Proof of Work. Moreover, blockchain is among the most researched technological applications for financial digitalization, underpinning most of the platform solutions in trade finance.

The fourth layer of the technology stack provides analytical capabilities for a company. It encompasses AI and big data analytics, which are closely interrelated. Big data provides AI with rich data to develop algorithms, and AI supports big data with efficient data analysis (Curry et al., 2022). AI is defined as advanced computer programs that are exploited to perform tasks or solve problems that would typically require human presence (Jones, 2023). AI can work through vast volumes of data and learn from the detected patterns. Big data analytics refers to massive amounts of data collected and analyzed efficiently through advanced techniques (Curry et al., 2022). These datasets are typically too complex and high-volume for traditional computing systems. However, modern technologies can extract insights from them for decision-making optimization.

Furthermore, several digital applications have been developed to support the L/C digitalization. Most of the solutions are built on the enabling technologies previously introduced. The specific solutions represent practical, deployable tools that address the core challenges by facilitating business workflows. As shown in Table 2, this study classifies the solutions into three functional categories: electronic documentation, process automation, and platforms. The remainder of this section examines the technical aspects of the solutions, along with the prerequisites and implications of their adoption.

Electronic Documentation	**Process Automation**	**Platforms**
eDocs & ETRs	OCR ADE Smart Contracts	L/C Platforms Single Window

Table 2. Categories of specific solutions.

Shift to electronic documentation is a cornerstone of digitalization, promoting supply chain integration, document integrity, and operational efficiency (Alsheyab, 2025; ICC, 2024). Maritime transport accounts for roughly 80% of world trade, explaining the prominence of electronic bill of lading (eB/L) in academic and industry discussions (Dubovec, 2006). Most eB/L initiatives have relied on closed platforms managed by intermediaries (Takahashi, 2016). Hence, the solutions have only been accessible to platform members,

limiting the scalability. Equally, there has been limited success in attempting to replace the B/L with the sea waybill, which acts as proof of carriage and receipt (Abdellatif, 2020). The issue is that the sea waybill is non-negotiable, implying that the transfer of ownership of the commodity cannot be made against endorsement. Therefore, the sea waybill is not eligible as a security or financial instrument, as the buyer can claim the delivered goods without the bank's document-based approval.

Moreover, automation technologies offer opportunities to streamline the process. Standard optical character recognition (OCR) is a technology that converts printed or scanned files into machine-readable formats, acting as a bridge between manual procedures and emerging technologies. Where L/C requires paper-based documentation processing, OCR can be a simple but valuable solution to reduce manual data entry and potential errors. As the dependence on paper persists, OCR enables a modern way of managing unstructured data (Patel & Ganne, 2021). According to ICC (2020), 28% of banks use OCR for digital trade finance. Automated documentation examination (ADE) refers to the complete or partial automation of the L/C process enabled by various technologies. Drawing on previous literature, most ADE solutions are driven by AI, OCR, or robotic process automation (RPA) technologies.

ICC (2021) distinguishes six levels of ADE for documentary credits. Levels one and two are based on basic automation, where solutions such as scanning, OCR, and RPA are utilized. This level of automation enables the reading of structured SWIFT MT700 messages, performing basic document matching, and extracting individual information from data fields. At these levels, the required human presence remains high. At level three, human presence takes on a more supervisory role, and the automation is driven by advanced technologies such as analytics, machine learning (ML), and natural language processing (NLP). Partial ADE begins to offer real value to an exporter. The advanced solutions distinguish document requirements and non-literally analyze conditions.

At levels four and five, the process is virtually fully automated, with human interaction required only in exceptional instances (ICC, 2021). The process integrates deep learning (DL), enabling the review of conditions against the UCP rules and the identification of inconsistencies between documents. Achieving merely a partial ADE reduces labor costs and allows efficient allocation of human resources. Furthermore, the shift reduces operational costs by increasing the ability to process higher L/C volumes. ICC (2021) underlines that the core challenge for automating the L/C process is paper-based documentation with non-standardized and unstructured data. However, they argue that standardization is not a necessity for more advanced technologies. Advanced AI solutions can extract and analyze data from a wide variety of sources. Nevertheless, this raises the question of what level of automation is potentially achievable within the existing ecosystem.

The third component of process automation, a smart contract, is a programmed protocol stored in a blockchain that automatically executes and updates the process state once predefined criteria are met (Toorajipour et al., 2022). Smart contracts offer great value to the L/C in cases where sufficient digital data is available and utilized. Today, the transmission of paper documents extends the process duration by several days, whereas a smart contract can validate events and update the process workflow in a matter of minutes. Furthermore, a smart contract can contribute to the security of the transaction and to fostering trust between the participants, specifically due to the immutable nature of the blockchain (Chang et al., 2019a).

Finally, platforms are digital systems or interfaces that streamline the L/C process by connecting stakeholders, reducing the dependence on paper, and automating the workflow. The platforms foster communication among participants and may enable real-time tracking of events. L/C platforms enable efficient management and processing of transactions, while single window is a national-level system that facilitates cross-border trade at the ecosystem level. It aims to coordinate activities such as customs clearance and facilitate interaction between traders, transporters, and authorities.

3 Literature Review

This section reviews prior literature on the L/C process digitalization by summarizing key perspectives and empirical findings. It aims to strengthen the study's theoretical basis by merging and analyzing the main contributions related to the digital transformation of trade finance. While previous research has examined the potential benefits and limitations of technological solutions, there are few findings available on the practical implications of digitalization for the business performance of export companies.

Despite the limited number of initiatives, prior research has provided some evidence of the benefits of digital solutions. González et al. (2023) examine the quantitative impact of digital trading practices on transaction costs by using a structural gravity model and statistics describing the development of digitalization. They find that the digitalization of trade processes reduces transaction costs, increasing both the company's domestic and foreign trade. Furthermore, their findings suggest that the leap to digital procedures has a statistically positive effect in all industries. Kim et al. (2022) provide similar findings on the digitalization of corporate trade finance. They argue that the adoption of digital processes can further improve transparency and traceability of operations in global supply chains, which is vital in times of economic uncertainty. This reduces the risks for companies engaging in cross-border trade and facilitates access to trade finance instruments.

Zhou and Li (2023) investigate the impact of a company's digital transition on its trade credit financing. They find that by digitizing trading processes, companies can reduce their dependence on financial intermediaries and raise the ceiling for attaining bank credit, which reduces trade credit finance in the overall picture. The negative correlation is strongest for companies that are large, face intense competition, allocate their capital efficiently, and have a low risk of default. Moreover, OECD (2021) examines how digital advances can shape trade finance practices to support the trading functions of SMEs better. They suggest that digitalization can increase the inclusion in trade finance primarily in three ways: by enhancing the end-to-end quality of processes, expanding the availability of trade finance instruments, and increasing the supply chain finance suppliers.

In many instances, a company's technological infrastructure constrains digitalization. An OECD (2021) study shows that the limited interoperability of platforms restricts the effective integration of digital solutions. The same challenge extends to the global level, where fragmented initiatives hinder scalability and seamless operation across supply chains. Another internal challenge for firms is the lack of required expertise. Other commonly cited barriers to digitalization include the high cost of technology adoption (Kim et al., 2022), low benefits for SMEs due to high credit and capital costs, and concerns about data privacy and cybersecurity (OECD, 2021). These findings underline the complex challenges banks and multinational companies face in their digitalization efforts. It is evident that the industry requires widespread standardization, global collaboration, and investments to establish a cost-effective, secure, and inclusive trade ecosystem.

3.1 Technological Drivers of Digitalization

Shee et al. (2018) suggest that cloud computing benefits trading partners and supply chain stakeholders by providing accurate data and enabling efficient tracking of sales orders and inventory status throughout the supply chain. The main advantages of the cloud are access to computing resources without extensive investment, increased digital innovation as the company has easier access to IT infrastructure, customizable and scalable solutions to meet business objectives, and management of massive data volumes to enhance business analytics (Gangwar & Date, 2016; Shee et al., 2018). Moreover, cloud adoption enhances supply chain efficiency by reducing costs and errors while improving process quality. By enabling cost-effective data sharing across functions such as production planning, delivery monitoring, and inventory management, cloud computing supports the alignment of stakeholders and strengthens operational sustainability. Shee et al. (2018) find that software as a service (SaaS) cloud solutions provide a stable and flexible foundation for firms operating in complex cross-border supply chains.

Gangwar and Date (2016) note that a company needs to consider security standards before migrating most of its data to the cloud. Cloud services may involve data transfer between various countries where data protection legislation differs. Moreover, existing information security systems typically leverage individual servers, meaning that integrating them into a cloud solution requires specific diligence from the implementing company. Thus, the company needs to establish a robust security policy to integrate systems in a manner that ensures interoperability between the cloud infrastructure and legacy systems. Moreover, data protection laws have hindered the shift of global banking to IT infrastructure within the trade finance framework (ICC, 2020).

In parallel, IoT has emerged as an indirect enabler, supporting the L/C process digitalization. IoT can be leveraged for L/C optimization, notably through its tracking capabilities and enhanced data analytics (Sousa, 2018). Today, more than 20% of vessels utilize an IoT-connected tracking device to manage global shipments, contributing to the transparency and flow of the process (WTO, 2022). Moreover, Larson (2018) suggests that a blockchain-based L/C incorporating IoT will make the transaction more efficient. The applicant can define the conditions the IoT device will monitor during delivery. Document verification relies on automation and the ability of the IoT to detect deviations in the specified requirements, such as the condition of the goods or the delivery time criteria.

Carr and Ramezani (2022) state that APIs improve export efficiency by reducing bottlenecks in intermodal logistics. In their absence, stakeholders struggle to leverage shared data effectively, undermining operational performance. They argue that to fully capture ecosystem-wide value, firms must migrate from legacy systems to SaaS and cloud-based solutions. Similarly, the ICC (2023b) emphasizes that complete digitalization requires replacing paper documents with structured data transferable through APIs, enabling real-time processing and greater transparency. In practice, APIs facilitate process automation through direct data exchange, streamlining export operations and terminal data portals by providing real-time information on shipments, including vessel volumes, delivery times, and payments (Carr & Ramezani, 2022). However, the fragmentation of existing

systems limits full integration, hindering the broader digitalization of trade processes. Until a standardized approach to use APIs in trade finance emerges, many companies remain reluctant to adopt the technology.

Furthermore, blockchain technology has the potential to address typical trade finance issues by improving a company's operational efficiency, establishing trust, and alleviating the credit risk (Kim et al., 2022). Kowalski et al. (2021) find that the deployment of blockchain improves trust by enhancing transaction security, communication quality, benevolence, and predictability of the counterparty's actions. They argue that as the blockchain matures over time, it enables trustless transactions. This outlook is reinforced by Kandaswamy and Furlonger's (2018) forecast, which indicates that blockchain will begin to deliver significant value to firms after 2027, with successful models and large-scale investments driving global adoption.

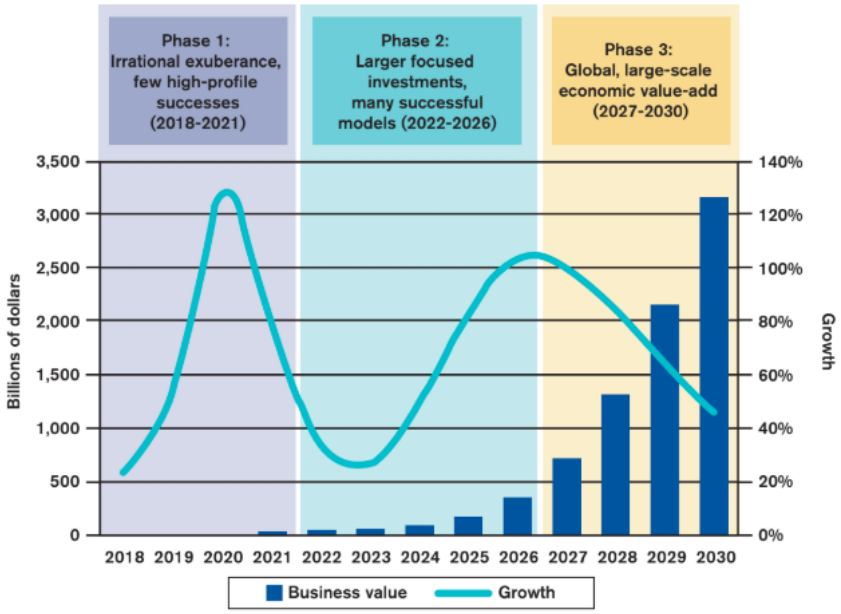

Figure 4. Estimate of blockchain value-add for firms (Kandaswamy & Furlonger, 2018).

Several studies have examined the implications of applying blockchain to the L/C process. Chang et al. (2019b) show that blockchain can consolidate trade finance procedures and enhance a company's cash management. They combine data from initiatives to draw

conclusions about the applicability of blockchain for trade automation. Consistent with the results of Kim et al. (2022), their findings suggest that blockchain can improve the process immutability and transparency, which promote trust and sustainability in trade finance. Similarly, Chang et al. (2019a) find that blockchain-based L/C platforms offer exporters advantages through greater automation, cost efficiency, and transparency. Notably, digital transferability makes the proposed model efficient compared to the legacy systems. Moreover, they underline that blockchain initiatives have demonstrated significant benefits through improved logistical tracking and document processing. The initiatives have reduced process lead times from weeks to days or, in some cases, even hours.

However, adoption lags have limited the positive impact of the technologies on foreign trade productivity (Kim et al., 2022). The Commonwealth's analysis (2022) suggests that smart automation and AI have attracted considerable interest in trade digitalization. In 2021, AI and smart automation were mentioned virtually as often as in the preceding five years, underlining the industry's growing interest in digital solutions. Moreover, subsets of AI such as ML, DL, and NLP can be particularly valuable for L/C process digitalization (Khalil et al., 2025; Ozturk, 2024).

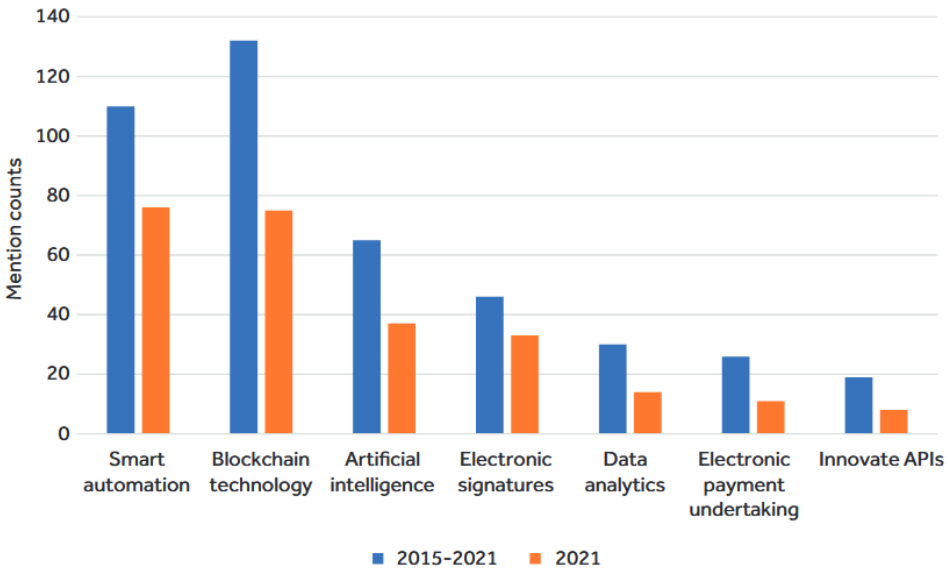

Figure 5. A discourse analysis of technologies (The Commonwealth, 2022).

Studies suggest that the benefits of AI and big data are concentrated among large companies. Begenau et al. (2018) find that big data enables large firms to reduce information asymmetry and lower the cost of capital more effectively than smaller firms, while their extensive resources and user bases allow them to train AI algorithms more efficiently (WTO, 2024). Ozturk (2024) further examines how multinational companies such as DHL and Maersk utilize AI to improve their trade operations. He finds that AI can reduce manual labor, errors, and transaction times by automating document preparation and verification. Furthermore, AI can generate forecasts based on historical data and market conditions, supporting more accurate cash-flow planning and overall financial management.

AI enables transparency in trade finance processes when coupled with blockchain (Ozturk, 2024). Together, these technologies contribute to the integrity of transactions by strengthening immutability and the precision of verifications. WTO (2024) provides similar findings on the impact of AI on process efficiency and transparency. They argue that AI increases supply chain visibility through real-time data analytics, automation, and forecasting. Their analysis suggests that AI is particularly effective in generating credit and risk scores. It automates and refines a company's internal and external screening by accessing large data pools and identifying emerging patterns embedded in the data.

3.2 Digital Implementations in the L/C Process

Plomaritou and Jeropoulos (2022) highlight recent progress in the adoption of eB/Ls within maritime business. They report that BIMCO has introduced a clause that allows the use of eB/Ls in certain charter contracts, while Bolero and CargoDocs have established eB/L platforms approved by international P&I clubs. Moreover, TradeLens and CargoX have introduced successful blockchain-based eB/L solutions. Consistent with these developments, FIT Alliance (2024) reports a 49% increase in eB/L adoption and a 46% increase in intention to use compared to 2022. However, Figure 6 reveals significant differences between stakeholders, with banks and forwarders trailing behind in adoption.

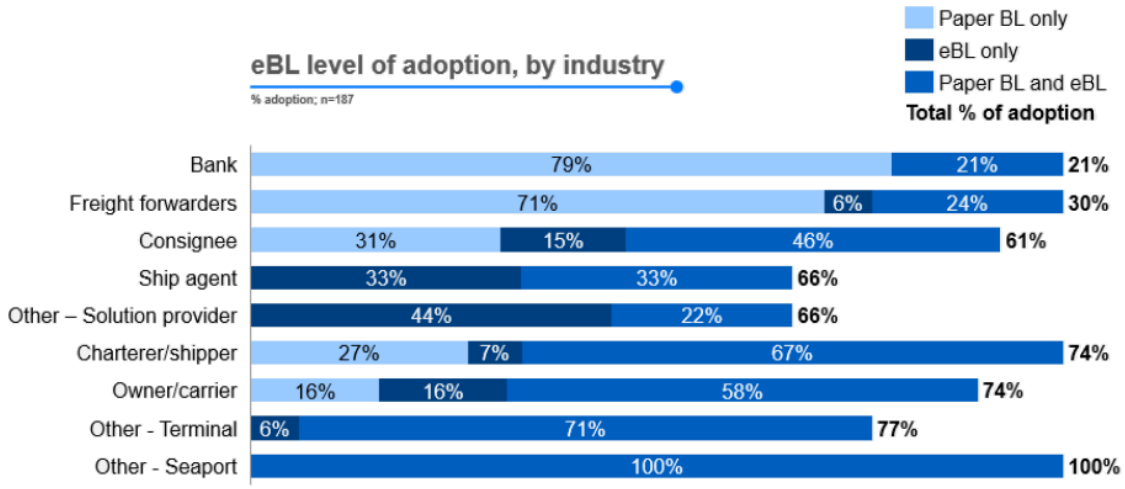

Figure 6. Adoption level of eB/L by industry (FIT Alliance, 2024).

Plomaritou and Jeropoulos (2022) argue that the blockchain can enable the widespread adoption of eB/Ls. CargoX's pilot project demonstrated that eB/L could be processed in minutes for $15 on a public blockchain network. Similarly, TradeLens' trial in partnership with Maersk enabled a 40% time saving and a cost reduction of several thousand dollars. Takahashi (2016) proposes an open, decentralized blockchain-based eB/L model that facilitates peer-to-peer transactions, reduces errors, and improves security. Moreover, other studies similarly highlight the potential of blockchain-based eB/Ls to overcome current integration and security issues and streamline documentation processes (Abdellatif, 2020; Wunderlich & Saive, 2019; Todd, 2019).

Takahashi (2016) argues that the blockchain eB/L can be classified as a negotiable electronic transport record, facilitating its legal recognition under the MLETR, which is currently being implemented globally. MLETR enables the effective application of ETRs in domestic and foreign trade (UNCITRAL, 2018). Abdellatif (2020) provides similar findings, as his proposed Ethereum-based eB/L would enable digital transfer of ownership. In this solution, only one entity has exclusive control, eliminating the double-spending issue. Furthermore, smart contracts ensure the security and immutability of transferability.

ICC (2024) analyzes the digitalization status of key trade documents, showing that out of 36 key documents, 21 are electronically standardized, six suffer from a lack of interoperability of fragmented standards, and nine are in the early phases of digitalization. Despite the established technical capacity, a large portion of the documentation continues to rely on paper processing due to regulatory gaps. While the ICC's eUCP is a key enabler of electronic transactions, the paper dependency disrupts the document examination. Consistent with the ICC's vision (2024), prior studies cite the role of inadequate standardization and regulatory frameworks as barriers to the widespread adoption of ETRs.

Moreover, studies have examined the role of process automation solutions in digitalization. AI leveraging intelligent OCR can identify and fill in different templates based on data from a physical document (Alshaleel, 2024). It is estimated that intelligent OCR can improve productivity in manual tasks by up to 50% (Dab et al., 2016). Despite being in its infancy, ML-enabled OCR could take automation one step further by filling in templates and by entering the data into a specified system. Thus, enhanced OCR technologies contribute to cost savings, process agility, and error reduction (Alshaleel, 2024). Reportedly, these solutions can enable up to 80% reductions in manual confirmation, and 70% reductions in manual data entry into systems. Patel and Ganne (2021) find that several FinTech companies leverage AI-enhanced OCR models in trade finance.

However, OCR has limitations, as it cannot ensure complete accuracy when processing non-standardized documents. Its estimated precision ranges between 70% and 90% (Patel & Ganne, 2021; Deutsche Bank, 2024). Second, regulatory issues such as document authentication, compliance, and data privacy require attention going forward (Alshaleel, 2024). L/C documents tend to contain confidential information, raising the necessity of ensuring compliance with data protection legislation when relying on external service providers. Finally, as OCR accelerates digitalization by creating machine-readable data, it paradoxically reduces its own necessity over time as the industry's digital transition proceeds (Deutsche Bank, 2024).

Mahadevkar et al. (2024) reinforce the relevance of AI-based solutions in the future. They find that template-based OCR is currently a key tool for process automation, but its dependence on a defined template greatly reduces its flexibility. RPA is effective for rule-based automation but similarly faces scalability issues when dealing with unstructured data. Hence, they propose hybrid models that combine existing solutions with AI-based DL or NLP to increase the flexibility of processing non-standardized data. Similarly, Baviskar et al. (2021) argue that while RPA contributes to cost savings, it is only applicable to a process consisting of repetitive, standard, or rule-based tasks. They show that up to 95% of companies encounter unstructured data, which renders RPA an inefficient solution for automating complex value chains. To achieve effective end-to-end automation, they propose AI-based RPA or OCR workflows that leverage NLP and computer vision, as AI algorithms can efficiently extract data from invoices or purchase orders. However, they note that AI is not a silver bullet for streamlining trade finance. It encounters difficulties when processing multiple layouts, such as varying non-standard invoices.

Khalil et al. (2025) investigate how AI can increase the automation and efficiency of the L/C document inspection process. They propose an integer linear programming optimization model that produces initial decisions and subsequently assigns documents for manual human review. When assigning documents for manual review, the developed AI model considers attributes such as employee experience, document value, and complexity. This approach increases transactional efficiency while maintaining reliability and compliance. The model reduced the operational risk of the process by 68.3%, driven by improved regulatory compliance, reliability, and error minimization (Khalil et al., 2025). Its utilization rate was as low as 34% for strategies underlining risk management and as high as 73% for strategies aiming to maximize process efficiency.

Chang et al. (2019a) propose an L/C process redesign relying on a consortium chain. Their model is driven by automating and streamlining the logistics flow, document flow, and cash flow of L/C through smart contracts. The trading smart contract replaces the commercial contract, digitally recording terms and transactions of a trade. The logistical

smart contract streamlines the document flow, replacing the transport documents. It leverages the conditions contained in the TSC and enables real-time data sharing and delivery tracking. The L/C smart contract replaces the current L/C and activates upon approval by the stakeholders. The model facilitates banks' ability to monitor payment transactions and reduces the risks and costs of documentary processing.

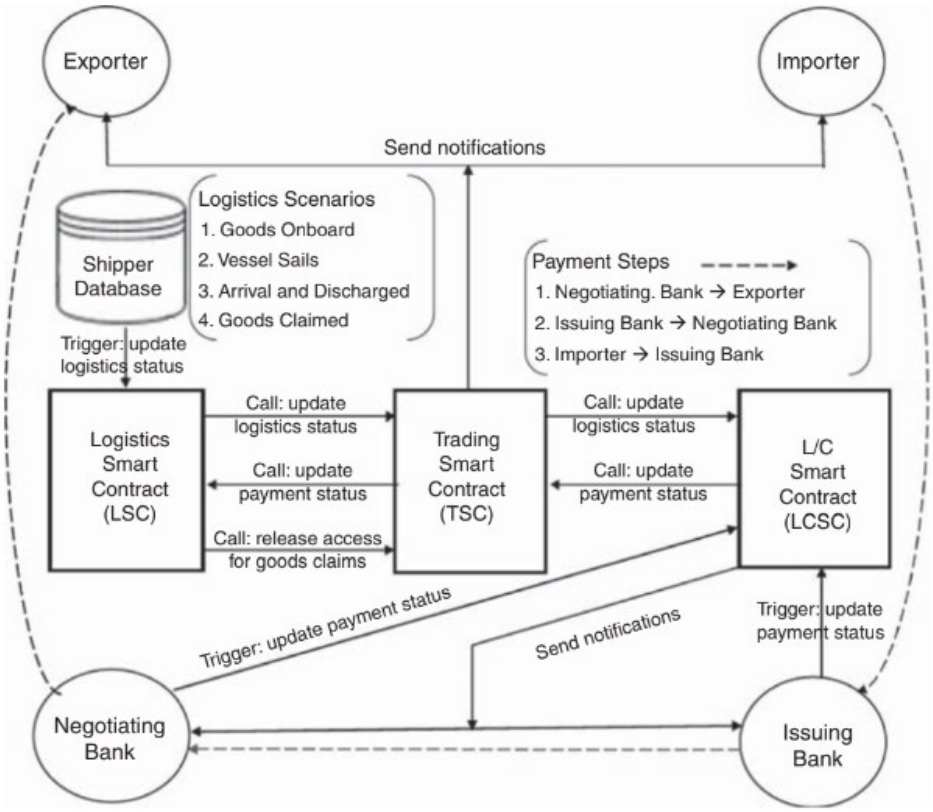

Figure 7. Interaction of smart contracts in the blockchain L/C (Chang et al., 2019a).

However, the model proposed by Chang et al. (2019a) faces several challenges. Technical constraints such as block size, platform security, and transaction speed limit the model's practicality. When applied to real-world L/C transactions, additional barriers arise due to unstructured and inaccessible data (Baviskar et al., 2021). Hence, the ecosystem requires a collective effort to render process-related data digitally available to all stakeholders, as an individual actor cannot create value without ecosystem-wide participation.

Similarly, Toorajipour et al. (2022) propose blockchain-based L/C model designed to enhance the process through smart contracts. Their approach addresses challenges related to third-party platforms, such as complex procedures, high costs, and data integrity concerns. The proposed model renders the transaction trustless, speeds up data flow, lowers costs, reinforces security, and promotes process transparency by executing payment contracts automatically via smart agreements. The decentralized approach allows disintermediation, reducing the need for banks to act as intermediaries. The model is composed of three transaction packages and eight phases. First, participants establish and validate a smart agreement defining the transaction terms. Second, the buyer's payment is blocked by a smart contract until conditions are fulfilled. Finally, once the goods are delivered and the terms are confirmed, the payment is released to the vendor, and the transaction is permanently recorded on the blockchain.

Bhat et al. (2021) propose a blockchain-based model for standard L/Cs, using Ethereum smart contracts to enhance trust and security. They argue that the public platform ensures the security of users and provides decentralization. Contrary to the model proposed by Toorajipour et al. (2022), their solution retains the involvement of banks, although the smart contract can function as an intermediary. This indicates that the role of banks in the proposed process will undergo a transformation, and the document validation efforts will be reduced. The solution is an integrated model for stakeholders throughout the process and enables real-time document processing, ownership transparency, and automated payments with lower transaction costs. However, consistent with prior studies, they note that widespread adoption requires legal reforms to recognize digital elements and ensure secure transactions.

In recent years, many platform projects have been developed in trade finance. Several experiments are built on blockchain technology, with Ethereum and Hyperledger being of particular interest to companies (Chang et al., 2019b). According to the ICC (2020) survey, online platforms are the most used solutions for the digitalization of trade finance in banking. According to the study, this is due to platform solutions enabling banks

to offer their customers a bridge to digital trade finance services. Moreover, the value offered by this channel attracts a high proportion of large trading companies to leverage SWIFT-based multi-banking platforms.

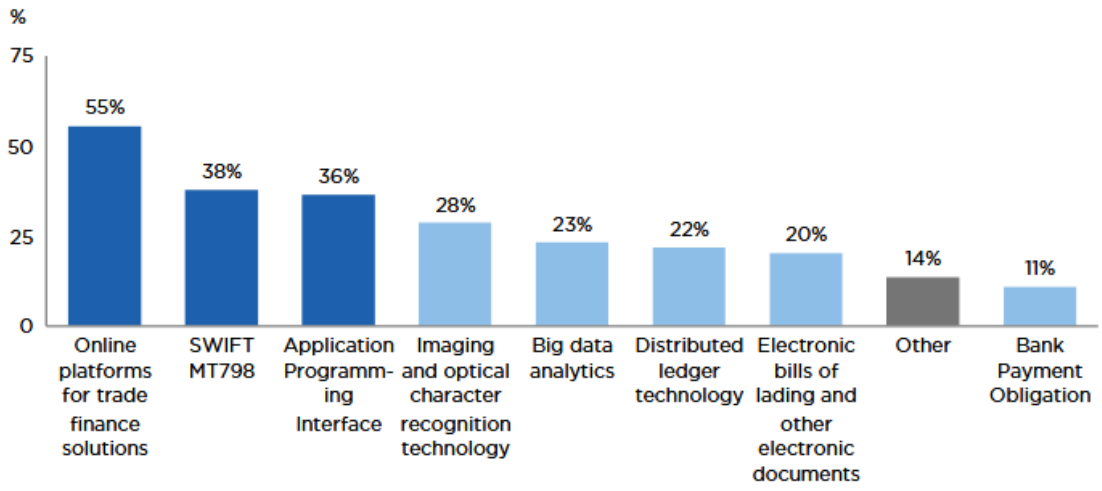

Figure 8. Digital trade finance solutions applied in banking (ICC, 2020).

However, the prevailing platforms are largely based on a closed architecture, where network members must be pre-approved. Technical challenges, and specifically the limits imposed by the regulatory environment, have driven financial institutions to exploit closed structures (Takahashi, 2016). The disadvantages of closed platforms are their inflexibility, lack of scalability, and inability to communicate with other platforms or interfaces. While DLT and blockchain face the previously cited technical uncertainties regarding privacy, scalability, and transactional efficiency, most existing platform solutions rely on them.

Chang et al. (2019b) assess the potential of blockchain-based initiatives in the L/C process by conducting a multi-case study with a paradigm shift approach. They cite that Barclays' collaboration with the decentralized blockchain platform Wave yielded impressive results, reducing the L/C issuance and approval time to only four hours. In the project, Wave utilized a shared ledger to record all core trade documentation. This enabled participants to inspect the data in the chain, providing real-time information on the

process. Furthermore, the platform leveraged smart contracts, whereby the presentation of a transport document initiated an exchange of ownership.

Another case discussed by Chang et al. (2019b) is a trial between Maruben and Sompo using IBM's Hyperledger platform to replace traditional L/C and related documentation. They claim that the platform successfully reduced the use of documentation, and the entire process from signing a sales contract to reimbursement could be carried out on a blockchain network. This enabled the transaction lead time to be reduced from two weeks to a few hours. Furthermore, BBVA's experiment with the Ethereum-based blockchain platform Wave yielded similar results. They reported a total transaction time reduction from ten days to less than three hours. The solution replaced traditional documentation with digital versions and electronic signatures. Smart contracts were used to trigger conditional transactions aligned with the commercial contract. The project also produced value for carriers, improving process transparency and tracking capabilities.

However, while DLT approaches offer paperless processing, speed, and immutability with auditability capabilities, wider adoption requires common standards and scalable infrastructure (Toorajipour et al., 2022; Chang et al., 2019b). Moreover, to substantially reduce the process lead times, the demonstrated platform cases executed the entire L/C transaction within a blockchain network connecting all stakeholders. In the trials, the documentation was transferred through the platform in a completely digital format, and the process was further automated through smart contracts. However, as previously identified, the main practical bottlenecks are the closed platforms and the lack of legal recognition for electronic documents (Takahashi, 2016; Abdellatif, 2020). Notably, the absence of a legal framework enabling the transferability of transport documents poses a major obstacle. By addressing these hurdles, platform solutions could realistically encompass the entire L/C process and scale widely to reach new participants.

Sources	Main Findings	Restrictions or Considerations
González et al. (2023); Kim et al. (2022)	Digitalization reduces transaction costs, increases trade, and improves transparency and traceability in supply chains.	General analyses. No specific findings on efficiency impacts on the L/C process from exporter's perspective.
Zhou & Li (2023); OECD (2021)	Digital transition reduces dependence on intermediaries, facilitates access to credit particularly for SMEs.	The effects depend on firm size. Studies focus more on financial availability than on efficiency.
Kim et al. (2022); OECD (2021)	Main barriers and challenges to digitalization include lack of standardization and regulation, platform incompatibility, high costs, and insufficient expertise.	Limited empirical evidence in the L/C process context.
Shee et al. (2018); Gangwar & Date (2016); ICC (2020)	Cloud computing improves supply chain integration and cost efficiency while providing a scalable IT infrastructure.	Security risks and regulatory challenges may hinder adoption.
Sousa (2018); WTO (2022); Larson (2018)	IoT enables real-time monitoring and automation. Moreover, it increases L/C process transparency.	Lack of standardization and limited implementation.
Carr & Ramezani (2022); ICC (2023b)	APIs streamline the process, enable seamless data transfer, and support automation.	Fragmentation of the ecosystem and lack of standards delay adoption.
Kim et al. (2022); Kowalski et al. (2021); Chang et al. (2019a,b); Kandaswamy & Furlonger (2018)	DLT and derived solutions increase automation, trust, security, and transparency of the process. Blockchain-based pilots have proven considerable efficiency gains and reduced lead times.	Technical issues, scalability, and regulatory gaps are holding back widespread adoption.
Begenau et al. (2018); Ozturk (2024); Khalil et al. (2025); WTO (2024)	AI and big data automate document review, reducing errors and manual work. Khalil et al. (2025) report a 68.3% reduction in operational risk.	Not mature for the L/C process. Requires standardization and human intervention.
Plomaritou & Jerupoulos (2022); FIT Alliance (2024); Takahashi (2016); Abdellatif (2020)	eB/L enables more cost-effective process. In pilots, process time has been reduced from days to hours. Blockchain-based pilots are promising.	Slow and fragmented take-up. Banks and forwarders lagging. Regulatory gaps hinder adoption.
Alshaleel (2024); Dab et al. (2016); Baviskar et al. (2021); Patel & Ganne (2021)	OCR and RPA automate data input. Reportedly 50-80% reduction in manual work depending on the process phase (Dab et al., 2016; Alshaleel, 2024).	Limited accuracy of OCR. Both technologies struggle in unstructured environments.
Chang et al. (2019b); Takahashi (2016); ICC (2020)	Digital platforms accelerate processes and increase real-time transparency.	Often closed systems. Scalability and lack of standardization prevent widespread collective adoption.

Table 3. Synthesis of prior literature.

4 Data

The primary data for the research was collected through semi-structured interviews based on predefined questions. The chosen data collection method consisted of presenting a specific set of questions for each group of interviewees while allowing for a change of sequence and follow-up questions where needed (Bryman, 2016). This approach allowed for a rich dialogue, contributing to the depth and detail of the responses through the interviewee's reflection. Furthermore, the selected method enabled discussion of topics that had not been fully considered in advance.

This thesis utilized observations and case company's system data as secondary data sources. Participant observation has enabled monitoring of the case company's processes, policies, and stakeholder engagement within the everyday operating environment. In participant observation, the researcher identified meanings by participating in the studied event in a social setting (Yin, 2009; Bryman, 2016). The observations were specifically focused on the structure and function of the existing process, the role of employees, and communication between different departments and stakeholders. The gathered observations have contributed to the development of the study's understanding of the investigated phenomenon. Specifically, the observations have provided contextual knowledge which has guided the formulation of the theoretical background and the interview questions.

The first stage of interviews was carried out internally in the case company. The focus was on assessing the operational efficiency and challenges of the existing L/C process while considering the organization's perceived readiness for digitalization. The respondents included experienced professionals in trade finance, export documentation, and corporate treasury. By including respondents from various departments, the study aimed to establish a comprehensive view of the process from different perspectives. This contributed to developing an understanding of the specific objectives and challenges of each stage. Moreover, the internal interviews provided an explicit understanding of the state of play and supported the development of targeted recommendations.

Conversely, the second stage interviews were conducted with industry professionals from outside the case company. Respondents included experts from banks, working groups, freight forwarders, and other export companies involved in trade finance. External respondents have a deep knowledge of the L/C process and digitalization within the trade finance ecosystem. The external interviews provided insights into the most potential technologies, their impact on the firm's business performance, the implications of the surrounding legal frameworks, current challenges, as well as industry developments and trends. The distinction between internal and external interviews contributed to the collection of rich and profound data on the researched phenomenon.

The study involved 12 interviewees, of whom five are internal respondents of the case company and seven are external respondents. The interviews were conducted via Microsoft Teams, utilizing the software's transcription tool. One of the interviews was conducted in English, and the remainder in Finnish. The Finnish interviews were manually translated into English by the researcher to ensure accuracy and contextual consistency. The interviews ranged in duration from 24 minutes to 77 minutes, with an average duration of 43 minutes 44 seconds. Table 4 below presents the respondents of the study.

Furthermore, the data has been anonymized to ensure the publicity of this study while maintaining sufficient anonymity and confidentiality of the case company and its stakeholders. Hence, a three-step anonymization process was applied. First, all identifiers, including names, exact job titles, and organizations, were removed from the transcripts. Interviewees were referred to by alternative identities (IDs). Second, industry- and company-specific details were generalized. Third, the recordings and transcripts were only available to the researcher and were deleted upon completion of the thesis.

ID	Organization	Role	Responsibilities and Background
I1	Case company	Trade Finance Manager	Function leader.
I2	Case company	Trade Finance Manager	Operational leader.
I3	Case company	Trade Finance Manager	Function leader.
I4	Case company	Treasury Manager	Corporate-level leader.
I5	Case company	FICO Director	Corporate-level director.
E1	Bank	Product Owner	System development and maintenance. Expertise in L/C standardization, supported by experience with blockchain and AI proof-of-concepts.
E2	Bank	Letter of Credit Expert	Responsible for interpreting complex L/C terms and conducting training. Comprehensive experience in trade finance. Actively engaged with digitalization through their organization.
E3	Bank	Business Developer	Comprehensive background in payments standardization, including experience in IT and banking. Expertise in trade finance digitalization, standardization, and harmonization.
E4	Bank	Lead Product Manager	Leading product management for trade. Has led a trade finance function on the corporate side. Member of a digitalization working group, with experience in digitalization projects.
E5	Exporting company	Trade Finance Manager	Comprehensive trade finance experience in a corporate setting. Extensive knowledge of L/Cs. Familiar with digitalization through an industry commission and a working group.
F1	Freight forwarder	Sea Freight Coordinator	Responsible for general cargo and the operational aspect of project shipments.
F2	Freight forwarder	Project Coordinator	Responsible for document preparation. Has hands on experience with eB/Ls.

Table 4. Interviewees of the study (n = 12).

The data consists of interviews with 12 respondents. The transcripts were reviewed and cleaned by the researcher. Interview questions, extra line spacing, and confidential details were removed from the data. Transcribed data was compiled into a structured .csv file for analysis, with each line corresponding to a single interview response. The file contains the respondent's identifier (ID) and each response of the respondents. The quantitative text analysis was executed in the Python programming language using libraries for NLP, sentiment analysis, regression analysis, and so forth.

Variable	Description	Source
ID	Interviewee code used to anonymize and differentiate respondents	Corpus
Group	Stakeholder group classification (Exporter, Bank, Forwarder)	Corpus
WC	Total number of words in a single interview response	Corpus, Python text analysis tools
S.TB	TextBlob sentiment polarity score (Overall)	Corpus, Python TextBlob Library
P.TB	TextBlob sentiment polarity score (Positive)	Corpus, Python TextBlob Library
N.TB	TextBlob sentiment polarity score (Negative)	Corpus, Python TextBlob Library
S.LM	Loughran-McDonald dictionary sentiment score (Overall)	Corpus, Loughran & McDonald (2024)
P.LM	Loughran-McDonald dictionary sentiment score (Positive)	Corpus, Loughran & McDonald (2024)
N.LM	Loughran-McDonald dictionary sentiment score (Negative)	Corpus, Loughran & McDonald (2024)
S.NRC	NRC Word-Emotion Association Lexicon sentiment score (Overall)	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
P.NRC	NRC Word-Emotion Association Lexicon sentiment score (Positive)	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
N.NRC	NRC Word-Emotion Association Lexicon sentiment score (Negative)	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Anger	Frequency of words associated with 'Anger' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Anticipation	Frequency of words associated with 'Anticipation' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Disgust	Frequency of words associated with 'Disgust' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Fear	Frequency of words associated with 'Fear' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Joy	Frequency of words associated with 'Joy' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Sadness	Frequency of words associated with 'Sadness' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Surprise	Frequency of words associated with 'Surprise' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
Trust	Frequency of words associated with 'Trust' in the analyzed text units	Corpus, NRC Lexicon (Mohammad & Turney, 2013)
S.BERT	BERT sentiment score generated by a pre-trained ML model (Overall)	Corpus, Python Hugging Face Transformers
P.BERT	BERT sentiment score generated by a pre-trained ML model (Positive)	Corpus, Python Hugging Face Transformers
N.BERT	BERT sentiment score generated by a pre-trained ML model (Negative)	Corpus, Python Hugging Face Transformers
Exporter	Stakeholder group Dummy (1=Exporter, 0=Not Exporter).	Corpus
Bank	Stakeholder group Dummy (1=Bank, 0=Not Bank).	Corpus
Adoption	Digital adoption Dummy (1=Mentioned, 0=Not mentioned)	Corpus

Table 5. Summary of variables used in the analysis.

Table 5 presents the key variables used in the quantitative text analysis. The table describes the variables and their sources. All variables used in the regression models are included, such as sentiment scores, NRC emotions, word count, and dummy variables representing stakeholders and adoption of digitalization. Table 6 displays summary statistics for the variables. The number of observations (N = 298) represents the number of individual responses analyzed. The table reports the mean, standard deviation, and extreme values of the distribution for each variable. The Word Count variable was included as a control variable to account for the variation in response lengths between different interviewees. Since sentiment scores tend to vary with the amount of text, the inclusion of Word Count in the models prevents bias. As Table 6 shows, the approximate average response is 131 words, with considerable variation between responses. Hence, word count improves the comparability of the different responses and helps to control the effect of the amount of text on the analysis variables.

Variable	N	Mean	Std. Dev.	Min	25%	50%	75%	Max
Word Count	298	130.52	95.437	3	64	101.5	171	480
TB Sentiment	298	0.101	0.155	-0.537	0.006	0.100	0.190	0.600
TB Positive	298	0.121	0.123	0.000	0.006	0.100	0.190	0.600
TB Negative	298	0.020	0.064	0.000	0.000	0.000	0.000	0.537
LM Sentiment	298	-0.003	0.009	-0.062	0.000	0.000	0.000	0.024
LM Positive	298	0.001	0.004	0.000	0.000	0.000	0.000	0.048
LM Negative	298	0.003	0.009	0.000	0.000	0.000	0.000	0.062
NRC Sentiment	298	0.224	0.232	-0.667	0.091	0.250	0.344	1.000
NRC Positive	298	0.301	0.175	0.000	0.200	0.300	0.385	1.000
NRC Negative	298	0.077	0.100	0.000	0.000	0.053	0.105	0.667
BERT Sentiment	298	0.001	0.239	-0.773	-0.151	-0.008	0.158	0.797
BERT Positive	298	0.327	0.189	0.013	0.182	0.297	0.442	0.947
BERT Negative	298	0.318	0.178	0.019	0.172	0.294	0.420	0.933

Table 6. Summary statistics.

5 Methodology

This section presents the methodological approach and design of the study, justifying the selection of analytical methods regarding the research questions and objectives. The study relies on a mixed-methods approach, where the data collected is analyzed through quantitative text analysis and thematic analysis. The combined methods allowed for a holistic analysis of the data in quantitative and qualitative terms. Moreover, the section discusses how the reliability and validity of the study were ensured.

5.1 Research Philosophy and Design

Research philosophy refers to the underpinning beliefs and assumptions about knowledge that construct the study (Saunders et al., 2023; Creswell 2009). It sets the research perspective and largely determines how research acquires and interprets the surrounding data. Epistemological considerations focus on the question of what should be deemed valid knowledge within science. The epistemological assumption includes two categories: positivism and interpretivism. The definition of positivism varies in literature, but generally, it is based on the notion that only measurable and observable knowledge is acceptable (Bryman, 2016). On the contrary, interpretivism suggests that phenomena in the social world are not unambiguously measurable in the way that natural science is but rather focus on subjectivity and people's interpretations of reality.

This research builds on an interpretivist philosophical approach, as the collected data is subjective and reflects the perspectives of various stakeholders. Through the chosen approach, this study aims to highlight the different arguments for the concrete benefits that a company can achieve through digital transformation. According to Bryman (2016), ontological considerations focus on the nature and existence of reality and question what is being studied. Constructionism is linked to an interpretive research philosophy and claims that there is no absolute reality, but that it is socially constructed from people's subjective perceptions and experiences. This study incorporates a constructivist

ontology, recognizing that knowledge and meaning are socially constructed and context-dependent. Furthermore, the study's philosophical approach is guided by a pragmatic paradigm that enables the integration of qualitative and quantitative methods to effectively address the research questions (Creswell, 2009).

This thesis employs a case study design to generate answers to specified research questions. The study is exploratory by nature, seeking to identify and understand the implications of an emerging phenomenon (Creswell, 2009). More specifically, the study applies a single-case design, where the analysis focuses on a single unit (Yin, 2009). In this context, the analyzed unit is the case company's L/C process, where the chosen strategy addresses the challenges and opportunities.

This exploratory case study aims to develop an empirical understanding of the structure and dynamics of the phenomenon under investigation (Creswell, 2009; Bryman, 2016). The approach is well suited for studying contextual and complex phenomena. This study employs a concurrent mixed-methods design, combining qualitative thematic analysis for an in-depth interpretation of the data with quantitative text analysis to identify patterns and relationships (Creswell, 2009). The combination of methods contributes to the depth and generalizability of the analysis in the case study setting.

This study is inductive in its approach, as it builds understanding based on empirical observations (Bryman, 2016). The inductive approach does not test predetermined hypotheses but identifies patterns from the observations. The approach enables themes to emerge from the data, guiding the development of insights (Saunders et al., 2023). Furthermore, the stance is data-driven and contributes to the development of knowledge on novel phenomena. The primary data were collected through semi-structured interviews, while secondary data from observations were used to enhance the understanding of the key characteristics and objectives of the L/C process and the case company’s trade finance operations.

By utilizing purposive sampling, this study selected interviewees with a comprehensive understanding of the subject studied. The purposive sampling strategy is based on the researcher's assumption that certain individuals possess informative and relevant insights into the phenomenon being examined (Robinson, 2014). Within the case company, interviewees were selected to ensure a deep and diverse understanding of the existing L/C process. In contrast, external participants were selected to provide broader perspectives on digitalization and the L/C process within the wider trade finance framework. Furthermore, aspects of maximum variation sampling are integrated into the chosen sampling strategy, as the study aims to ensure the representation of interviewees from diverse backgrounds (Moser & Korstjens, 2018). When selecting internal interviewees, this implies interviewing professionals from different departments and roles. Externally, the emphasis is on gaining insights across organizational boundaries by selecting interviewees from a variety of stakeholders.

5.2 Data Analysis

The data analysis combines quantitative text analysis and thematic analysis, which are presented in this section. First, this study employs quantitative text analysis to generate findings on how discourses regarding digitalization themes, such as solutions, adoption, benefits, and challenges, are distributed across the data and among stakeholders. Moreover, this methodological approach evaluates how the emotional tone of the data occurs and whether it has a systematic relationship with the discourse of digital adoption. This quantitative analysis was conducted in the Python programming language using the established libraries. The analysis is divided into three steps, (1) content analysis, which is based on frequencies and correlations of themes, (2) sentiment analysis measuring the emotional nuance of the data through various models, and (3) logistic regression analysis which statistically tests which emotions and sentiments are significant in the context of adopting digital trade finance.

The first stage of the text analysis consisted of keyword-based content analysis, where the data's semantic emphases and thematic correlations were analyzed. The analysis was conducted on a cleaned .csv data file, where each observation unit was a single response from the interviewee. Where differences between stakeholders were analyzed, aggregation was performed using the groupby function at the ID level. The content analysis formed the basis for the quantitative analysis by extracting key themes, topics, and discourses from the data, which were used for further analysis. Moreover, embedding-based clustering was experimented with, where responses were converted into semantic vectors and grouped into thematic clusters without predefinitions. However, due to the specificity of the subject and the limited amount of data, the content of the clusters proved to be overlapping and too generic. Hence, clustering was not applied in this study.

The content analysis was carried out using manually generated keyword-based themes, which allowed key themes to be transformed into quantifiable variables. The themes were primarily built around the objectives of the study and the phrases that recurred in the data. The CountVectorizer method was used to count theme occurrences, and the values were normalized to frequencies per 1,000 words to ensure comparability across stakeholders and varying response lengths. Practically, the themes were formed according to a three-level approach. First, overarching themes were defined, which were further subdivided into topics. The topics were constructed from keyword lists that included key terms, synonyms, and inflection points for each topic. Keywords were identified during the thematic analysis, where the data were iteratively worked through. Finally, the associations between technology-specific and benefit-specific variables were examined using Pearson (pearsonr) and Spearman (scipy.stats.spearmanr) correlation coefficients. The correlations provided preliminary findings to the extent to which various digital solutions were associated with benefit themes in the data.

Secondly, sentiment analysis was applied to evaluate the tone and polarity of interview responses. This approach was inspired by Sapkota and Groby's (2023) study, which employed four sentiment measures to analyze the determinants of ICO success. In this study,

sentiment analysis was employed to evaluate the data from various perspectives and among stakeholders. The sentiment was analyzed through three lexicon-based dictionaries and one machine learning-based model. These methods produced independent but complementary results. First, the analysis made use of Python's TextBlob (TB) library to generate a general polarity score in the range [-1, 1], where negative values indicate a negative tone of the language, while positive values indicate a positive tone. TB offers the advantage of simplicity and efficiency and is well suited to moderately small and free-form data sets.

Second, the Loughran-McDonald (LM) dictionary was employed, which is based on a specific financial vocabulary and is typically well-suited to financial text analysis. This model distinguishes between negative and positive expressions, as well as discourses describing uncertainty. The word_tokenize tool of the Python nltk library was used to measure LM sentiment. Third, this research relied on the NRC Word-Emotion Association Lexicon, which measured the tone of the data through eight basic emotions (anger, anticipation, disgust, fear, joy, sadness, surprise, and trust), as well as positive and negative sentiment. The measurement included nltk-based tokenization and normalization of topic frequencies to ensure comparability of results. Fourth, a pre-trained deep learning language model, BERT, was utilized for analysis. It scores the sentiment of responses on a scale of 1-5, which was eventually converted to a continuous scale for this study. Since BERT is based on deep learning, it provides a richer interpretation of the sentiment compared to the other lexicon-based models in this study.

As a final step of quantitative text analysis, logistic regression models were employed to examine the explanatory power of the sentiment tools on stakeholders' attitudes towards the adoption of digital trade finance. Although the regressions were performed on all sentiment measures, only NRC and BERT-based analyzes were selected for the final models as they produced statistically and interpretatively meaningful results. In contrast, models based on LM and TB lexicons proved to be weakly explanatory (Pseudo $R^2 < 0.06$) and did not detect significant sentiment variables. Hence, they were excluded from the

final reporting. Prior to the selection of the regression models, multicollinearity testing was performed using the variance inflation factor (VIF) values. While moderate correlation (VIF < 5) was identified between some variables, it did not exceed generally accepted thresholds, and the stability of the models was not considered to be at risk.

The three regression models are based on the binary dependent variable (Adoption), which takes value 1 if the interview response indicates digital adoption. The models were estimated by logistic regression using maximum likelihood estimation with the Python statsmodels library. In all models, response length was controlled with word count (WC), and stakeholders were considered with dummy variables. Interaction terms were calculated to investigate whether the effect of sentiment varies between groups. Equation (1) below is the regression model for the complete NRC Emotion Lexicon. The model uses the eight basic emotions of the lexicon and measures of positive and negative sentiment. The model accounts for dummy variables for stakeholders and uses interaction terms to model the effect of differences across groups. WC is used as a control variable.

$$\begin{aligned} logit(p_i) = \beta_0 + \beta_1 \cdot anger_i + \beta_2 \cdot anticipation_i + \beta_3 \cdot disgust_i + \beta_4 \cdot fear_i + \beta_5 \\ \cdot joy_i + \beta_6 \cdot sadness_i + \beta_7 \cdot surprise_i + \beta_8 \cdot trust_i + \beta_9 \cdot P.NRC_i \\ + \beta_{10} \cdot N.NRC_i + \beta_{11} \cdot Exporter_i + \beta_{12} \cdot Bank_i + \beta_{13} \\ \cdot (P.NRC_i \cdot Exporter_i) + \beta_{14} \cdot (P.NRC_i \cdot Bank_i) + \beta_{15} \cdot (N.NRC_i \\ \cdot Exporter_i) + \beta_{16} \cdot (N.NRC_i \cdot Bank_i) + \beta_{17} \cdot WC_i \end{aligned} \quad (1)$$

Equation (2) is a plain NRC model that focuses on sentiment alone, without emotions. As with the complete model, this model includes interactions by stakeholder and WC as a control variable.

$$\begin{aligned} logit(p_i) = \beta_0 + \beta_1 \cdot P.NRC_i + \beta_2 \cdot N.NRC_i + \beta_3 \cdot Exporter_i + \beta_4 \cdot Bank_i + \beta_5 \\ \cdot (P.NRC_i \cdot Exporter_i) + \beta_6 \cdot (P.NRC_i \cdot Bank_i) + \beta_7 \\ \cdot (N.NRC_i \cdot Exporter_i) + \beta_8 \cdot (N.NRC_i \cdot Bank_i) + \beta_9 \cdot WC_i \end{aligned} \quad (2)$$

In equation (3), contextual sentiment scores based on the multilingual BERT model are employed. In structure, it is similar to the plain NRC model (2) with interactions by stakeholder and WC as control.

$$logit(p_i) = \beta_0 + \beta_1 \cdot P.BERT_i + \beta_2 \cdot N.BERT_i + \beta_3 \cdot Exporter_i + \beta_4 \cdot Bank_i + \beta_5 \cdot (P.BERT_i \cdot Exporter_i + \beta_6 \cdot (P.BERT_i \cdot Bank_i) + \beta_7 \cdot (N.BERT_i \cdot Exporter_i) + \beta_8 \cdot (N.BERT_i \cdot Bank_i) + \beta_9 \cdot WC_i \quad (3)$$

The second method of analysis employed in this study was thematic analysis, which relies on finding patterns and meaning flexibly in qualitative data (Nowell et al., 2017). Thematic analysis was chosen as a method as it allows understanding phenomena at an in-depth level and contributes to the development of rich insights. Thematic analysis is a particularly advantageous method when the research objective is to systematically analyze the similarities and differences in the data and the perspectives of the respondents (Braun & Clarke, 2006; Nowell et al., 2017). It enables similarities emerging from qualitative data to be combined into themes, contributing to the development of answers to the research questions.

Furthermore, the method aligns well with the study's mixed-methods approach, as it provides deeper insights to support and contextualize the quantitative findings. The thematic analysis was conducted primarily according to the six-step process introduced by Braun and Clarke (2006). However, the analysis in this study drew further on the insights of Nowell et al. (2017), who suggest that the process is iterative and reflective, rather than merely linear. The first phase of the process was to become familiar with the data. This occurred naturally through transcription and translation of the data, which required the researcher to engage intensively with the interview material. Hence, at this stage, preliminary observations on commonly occurring topics and possible themes emerged.

This phase was followed by the development of preliminary codes. Coding was done manually through the entire dataset using a coding framework (Nowell et al., 2017). In this stage, an inductive approach was employed, where meanings were extracted using a data-driven approach. Typically, the respondent's sentences formed codes, although in many cases the sentence was separated into two or more different codes. This split was made when the topic of the response diverged beyond the original topic, or when the latter part of the sentence explicitly highlighted a different set of observations. A strict condition for classifying sentences into multiple codes was that it did not detach the observation from its context.

The third phase of thematic analysis was a search for themes (Braun & Clarke, 2006). Here, codes were categorized into broader initial themes that formed logical units. A key aspect was to consider the relationships and dependencies between the data to ensure that the codes were meaningfully clustered into the main themes. This phase was followed inextricably by phase four, where the themes were critically examined. This involved a close examination of the themes to ensure their coherence. Once the initial main themes were established, overlapping themes were merged, and the necessary sub-themes were formed.

In the fifth phase, the themes were named, and their common thread was defined (Nowell et al., 2017). The key was to determine what was unique about each theme and how they contributed to answering the research questions (Braun & Clarke, 2006). The themes were organized in a way that reflected the actual data structure and supported the research objectives. In the final phase of the analysis, the results were reported in a way that captured the prevailing views of stakeholders, as well as analytically significant dissenting perspectives. The purpose of this was to provide a holistic and accurate picture of the data. Moreover, excerpts from the unprocessed data were used to reinforce the validity of the analysis and the original narrative (Braun & Clarke, 2006).

5.3 Reliability and Validity

The reliability and validity of the text analysis were reinforced with several methods. First, data pre-processing was performed consistently, including text cleaning, tokenization, and normalization. The variables for the content analysis were based on predefined themes that emerged naturally from the data during the thematic analysis. This approach aimed to support content validity. Moreover, several different sentiment tools were used in the analysis, which allowed for comparison and triangulation of results between different methods. The regression models accounted for the length of responses with the Word Count variable, which reduced the bias arising from different-length responses. Model stability and explanatory power were tested through multicollinearity, statistical significance of the model, and goodness of fit. These measures were applied to ensure that the analysis was methodologically valid, replicable, and transparent.

For thematic analysis, reliability was reinforced by following the established model of Braun and Clarke (2006) and the trustworthiness criteria presented by Nowell et al. (2017). The analysis was conducted reflexively and iteratively, meaning that the data were carefully studied, coding was performed in several stages, and themes were refined as the analysis progressed. Both explicit and implicit meanings were utilized to support the coding. All steps of the analysis were systematically documented in a Word file to validate the audit trail (Nowell et al., 2017). Moreover, reflective writing and notes supported the analysis throughout the process. The themes of the thematic analysis were formed inductively yet linked to the research questions as previously discussed. Divergent perspectives were also considered and interpreted as part of the whole. Finally, the themes were checked several times to ensure coherence and significance.

6 Results

This chapter presents the empirical findings of the study. The results are derived from both quantitative and qualitative analyses to provide a comprehensive understanding of the L/C digitalization. First, quantitative text analysis offers insights into data emphasis, sentiment, and regression models. Second, thematic analysis identifies the key themes and perspectives, providing contextual views that complement the quantitative findings.

6.1 Quantitative Text Analysis

This subsection presents the results of quantitative text analysis. First, the frequency and correlations of key themes are examined based on keyword-based content analysis. Next, the general and theme-specific tone of the data is analyzed using four sentiment tools. Finally, it is examined to what extent the different sentiment variables explain the adoption of digitalization in the context of the L/C process. The methods form a quantitatively structured perspective that supports the findings of the qualitative analysis.

6.1.1 Thematic Frequencies and Correlations

Content analysis was used to examine the distribution of the data across recurring themes and topics. Table 7 shows the frequencies of the main themes and topics via individual mentions. The results illustrate how the concepts appeared in the responses. In the Technology theme, Automation (166) and Integration (134) were the most frequently mentioned topics. Automation included keywords such as AI, OCR, and RPA. Respectively, Integration included keywords about connected systems, APIs, and interoperability. Surprisingly, mentions of eDocs (42) remained relatively low across the dataset. This likely occurred since respondents often referred first to existing documentation before discussing its electronic counterpart. In such cases, keyword-based content analysis may not identify mentions as it is not a context-bound tool.

The four main topics in the Benefits theme were evenly distributed across the data, with frequencies ranging from around 22% to 30% within the theme. However, Efficiency was the most cited topic (43). There was slightly more dispersion for Challenges, although again the frequencies were consistently distributed. Manual Work (48), Delays (32), and Errors (30) were the most frequently cited Challenges. The Neutral theme included recurring topics in the data that did not fit into the theme of Technologies, Benefits, or Challenges. Adoption was the most cited topic in the analysis conducted (243), including a wide range of keywords on the adoption of digitalization and implementation of digital solutions. The Digitalization topic (118) contained similar keywords to the Adoption topic, but without explicit references to implementation. Hence, its frequency was inherently lower.

Theme	Topic	Mentions	Mentions (% of theme)
Technologies (Total = 383)	Automation	166	43.3 %
	Integration	134	35.0 %
	eDocs	42	11.0 %
	Platforms	41	10.7 %
Benefits (Total = 143)	Efficiency	43	30.1 %
	Cost Saving	35	24.5 %
	System Integrity	33	23.1 %
	Cash Flow	32	22.4 %
Challenges (Total = 167)	Manual Work	48	28.7 %
	Delays	32	19.2 %
	Errors	30	18.0 %
	Uncertainty	20	12.0 %
	Complexity	19	11.4 %
	Communication	18	10.8 %
Neutral (Total = 407)	Adoption	243	59.7 %
	Digitalization	118	29.0 %
	Regulation	46	11.3 %

Table 7. Frequency of main themes and topics.

Table 8 presents the most cited topics by stakeholders for Technologies, Benefits, and Challenges. For Technologies, Automation was the most frequently recurring topic for all groups. The normalized values in Table 8 indicate the number of times the topic appeared per 1000 words. Therefore, it enables an equal comparison of topics between stakeholders, as it removes the bias due to different lengths of responses. The results suggest that bank respondents referred to Automation nearly twice as often as exporters and more than 2.5 times as frequent as freight forwarders.

Theme	Group	Top Topic	Mentions	Mentions Normalized
Technologies	Bank	Automation	84	21.0
	Exporter	Automation	66	11.0
	Forwarder	Automation	16	8.0
Benefits	Bank	System Integrity	24	6.0
	Exporter	Cash Flow	20	3.33
	Forwarder	Cost Saving	8	4.0
Challenges	Bank	Manual Work	15	3.75
	Exporter	Manual Work	28	4.66
	Forwarder	Errors	6	3.0

Table 8. Most frequently cited topics by stakeholders.

As for Benefits, banks were again the most actively engaged group by the frequency of mentions. Their most cited topic was System Integrity with six normalized mentions. The System Integrity topic included keywords such as trust, transparency, and compatibility, reflecting the connectivity, integrity, and security of digital systems. Moreover, the findings show that while banks emphasize the security and interoperability of systems, exporters focus on enhancing cash flow. In contrast, forwarders were most concerned with cost savings. Regarding Challenges, both banks and exporters highlighted the Manual Work. However, exporters highlighted the L/C process challenges most intensely, with a normalized mention score of 4.66. Forwarders most frequently referred to errors.

Table 9 demonstrates how different Technology and Neutral topics correlate with Benefit topics using Pearson's correlation coefficient. Pearson's correlation measures the linear dependence between variables and helps to identify direct connections in the data. The results show that the topics with the strongest positive correlation are eDocs and Cost Savings (0.81). Moreover, Cost Savings correlates positively with Platforms (0.54), Regulation (0.52), and Digitalization (0.35). System Integrity topic appears neutral overall. Looking at the most negative values, we find that Efficiency correlates strongly negatively with Regulation (-0.71) and Platforms (-0.65). In other words, the more the respondents referred to Regulation, the less they brought up factors related to Efficiency.

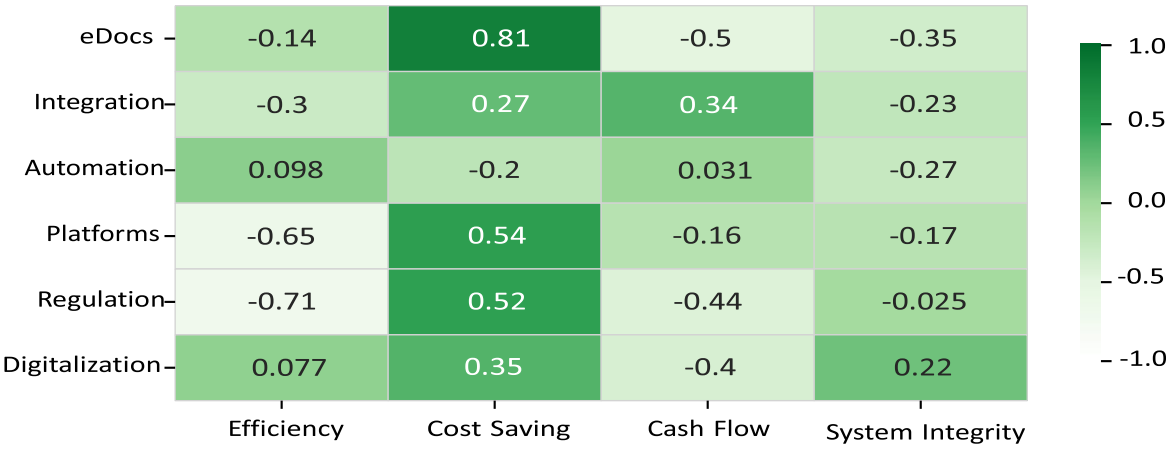

Table 9. Pearson correlation matrix of topics.

In contrast to the previous literature, Cash Flow-related discourse correlates negatively with eDocs (-0.5) and Digitalization (-0.4). This finding suggests that although eDocs is strongly seen as a factor contributing to Cost Savings, respondents do not perceive its direct impact on Cash Flow as clearly. However, discourse related to Integration correlates positively with Cash Flow (0.34). Thus, issues such as interoperability, connected systems, and interfaces were often linked to Cash Flow in respondents' discourse.

Table 10 shows the relationships between the topics using Spearman's correlation coefficient. Spearman measures the monotonic relationship between variables, meaning that it does not require linearity but instead examines whether values increase in the same order. Spearman can reveal hidden order relationships and is less sensitive to outliers than Pearson. For the most part, the results for both correlation coefficients are similar. eDocs and Digitalization have a strong positive correlation with Cost Savings in Spearman's correlation as well, suggesting that the digitalization of trade finance, and electronic documentation in particular, are consistently and broadly associated with lower costs, regardless of the linearity of the relationship.

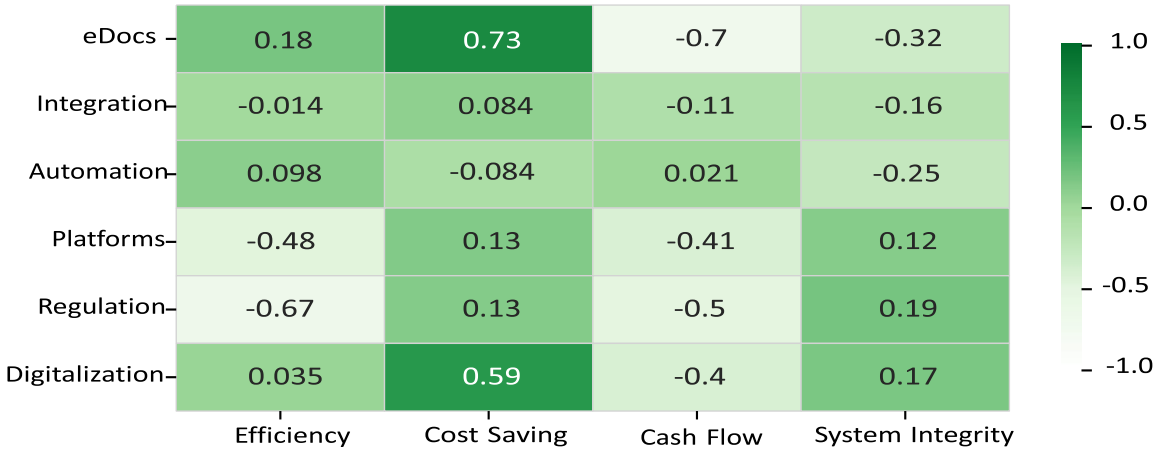

Table 10. Spearman correlation matrix of topics.

Spearman's correlation indicates a stronger negative relationship between eDocs and Cash Flow (-0.70) than Pearson's (-0.50). This suggests that the more respondents refer to electronic documentation, the more consistently their talk of cash flow benefits decreases. This pattern recurs systematically in the data, reflecting that respondents do not directly link their discourse on eDocs to liquidity. The correlation coefficients show a significant difference between Integration and Cash Flow. Pearson suggests that Integration is positively related to Cash Flow (0.34), while Spearman (-0.11) does not support this observation as an ordinal relationship. This finding indicates that although the topics appear linearly in some responses, there is no consistent relationship between them.

Regulation shows a strong negative correlation with efficiency, reflecting the interviewees' experiences of barriers to digitalization. Although eDocs could be expected to improve exporters' cash flow, the data did not reveal an explicit connection. In contrast, the connection was strongly negative. This may stem from the fact that cash flow improvements are often implicit to operational staff and therefore less emphasized, although evident. The correlations describe the co-occurrences of topics rather than direct business impacts, which are not conveyed linearly in the data. However, the results of the Pearson and Spearman correlations largely support each other, suggesting that the results are not random or dependent on individual responses.

6.1.2 Sentiment in Digitalization

Sentiment analysis using four different sentiment tools was conducted to assess the overall tone and the sentiment of individual responses. Figure 9 uses the NRC lexicon to present the most frequently occurring positive and negative words in the data. The figure shows that the most common negative words are challenge, problem, risk, and delay. Although the frequencies of negative words are relatively high, they remain lower overall compared to positive words. The data contains a wide range of positive and neutral words related to the customer perspective, deliveries, payments, and solutions.

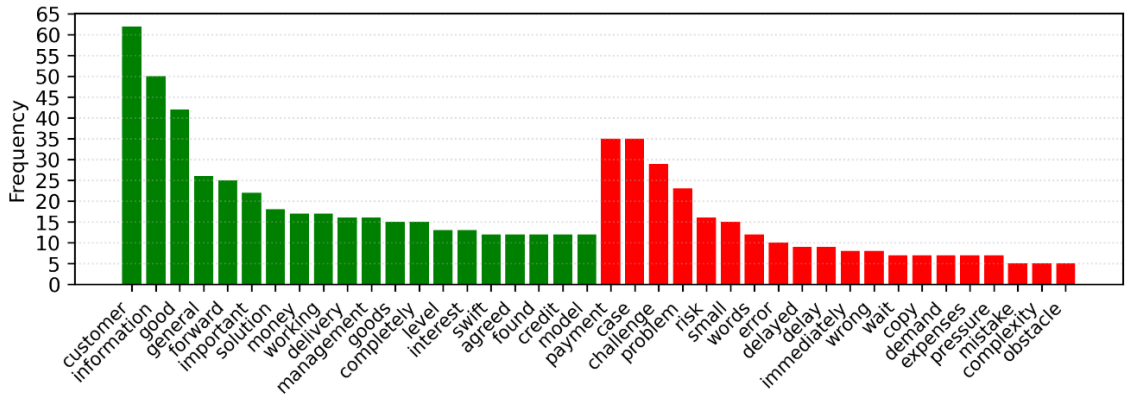

Figure 9. Most frequent positive and negative words based on the NRC.

Figure 10 looks at words that got the strongest negative and positive scores on average using the NRC lexicon. Sentiments were assessed by calculating the average sentiment for each word from all occurrences, but only words that appeared at least three times in the data were included. This selection eliminates biases caused by randomness. The most negative words were largely related to errors that were identified in the thematic analysis as part of the current complex process. The words do not only describe technical difficulties but also indicate the respondents' criticism of the processes. In turn, the most positive words were often related to control and clarity. This finding suggests that respondents associate positive sentiment with situations where they feel in control of the process and its progress. In contrast, negative sentiment is associated with situations where this sense of control is weak.

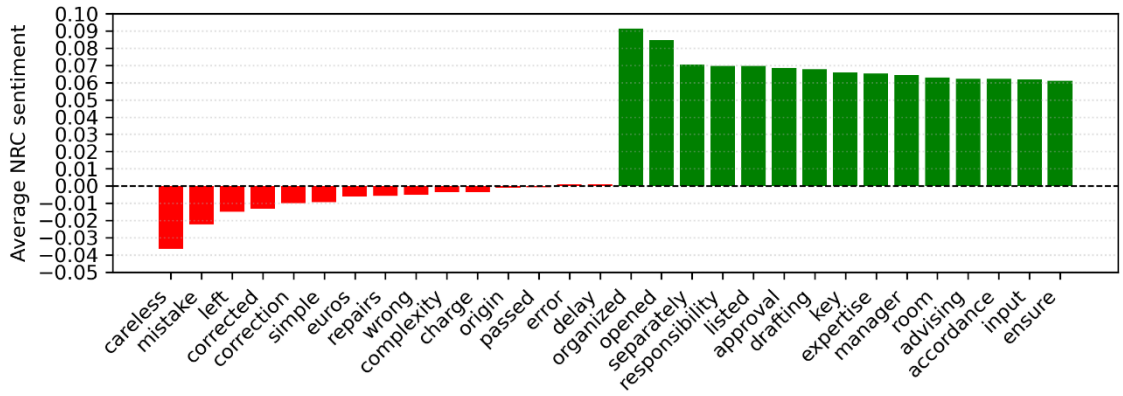

Figure 10. Most polarizing words by average sentiment based on the NRC.

Furthermore, sentiment related to digitalization was examined by stakeholders. Figure 11 shows the average sentiment score for each group using the TB and NRC lexicons. The sentiment score was calculated from responses that included references to digitalization. 95% confidence intervals were added to the figure to highlight the variation between stakeholders. TB suggests that the sentiment of all groups toward digitalization is positive. This lexicon estimates that the tone of the bank respondents was the most positive on average (0.119), followed by exporters (0.091) and freight forwarders (0.076). However, the confidence interval is widest for forwarders, indicating that this group has the most varied views on digitalization. The NRC lexicon yielded lower average sentiment

scores, which were nevertheless positive. The lexicon ranked exporters as the most positive group (0.031), followed by banks (0.029), while freight forwarders received the lowest score (0.017) in this lexicon as well. The confidence intervals are very narrow for exporters and banks, but the variation is more pronounced for forwarders. NRC measures the sentiment associated with individual words, which makes it more conservative and, to a certain extent, more limited in scope than the context-based TB.

The findings show that all groups have a positive attitude toward digitalization, with bank respondents being the most positive on average. The parallel use of two lexicons provides a reliable picture of sentiment, as the results are not based solely on individual observations or measurements. Based on the TB, the bank group's attitude toward digitalization is statistically significantly more positive than that of forwarders, as the 95% confidence intervals of the two groups barely overlap. However, no significant difference was observed between exporters and forwarders. According to the NRC, the differences between the groups remain small and the confidence intervals overlap, implying that no statistically significant differences were observed in the sentiments between them.

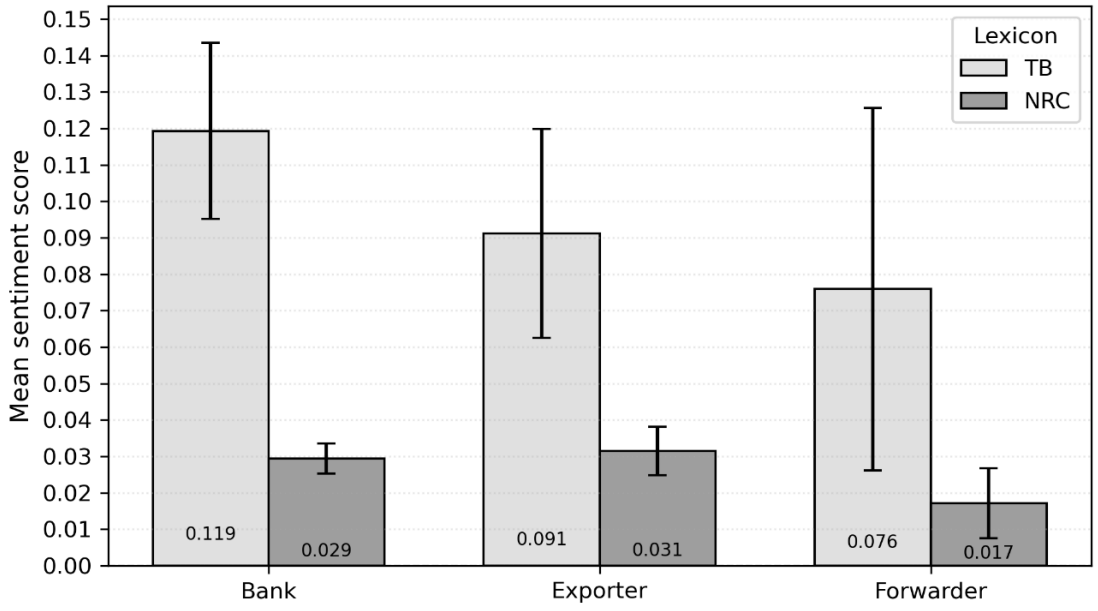

Figure 11. Stakeholder sentiment toward digitalization based on TB and NRC.

The benefits and challenges identified in the content analysis were examined in greater depth through sentiment scoring. Using each of the four sentiment tools, Table 11 investigates which Benefit topics had the most positive sentiment and which Challenge topics had the most negative sentiment. Since sentiment metrics use different measurement scales and emphasize sentiment differently, they are not directly comparable. Therefore, each metric assigned its ranking for each topic, from which a combined average ranking was calculated, considering equal weightings of each metric. This approach enables a comparable analysis between different sentiment tools.

Theme	Topic	TB	NRC	BERT	LM	Avg. Rank
Benefits	System Integrity	0.1236	0.0402	0.1667	0.0021	1.25
	Efficiency	0.1323	0.0296	0.0814	0.0007	2.00
	Cost Saving	0.0749	0.0210	-0.0143	-0.0008	3.25
	Cash Flow	0.0654	0.0303	-0.0156	-0.0079	3.50
Challenges	Delays	0.0506	0.0159	-0.1250	-0.0182	1.50
	Errors	0.0535	0.0148	-0.0833	-0.0262	1.50
	Complexity	0.0583	0.0251	-0.0278	-0.0009	3.50
	Uncertainty	0.1007	0.0247	0.1250	-0.0037	3.75
	Communication	0.1346	0.0274	-0.0278	-0.0024	4.33
	Manual Work	0.1194	0.0431	0.0000	-0.0024	4.33

Table 11. Average sentiment ranking of Benefits and Challenges.

The findings presented in Table 11 indicate that the most positive benefits were System Integrity and Efficiency. In other words, the discourse related to these topics was exceptionally positive, reflecting the respondents' expectations of the benefits of L/C process digitalization. Cost Saving and Cash Flow received lower scores on all sentiment metrics. However, this finding supports previous observations from the correlation coefficients presented in Tables 9 and 10, as Cash Flow correlates negatively with Technology topics. In other words, the topic was not typically associated with digitalization, but as found in the thematic analysis, it was often discussed in connection with the existing challenges. This association has likely contributed to the lower average sentiment for the topic.

The most negative Challenge topics were Delays and Errors, both with an average ranking of 1.50. The sentiment for both topics was negative as measured by BERT and LM, yet neutral as measured by TB and NRC. Manual Work and Communication received a more neutral ranking on average, which may be due to the use of neutral language in the discourse related to these topics, despite them being perceived as ineffective, as suggested by the thematic analysis. Furthermore, the results indicate that the positive sentiment associated with Benefit topics is slightly stronger than the negative sentiment associated with Challenge topics.

Table 12 presents the sentiments related to Technology topics across the entire data set. The average sentiment score was calculated for each solution based on each of the four sentiment metrics. For all topics, TB produced consistently positive scores. It provided the highest score for eDocs (0.137), indicating that the discourse related to electronic documentation was highly positive. In contrast, the LM lexicon provided only very neutral scores, with a negligible range of variation. In this respect, it is impractical to analyze the values produced by LM in more depth. However, the results are consistent with the characteristics of the lexicon, as it specifically measures the tone of text related to finance and economics, which tends to make it negative and less responsive to interview data.

Technology	**eDocs**	**Automation**	**Integration**	**Platforms**
TB Sentiment	0.137	0.102	0.111	0.114
LM Sentiment	-0.004	-0.000	-0.001	0.002
NRC Sentiment	0.028	0.030	0.042	0.027
BERT Sentiment	-0.024	0.054	0.011	0.122

Table 12. Average sentiment scores for Technologies.

Furthermore, the NRC lexicon's scoring was consistent. It produced positive values for all topics, with the highest being Integration (0.042). The other topics were consistently positive, ranging from 0.027 to 0.030. The results suggest that, according to the lexicon, responses related to interoperability and connected systems were the most optimistic or emphasized opportunities and trust. On the other hand, BERT indicated considerable variation between topics. It gave the highest average score to Platforms (0.122), followed by Automation (0.054). Integration was close to neutral (0.011), and, contrary to other sentiment metrics, eDocs received a distinctly negative score (-0.024). As opposed to vocabulary-based sentiment metrics, BERT analyzes the sentiment of sentences contextually. This implies that it may detect a reserved tone in the discourse, regardless of whether it contains positive references to the topic.

6.1.3 Explaining Adoption through Sentiment

Moreover, sentiment analysis was complemented by regression analyses examining the interdependence of key variables. Table 13 presents the logistic regression results for each specified model. The models aim to explain the probability of digital adoption based on different sentiment variables and stakeholders. All models were controlled for WC length and were statistically significant. For all models, positive sentiment associated with banks (P × Bank) is consistently positive and statistically significant. This finding suggests that for each increase in positive sentiment, the probability of discourse related to digital adoption increases significantly when the respondent belongs to the bank stakeholder group. Without the interaction term, the connection is not significant. Hence, the positive sentiment expressed by the banking group predicts concrete commitment to the digital adoption.

Variable	NRC Logit (1)	Plain NRC Logit (2)	BERT Logit (3)
Anger	-0.012 (-0.22)		
Anticipation	0.019 (1.46)		
Disgust	-0.121 (-1.86)		
Fear	0.016 (0.61)		
Joy	0.012 (0.43)		
Sadness	0.020 (0.56)		
Surprise	-0.039 (-0.96)		
Trust	-0.001 (-0.08)		
P.NRC	-0.013 (-0.68)	0.272 (0.18)	
N.NRC	-0.035 (-0.64)	2.173 (0.49)	
P.NRC × Exporter	0.051 (2.25) *	1.915 (0.99)	
P.NRC × Bank	0.084 (2.46) **	7.067 (2.10) **	
N.NRC × Exporter	0.020 (0.36)	-4.573 (-0.94)	
N.NRC × Bank	-0.023 (-0.36)	-3.397 (-0.61)	
P.BERT			-3.910 (-0.93)
N.BERT			-2.255 (-0.49)
P.BERT × Exporter			6.049 (1.31)
P.BERT × Bank			11.213 (1.96) *
N.BERT × Exporter			6.168 (1.23)
N.BERT × Bank			9.253 (1.54)
Exporter	-1.703 (-2.14) *	-0.259 (-0.28)	-3.903 (-1.30)
Bank	-1.107 (-1.20)	-0.966 (-0.83)	-5.775 (-1.67) *
WC	0.025 (4.67) ***	0.023 (4.91) ***	0.022 (5.01) ***
Constant	-0.374 (-0.50)	-0.867 (-1.01)	1.335 (0.48)
N	298	298	298
Pseudo R^2	0.365	0.287	0.264
Log-Likelihood	-90.534	-101.67	-104.87
Prob > χ^2	< 0.001	< 0.001	< 0.001

Table 13. Logistic regression results across three model specifications.

Note: Z-statistics are reported in parentheses.

Statistical significance is denoted by:

*** $p < 0.01$,

** $p < 0.05$,

* $p < 0.1$.

Exporters mentioned adoption less frequently on average than other stakeholders, as indicated by the negative and statistically significant Exporter dummy in Model 1. However, positive sentiment among exporters was significantly associated with adoption discourse, although the effect was weaker than for banks. This suggests that while exporters are more reserved towards adoption, they find digitalization appealing. Another interesting finding relates to the Disgust variable in Model 1. Although the emotion is not statistically significant, the negative value indicates that the more responses contain a dismissive tone, the less likely they are to be associated with digital adoption. Otherwise, emotions did not have a significant explanatory power in relation to adoption.

In all models, WC is a positive and highly significant explanatory variable. This finding may indicate that longer responses are more likely to refer to digital solutions, as they contain more extensive reflection or strategic visioning. Alternatively, it may indicate that responses discussing digitalization are inherently longer, which increases the likelihood of adoption in the data. Model 1 produced the best explanatory power. In contrast, Model 2 lost some explanatory power, indicating that the emotions in Model 1 added value to the regression. Although BERT provides contextual analysis, the model based on it was able to explain the least variation. This may indicate that the semantic sensitivity of BERT does not translate into stronger predictive power in this dataset. Based on the regression results, it can be concluded that positive sentiment is the most effective single indicator of adoption in cases where it appears in the bank respondent's response.

Figure 12 below shows the ROC curves and AUC scores for each regression model. The findings suggest that all models are significantly better than random classification at distinguishing responses related to the adoption of digitalization. The highest AUC value (0.89) was obtained with NRC Logit (Model 1), indicating that the model successfully utilized sentiment and emotion variations in assessing the likelihood of adoption. Models 2 and 3 received slightly lower scores, implying that emotions had a moderate explanatory power and that the deep learning-based contextual model did not match the accuracy of the vocabulary-based sentiment metric.

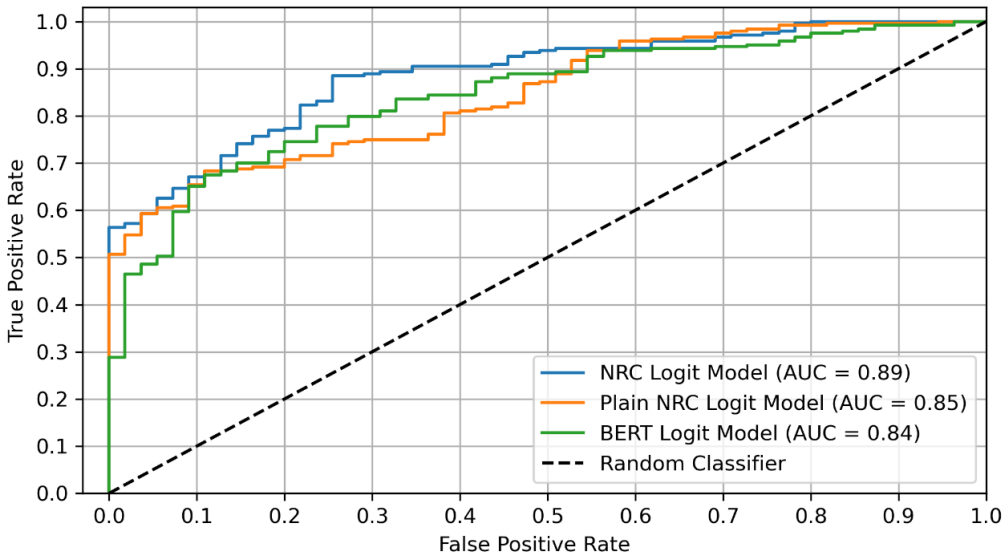

Figure 12. ROC curves and AUC scores for the logit models.

6.2 Thematic Analysis

This subsection presents the empirical findings of the thematic analysis. The interview data were systematically analyzed to identify underlying meanings, which were organized into six main themes. These themes structure the presentation of results and provide insights into how different stakeholders perceive the challenges, prerequisites, and implications of L/C process digitalization.

6.2.1 Existing Challenges

Respondents emphasized that the difficulties are not uniform across stakeholders but often stem from broader structural factors and the individual weaknesses of actors that hinder the ecosystem's modernization. E3 stresses that the challenges of the L/C process stem not only from paper-based and manual processes, but also from a long tradition of adhering to industry rules designed specifically for a paper-based process. Similarly, E5

criticizes that the existing rules are outdated and too permissive, allowing the counterparty to demand a wide range of varying terms, which renders the L/C an unstructured and complex instrument. Conversely, E1 outlines the challenges of the L/C process holistically at the ecosystem level. They describe that the process consists of consecutive pieces and several stakeholders, resulting in a wide variation in processing capacity at different stages. This translates into no one precise element to solve, but from a distance, the individual weaknesses of the participants accumulate into an inefficient process.

E1 further reflects this perspective in the digitalization efforts within the sector. They explain that banks' production mechanism is IT, implying that banks have abundant resources and capabilities to digitize. This contrasts with small businesses having few L/C transactions, as their cross-border trade relies heavily on bank solutions. Furthermore, E1 raises the question of when the L/C should specifically be enhanced and when the focus should be on the underlying trade process. The trade process remains irrespective of whether the L/C is redesigned or removed. They point out that several pilots have failed to serve the L/C and the trade process equally. Some of the developed solutions have not been compatible with the trade process, rendering the achieved digital process practically unusable, as different approaches are required for freight transportation.

E3 acknowledges the complexity of L/Cs and expects them to be threatened in the future by automated payment instruments. They argue that unless the L/C can be simplified through digitalization, alternative electronic payment undertakings could displace it. They underline that L/Cs incorporate good risk management features that would be unfortunate to lose. E3 considers that to secure the existence of the L/C, the only option is to modernize the product to allow for a digital exchange of information independently of paper. Digital tokenization on the bills of exchange and promissory notes is progressing in a way that could compete with L/Cs, while the OA payment method is becoming more common for standard transactions. The respondent expects L/Cs to evolve into complex instruments serving specialized trade, as the current cost structure and operating model are unlikely to remain viable over the next five to ten years.

The case company uses a SWIFT-based multi-banking system to process L/Cs. The platform does not cover the whole process, as from the Trade Finance team's point of view, drafting, advising, tendering, amendments, and ERP updates are done outside the platform (I1, I2). Moreover, I3 describes that the Export Documentation team drafts documents outside the tool. The invoice is created in the ERP system, the transport document is obtained from the forwarder, and other documents are created in-house. Once the documentation set is prepared, it is presented to the bank via the multi-banking system.

Labor was identified as the largest cost item in the exporter's L/C process (I1, I2, I3, I4). I2 stresses that drafting the L/C with the customer and reviewing the opening text consumes a lot of labor time. The interviewee estimates that with a familiar customer and established terms, drafting is simple and can take only a day. However, with a new or geographically challenging customer, drafting can take several working days. They report that the receipt of the L/C opening is dependent on the customer's bank. The duration typically ranges from a few days to weeks but can be months in challenging instances.

I3 reflects the intensity of the process from the perspective of document preparation. They note that human resources are barely sufficient to manage the volume of presentations, which has increased significantly over the past couple of years. I3 cites two primary reasons for the increased number of presentations: the Chinese market has continued to grow, and there is insufficient consolidation in the supply of goods. The interviewee estimates that it takes an average of four hours to prepare one presentation. They stress that creating a document presentation requires the employee to be present in the company's office, as it involves handling physical paperwork. They estimate the cost of mailing to be between €30 and €50 per submission.

I1 notes that the high number of partial deliveries entails additional costs, as each presentation incurs a standard cost and a percentage cost. However, I2 estimates that the costs charged by the banks are proportionately far lower compared to labor costs.

Furthermore, I1 points out that L/C payments are inherently slower than advance payments, tying up capital. Drawing on the data, the exporter's main challenges can be roughly sorted into four categories: the L/C drafting and terms management, communication with the logistics side, document preparation, and the role of the customer and its bank in the L/C opening process. I1 and I2 identify drafting and terms negotiations as the most time-consuming stages for the Trade Finance team. I1 adds that the underlying contract determines the accuracy of documentary requirements and whether deviations are required during the drafting period, while E1 affirms that effective management of L/C terms strongly affects process fluidity.

I1 argues that the logistical plan has a central impact on how fluent the negotiation is with the customer. Complex shipments require a variety of optional L/C terms, which can complicate how quickly the customer accepts or understands the terms. Additionally, many case company respondents highlight communication challenges with logistical side (I1, I2, I3). Specifically, identifying the transport plan to support L/C drafting is difficult due to limited information flow, and such gaps often delay document presentations when goods are dispatched without prior notice to the documentation team (I3).

E1 notes that the more manual and fragmented the L/C process is, the higher the likelihood of errors, which overemphasizes the paper-based aspect. E1 estimates that up to 75% of documents are sent for correction following the bank's examination. Similarly, I1 and I4 report that document discrepancies delay L/C payments. I3 indicates that, beyond document preparation, communicating and reviewing the transport document is the most time-consuming task for the Export Documentation team. Accordingly, the original transport document, typically the ocean B/L, is seen as a major bottleneck (I1, I3).

Finally, respondents refer to the central role of customers and their banks. I4 suggests that the wide geographical spread of customers and their banks create complexity for the process. They estimate that a simplified business environment would require less skilled trade finance specialists, allowing costs to be reduced. The process payments are

seen to be heavily dependent on the customer processing the L/C on time with their bank (I1, I2, I4). I2 reports that the L/C opening process tends to create a bottleneck, resulting in delayed reimbursements. Furthermore, I5 notes that besides the delays and country risk, increased compliance measures by banks have continued to increase, posing challenges to the process.

Identified Challenge	Description
L/C drafting and terms management	Manual drafting and negotiations are time-consuming. Manageability of L/C terms determines the process fluidity.
Communication with the logistics department	Identifying transport plan challenges the L/C drafting. Communication gaps with the logistics side delay the document preparation.
L/C opening process	Payments depend on the customer processing the L/C on time with their bank. The opening process tends to create a bottleneck, resulting in delayed reimbursements.
Document preparation	Manual work and high volume of presentations make document preparation challenging and prone to discrepancies. Original transport document can form a bottleneck in the process.

Table 14. Main L/C process challenges within the case company.

E1 argues that from the bank's perspective, the most time-consuming element of the process is the correction cycle, as a significant proportion of documents are sent for correction. Errors in document preparation increase banks' processing time considerably. E2 describes the L/C process as complex and demanding for banks. Similar to I5, they report that the compliance aspect has introduced a significant burden on the process. Increasingly, banks are required to screen trade participants for sanctions, money laundering, and ESG factors. The interviewee summarizes that these additional processes, piled on top of the product, increase the complexity and workload for banks.

Conversely, E3 highlights that it is essential for the banks to raise awareness of trade finance digitalization internally. E3 argues that there is a strong case for digitalization efforts, as banks are constantly being forced to deliver more value with diminishing resources. They note that trade finance is not the largest or most profitable business for

the banking sector, forcing banks to make certain trade-offs in their resource allocation. The interviewee claims that if banks fail to address this issue, they may be forced to cease operations where other entities are better placed to meet the digital requirements. This insight supports the findings of Grassi et al. (2022) on the future role of banks.

From the forwarder's standpoint, the process is generally efficient. F2 notes that delays mainly occur while waiting for the shipment to depart, as the carrier issues the master B/L only after dispatch. F1 adds that B/L preparation can be slowed by delayed confirmation during document review. According to F2, communication between parties is another common cause of delay, since the forwarder cannot finalize the document until receiving confirmation from the exporter. Occasionally, communication errors related to L/C requirements require B/L corrections. F1 highlights that the main challenge arises when the original document has already been mailed but must be amended. Nevertheless, both respondents report that errors are uncommon.

6.2.2 Prerequisites for Digitalization

Successful digitalization requires fulfilling several conditions within the trade finance ecosystem. Based on the data collected, this theme examines these conditions across legal, technical, and organizational dimensions. E3 identifies four fundamental elements for effective and holistic digitalization. First, the business side must understand the rationale and objectives of the transformation. Second, open and accessible standards must be in place. Third, digital trust is essential to ensure that stakeholders and goods can be represented reliably in digital form. By defining digital twins of the company, its representatives, and the delivered product, the counterparty can verify the authenticity of the actor involved. Finally, a supportive legal framework is required to recognize digital transactions and documentation. E3 underscores that the necessary solutions already exist but must be properly integrated, noting that technologies are not a burden but a tool to implement the vision.

E5 sees that regulation and standards play an extremely important role in digitalization. They note that L/C rules require a clearer structure to ensure that terms and data are produced consistently. E5 considers that precise legislation would contribute to banks' confidence in working with electronic instruments. E4 agrees on the key role of regulation and notes that without timely implementation, the lack of regulatory framework hinders digitalization. Moreover, E3 highlights that while it is generally thought that digitalization is simple in Nordic and developed countries, this is not always the case. They argue that historical and legal burdens may limit digitalization in Nordic countries relatively more than in digitally white regions such as Africa.

> Quite often, there are surprises in how quickly a country can change its ways of doing things, to rapidly enact legislation that enables easier foreign trade and improved foreign exchange reserves in that country. If we think rationally from a business point of view, suddenly we can implement many technical solutions that facilitate doing business. (E3)

Moreover, E2 indicates that operating in a digital L/C process would introduce the eUCP aspect, for which there is little practical experience so far. They suggest that the electronic framework of rules requires further investigation but is unlikely to be a major concern going forward. E3 expects that eUCP and URDTT are most likely to undergo refinement as the digital way of doing business becomes increasingly common. E5 identifies legislation as the cornerstone of electronic documentation, suggesting that it can be implemented to a certain extent in today’s transactions, but it is not widely scalable as the destination countries require paper documents. However, E4 estimates that a timeframe of around five years is sufficient to establish the necessary legal framework.

Interviewees consider it important that the ecosystem is governed by precise and common rules and standards (E4, E5). These factors contribute to the end-to-end digitalization and the integration of platforms and digital processes. However, E1 emphasizes that while regulatory modernization is a prerequisite for electronic documentation, it does not necessarily translate into all stakeholders going digital. E1 argues that further regulatory measures may be required to ensure all stakeholders engage in the new practices.

From a technical perspective, E4 states that a fundamental condition for digitalization is systems that enable the digital processing and transmission of B/L and other transferable documents. However, E5 stresses that currently, the implementation of the systems is hindered by unclear governance structures and uncertainty over the required connectivity. The interviewee adds that the upfront cost of the platform is not a critical barrier for companies, but rather the uncertainty of the investment. E3 discusses the issue from the perspective of an organization's existing operational structure. They argue that groundwork must be established to implement value-added tools. Where an organization's processes are purely manual and the underlying systems do not integrate well, streamlining the existing processes should be the priority. Moreover, E3 underlines the key role of APIs in achieving external integration.

E4 reports that the current direction is to seek and promote interoperability between different actors through integrations. E3 agrees that achieving API-based integration with the closest stakeholders is a priority for the exporter. E4 believes that focusing on standards would greatly facilitate the implementation phase of integrations. Furthermore, pilots and market maturation are required to discover an efficient way of working with the L/C process through integrations. Organizations should pay attention to the global alignment of processes, as without exception, large exporters operate in multiple markets, where fragmented practices create administrative burdens and extra costs (E4).

> We can't think the world will ever be such that we have one great tool where everybody registers and accesses things. Instead, you have your systems, while your bank and counterparty use other systems. However, they have seamless and, in a way, agnostic integration, so that regardless of what system you use, you can operate in the digital process. (E4)

E3 emphasizes that an organization must be capable of producing and transferring data reliably and traceably. Moreover, systems should enable access to sustainability and sanction registers to ensure that operation meets the requirements of financiers. “It is also important for us as a bank that we only support and finance companies that commit

to these modern world demands" (E3). Similarly, I4 highlights that to improve the transparency and traceability of the value chain, it would be valuable to be able to produce a product's digital image for the stakeholders. I4 argues that if all actors could generate their data in a digital and structured way, the sector's digitalization would leap forward.

From an organizational standpoint, several banking professionals emphasize the importance of in-house groundwork and preparation ahead of digitalization (E1, E3, E4). E1 suggests that since fragmentation is a serious challenge, a company must achieve visibility and coherence within the process to benefit from digitalization tools. They argue that in a complex workflow, paper can be even more manageable than digital files. Similarly, E4 stresses that a company must prioritize the harmonization and optimization of document creation and other aspects of the process to reach internal process quality by the time the external environment is ready to migrate to digital.

In turn, E3 underscores that the organization's internal systems should be easy to integrate to enable external interoperability and system development. Furthermore, the interviewee notes that it is not always appropriate to seek exclusively technical solutions to deliver the desired efficiency gains.

> It may not always be about the tools. More often, it may be more a matter of abandoning traditional ways of working and carefully evaluating where internal practices can be improved. Once the internal factors have been addressed, one must also consider how interest groups operate and look for partners. (E3)

Several interviewees expect the initial investments and operating costs associated with digitalization and electronic document platforms to be moderate (E2, E4, E5). Interviewees consider that various proof of concepts and pilots could be trialed at low up-front costs without licenses before the investment decision (E2, E3). Moreover, E2 and E5 reflect that investments are constrained by the uncertainty in choosing a specific platform, not by costs. Interviewees were not inclined to provide precise estimates of investment costs. However, E5 anticipates that costs will be in hundreds of thousands of euros rather than millions.

Consistent with the findings of Rogers (2003), E3 suggests that early adopters can contribute to cost savings as each party finances its own costs without licenses or additional fees. Alternatively, they underline that participation in pilots requires active market monitoring and testing of platforms before final investment. These efforts require resources and generate costs. However, the interviewee reflects that costs are also incurred by avoiding change and thus losing business opportunities. Moreover, E3 states organizations must be prepared to invest in the necessary systems and take prudent risks. They stress that acquisitions may occur, or players may disappear from the market, requiring additional investment or re-implementations.

6.2.3 Factors Promoting Adoption

In line with Auboin (2021), respondents point out that the Covid-19 pandemic temporarily disrupted trade finance but acted as a catalyst for digitalization (E1, E3, E4). The pandemic highlighted the importance of being able to operate digitally, leading to a greater allocation of resources to digital transformation. However, E1 argues that once the initial shock subsided, ecosystem participants realized that it was viable to continue with the existing operational structure. According to the interviewee, this weakened the momentum, and matters did not progress as far as expected. Additionally, compared to five years ago, competition in the sector has taken a more collaborative form (E3). Today, it is typical to compete on services rather than technology. That is, it is a question of who can provide a service in the most technically easy and integrable way.

Multiple respondents cite the impact of legislation and the ICC in promoting digitalization (E2, E3, E4). E3 reports that in the aftermath of the pandemic, the ICC established the Digital Standards Initiative, which is dedicated exclusively to fostering the digitalization of global trade. The ICC has introduced valuable tools to the sector and facilitated digitalization by lobbying policymakers and the business community (E2, E4). Furthermore, interviewees underline the key role of MLETR as an enabler of digitalization (E2,

E3, E4). E3 believes that as MLETR adaptations are made in critical markets, new types of bill of exchange and promissory note processes will begin to emerge, enabling a new way of financing global trade. The interviewee adds that their institution's consolidation on a single back-end system contributes to their ability to develop APIs beyond SWIFT to customer interfaces and different actors.

Case company respondents indicate that the company is equipped and willing to develop its operations (I1, I3, I4). However, they cite that many solutions and greater efficiency gains would require external development and stakeholder involvement (I3, I4). Similarly, E2 believes that all digitalization requires some degree of value chain involvement.

> Process improvement, the pursuit of efficiency, automation, simplification, standardization, and so forth, are the things we definitely want to do. However, since [the case company] is a growing business, the question is how we can manage and support a growing business without raising [the department's] costs a lot. (I4)

E5 notes that many organizations in the Nordics and Europe use multi-bank tools, which are expected to support the development and adoption of digital documents. Similarly, E3 anticipates that existing digital end-to-end processes in bank guarantees will foster progress in other trade finance products. Furthermore, E3 highlights the importance of robust back-end systems to enable business analytics. In the current global environment, precise control over tenors and amounts of funds tied up in long-term instruments is seen as crucial, and digitalization can further facilitate reporting and data transfer.

E2 suggests that exporting companies can promote digitalization by being proactive. They encourage exporters to scan their trading partners and to communicate openly with their banks. E2 believes that exporters have an important role and position to play in mapping industry capabilities and pushing stakeholders forward. F1 indicates that an exporter can pursue digitalization in partnership with a forwarder through open communication. The interviewee notes that it is essential to ensure system interoperability and that both sides are on the same level of development.

Interviewees refer to the prominent roles of China and Singapore as drivers of trade finance digitalization (E1, E3, E4). E1 explains that China's extensive use of L/Cs as a control tool and its dominant market share create a strong incentive to adopt electronic documentation. They argue that if Chinese imports move to electronic documentation, the willingness of Chinese banks to accept them as collateral will increase, potentially triggering a spillover into export markets. E3 further highlights China's role, noting that the Belt and Road Initiative seeks to expand transferable documents beyond sea freight to road, rail, and air transport, strengthening the financial aspect of logistics. E4 adds that several other Asian countries are also playing an active role in accelerating digitalization.

6.2.4 Technologies and Solutions

This theme explores respondents' perspectives on technical feasibility, applicability, and implementation requirements of potential technologies and solutions. The following section examines the operational and financial impacts of digitalization in greater detail. Respondents generally considered a five-year horizon ambitious for comprehensive digitalization (E3, E5). However, many expected that, as digital transformation is locally envisioned, several solutions are realistically achievable (E2, E3, E4, E5, F1).

Banks indicated that their processes are largely built on a single system supported by APIs to ensure interoperability (E1, E3). This approach aims to enable digital communication with stakeholders, and a seamless transition to digital means as the market matures (E3). E1 reports that their organization relies on a single system that is widely integrated in-house. It enables the administration of L/C responsibilities and all SWIFT traffic. Excluding documentation, their L/C process has no paper or discontinuity points internally, as data is transferred across systems via APIs. Similarly, E3 reports that their organization has made a great effort to migrate 90% of its dozens of different systems to a single back-office system. E3 argues that through APIs, the ongoing migration will enable open access to competing platforms alongside the closed and traditional MT798.

E2 states that their bank utilizes OCR to some extent for sanctions screening, and robotics to automatically extract data into certain fields. Beyond the updated back-end systems, bank respondents also identify a few other pilots that have been carried out or are underway. E3 reports that their bank has implemented electronic signature tools in the wake of the pandemic, which was the first tangible step towards electronic documentation. E1 reports that their bank experimented unsuccessfully with blockchain, while AI testing is ongoing. However, E1 notes that no suitable use case for robotics has been found, as it either does not fit the process or integrations has rendered it unnecessary.

6.2.4.1 Electronic Documentation

E4 estimates that by 2030, legislation supporting electronic documentation will be in place. E5 asserts that eB/L is technically feasible by 2030 but doubts implementation due to cost considerations and lack of wider stakeholder engagement. Furthermore, E2 does not envision a completely digital transactional world within another five years. However, the interviewee suggests that it is likely that authenticated digital B/Ls will be transferred via platforms, while other documentation outside the import formalities will be processed as PDF copies under a single electronic presentation. In turn, F1 expects electronic documentation to be realistically achievable by 2030 but does not believe that all countries will take up development at this pace.

Banks express a willingness to adopt electronic documentation, although some uncertainty arises regarding legalities and a lack of hands-on experience (E1, E3, E4). E4 is confident that banks are prepared to use electronic documents shortly. They argue that banks should not be too demanding in terms of background systems, provided that the legal framework is in place. E3 claims that their bank has laid the groundwork internally for the introduction of electronic documents. However, the organization needs to have further discussions with legal compliance on the prerequisites for adopting eB/L as part of the documentation set.

Case company respondents believe that the company should prioritize eliminating physical transport documents in its digitalization strategy (I1, I3). I3 argues that following this step, the entire documentation set should be produced electronically. The interviewee emphasizes that, in principle, all documentation is available electronically, but paper presentations incur additional work and costs. I4 reports that the case company has conducted a pilot around a paperless L/C process.

However, I4 reflects that the data was not systematically accessible. The respondent argues that the issue culminates in data models, data availability, and the data lake approach. E1 underlines that electronic documents work technically, yet market pilots have remained isolated experiments. The interviewee believes that China's shift to electronic transport documents for customs clearance would be a boost to wider uptake. Moreover, as previously discussed, a key challenge is selecting a platform to enable electronic documentation, since all parties aim to opt for low-risk and far-reaching investments (E2).

Several respondents considered partially digital document presentations feasible (E2, E3). E2 viewed a hybrid approach as achievable under eUCP rules, although it would require support from a specific vendor to implement electronic transmission of transport documents. E3 agreed that future presentation sets will combine paper and digital elements and noted that existing solutions, such as Enigio’s trace:original, already enable secure electronic document exchange without major system changes. According to E3, this system supports MLETR compliance by ensuring document transferability. In contrast, E1 emphasized that partial digitalization can create challenges for banks, as assembling documents from multiple sources may increase delays and process complexity unless effectively managed.

6.2.4.2 Automation

Respondents agreed that AI's role in L/C digitalization lies in streamlining support processes rather than replacing human involvement. E1 argued that there is no comprehensive solution that can effectively automate processes without human intervention while maintaining adequate risk management. However, they suggest that AI agents can optimize the process by compiling data and reducing manual work steps. Similarly, I2 and E2 noted that AI could create structure and support human decision-making. Case company respondents saw particular potential using AI for document review and reconciliation, where human validation would remain essential (I1, I2, I3). This would greatly streamline manual work and contribute to clean document presentations. However, I1 emphasized that such applications would require standardized document formats across customers, which is currently unrealistic. E4 added that implementing AI in global export companies would require integration with existing systems to ensure access to relevant data, while I2 stressed that adoption would also demand significant internal effort.

While respondents recognized the potential of AI, its current capabilities were perceived as limited, specifically in varying environments (E1, E3, E4, E5). E1 argued that new-generation AI solutions either work or they don't. They specify that if AI needs to be continuously trained, it is not possible to fully benefit from its rapid development cycle and scalability. This observation was supported by I4 and E4, who reported that years ago, AI tools such as Traydstream were capable of processing simple, standard cases but failed immediately when encountering exceptions or context-dependent cases.

The respondents indicated that the limited applicability of AI to the L/C process stems from the inconsistency of data and processes. I1 and E5 emphasized that the significant variation in the format and content of documents prevents the effective use of AI in trade finance. Hence, the need for standardization was highlighted in most responses, as AI is unable to learn from data where transaction volumes are relatively small and variation is high. This perspective challenges the idea that AI itself is a silver bullet for process efficiency.

> It would be better to have absolutely clear rules and to avoid long and complicated definitions. Instead, specific rules, conditions, and matters should be selected to ensure that the data is truly accurate. (E5)

E5 argues that using AI to automate the manual steps of the process is a temporary fix rather than a solution to the root cause. They suggest that true efficiency requires a structured and consistent operating environment in which AI can be applied selectively. This emphasizes the idea that AI serves primarily as a supporting tool rather than a fundamental solution for process development.

Similarly, E3 and E4 emphasized that structured data reduces errors and enables accurate checking. On the other hand, E5 questions the role of AI in an environment that is fully standardized and where simple rule-based automation might suffice. Consistent with the findings of previous literature (Mahadevkar et al. 2024; Baviskar et al. 2021), E1 argues that RPA requires highly standardized input to prevent cases from being transferred to deviation processing. In contrast, AI can thrive in less structured environments, although reliability is not yet at a sufficient level, which is why many control points are required. This observation is aligned with E4's view that the role of AI in certain applications is already well established, but its future role in the L/C process is still evolving.

E3 notes that the use of AI in trade finance could begin with AI-assisted document creation and revision, and in the future expand toward the use of generative AI as part of key functions in the trade process. In the long term, they believe that AI agents will become an integral part of trade finance teams. However, they emphasize that for agents to function as independent actors, they require more structured input. "Standardization of incoming data is essential." (E3)

6.2.4.3 Integration

Respondents agree that integration and interoperability are key prerequisites for the L/C process digitalization. E3 argues that before a company implements third-party solutions, it should ensure the interoperability of its internal back-end systems. They add that if there is no established, efficient, and clear structure for document processing, it is not reasonable to implement digital tools, as added value is only created when the company's in-house processes are up to date and the systems are integrable. E3 explains that their organization has been working for years to transition to a single back-office system, which they believe will enable the bank to effectively build interoperability with customers and system suppliers, utilizing API interfaces alongside MT798. According to the respondent, the transition to a single system will enable the bank to connect to the required digital solutions on the market within a five-year timeframe.

However, E1 highlights the challenges of API-based integration in the L/C process. Since the process is bidirectional and involves several varying steps, integration between participants can become cumbersome. E3 adds that, ahead of digitalization, it is important for companies to allocate sufficient resources to API integration, either through a partner or their own team. This enables smooth information exchange with key stakeholders.

Furthermore, several respondents highlight the importance of standardization. As discussed earlier, E4 emphasizes that the future of trade finance is based on an agnostic ecosystem, where all participants use their systems with integrations ensuring the information flow. E2 reports that the industry has been moving towards standardization. They argue that a few years ago, banks were carefully considering which vendor to use, as they could not invest in multiple platforms. However, the focus has now shifted to different systems communicating with each other, and choosing a particular vendor does not necessarily impose restrictions.

As a concrete example of integration solutions, E3 highlights single window systems used by customs and authorities, which enable the exchange of documents and information between key trade participants through a single interface. Similarly, E5 underscores the eB/L implementation Enigio, where an ocean B/L can be transferred as a file between participants. Moreover, the respondents refer to multibanking tools, which they believe could already be connected to the L/C process via API interfaces. Specifically, bank respondents perceive integration as the foundation for internal and external digitalization within an organization. While integration requires resources and expertise within a company, it equally depends on market-wide standardization and interoperability to enable seamless communication among stakeholders.

6.2.5 Impacts on Business Performance and Scenario Analysis

A key theme identified in the thematic analysis was the benefits of digitalization. This section summarizes the respondents' views on the achievable operational benefits and cash flow impacts. Moreover, this section presents a scenario analysis, which quantifies the financial impacts of electronic documentation using the case company’s data and the qualitative insights from interviews.

Respondents consider that the L/C process digitalization brings significant operational benefits, specifically in terms of documentation and manual work stages. Many respondents believe that costs and manual work can be significantly reduced, yet the benefits will not be evenly distributed among different stakeholders. E3 and E5 expect that the introduction of electronic documents could roughly halve documentation-related costs. Respondents estimate that savings would occur through reductions in postage and processing costs, as well as manual labor. Moreover, E2 estimates that banks' labor costs could be halved, given that a functional AI agent would be able to check L/C terms and perform sanctions screening. However, respondents emphasize that working with details in diverse environments still requires human presence until the ecosystem reaches a sufficiently high level of standardization (E5, F2).

For exporters and forwarders, it is expected that electronic documentation accelerates the process and reduces costs, as the use of eB/L eliminates courier costs and weeks of delays due to the transfer of physical documents (E5, F2). However, banks perceive the benefits to be more limited, as the mere transition to electronic documentation does not eliminate the work involved with L/C terms and compliance checks (E2). On the other hand, E3 emphasizes that the digitalization of trade finance is not a matter of replacing people. On the contrary, they see it as supporting the daily work of professionals by transferring their expertise into the information tools. The respondent argues that digitalization allows the advantages of L/C to be retained while improving efficiency and reducing the complexity of the current process.

E3 argues that benefits can be achieved with moderate investments. Pilot projects allow firms to gain cost savings and valuable experience before license fees or operating costs arise. A gradual, step-by-step approach helps build a solid foundation for digitalization. E3 notes that greater efficiency gains will only be realized in the longer term through standardization, harmonization, and investments. However, the respondent points out that total costs do not decrease in the same proportion as transaction costs. The introduction and integration of new systems require investment, and there is a risk that the chosen solution will not prove successful. Thus, investments yield benefits gradually, and the transition requires long-term work.

Several respondents indicate that the physical B/L is the most significant factor constraining the exporter's cash flow. I1 argues that merely digitizing the B/L would significantly accelerate the current process, even if other documentation were still processed traditionally. The views of E2 and E5 support this statement, as the respondents estimate that the existing process could be shortened to a matter of hours with the help of eB/L and electronic presentations. More specifically, E2 estimates that the process could accelerate hundreds of percent, while E5 highlights industry pilot cases where banks received electronic documents in a few hours instead of the current 3-4 weeks.

For exporters, the acceleration of the process translates into faster collection of receivables. E5 emphasizes that receiving payment for a million-euro shipment in weeks instead of six weeks significantly improves cash management. Moreover, forwarders highlighted the significant benefits they have experienced. F2 reports that their organization has experience using eB/L for the master B/L between them and the carrier through the WAVE platform. They indicate that while delivering a paper B/L from Finland to Brazil by courier costs €100 and takes a week, transferring the document through the platform costs $15 and typically requires only half an hour. However, F1 and F2 emphasize that for forwarders, eB/L does not greatly reduce the working time spent on document processing, but its benefits are based on a reduction in delays and postage fees.

While respondents recognize the cash flow benefits of electronic documentation, E2 and E4 point out that, from the banking perspective, L/C terms and compliance checks still need to be performed by humans. Respondents emphasize that this part of the process will only be significantly accelerated when documents are truly data-driven and inspection efforts can be further automated. Moreover, E1 argues that the electronic nature of documents does not in itself eliminate delays if the presentations contain errors.

E3 notes that improving cash flow supports the export company's working capital management. Digitalization is not only about accelerating individual transactions, but also about enabling organizations to more effectively manage their capital exposure to long-term financial instruments, conduct business in challenging countries, maintain flexibility in uncertain market conditions, and collect receivables more efficiently. In this context, the respondent emphasizes the importance of reporting and analytics, which builds on solid back-end system support and partnerships with banks.

> This is also the risk management perspective. The better the background system support, the easier it is to perform business analysis, and in the current global situation, it is extremely important to have precise control over where the funds are tied up and where they can be easily released if necessary. (E3)

To further quantify these impacts, a scenario analysis estimates the cost savings achievable by implementing electronic documentation in the case company's L/C process. The analysis builds on Monte Carlo simulations, which included four key process components. These consisted of the reduction in document processing time, postage costs, errors, and the total duration of the process. The parameters were derived from interviews and the case company's system data. The cost components were modelled using simple triangular and PERT probability distributions, which allowed for variation and uncertainty to be considered. All estimates are based on the case company's average L/C value.

Adoption rate (%)	Consevative		Estimate		Optimistic
20 %	242	323	404	484	565
40 %	484	646	807	969	1130
60 %	727	969	1211	1453	1695
80 %	969	1292	1615	1938	2261
100 %	1211	1615	2018	2422	2826

Total savings per document presentation (€)

Table 15. Scenario analysis of electronic document presentation cost savings.

The results in Table 15 suggest that fully electronic document negotiations can enable significant savings. The middle column of the table shows the estimated cost savings at different levels of adoption. At 100% utilization, the indicated cost savings would average €2,018 per document presentation. In the more conservative scenarios presented in the left columns, the cost savings would be around €1,200 at full utilization. The right columns show more optimistic scenarios, where full implementation would result in an average of nearly €2,800 per presentation. Thus, merely partial implementation offers significant potential. The key mechanism for the savings is the reduction in the total process time. Based on the analysis, the case company's presentation time could be reduced by an average of around 27% and the banks' processing time by approximately 18%. The total duration from the delivery of goods until the issuing bank receives the document set is estimated to decrease approximately 32%.

The distribution of savings between different cost components is distinct. Approximately 7% of cost savings are due to reductions in postage costs, labor time, and errors. On the other hand, approximately 93% of the savings are due to reduced process lead time, which was quantified as an improvement in cash flow. Specifically, the cash flow impact was calculated by discounting the average L/C value to the present using the simulated reduction in process time. Hence, the accelerated process reduces the capital costs of the case company as receivables are collected earlier. This observation supports the frequently highlighted view in the interviews that the key business value of electronic documentation stems from accelerating capital turnover and reducing financing costs. Notably, digitalizing the B/L alone would enable a significant portion of the benefits. Based on the analysis, using eB/L and sending other documents as PDFs via email would generate average savings of €1,461 per presentation, assuming 100% utilization of eB/L in projects. This would translate into a reduction of approximately 24% in the total process duration from the delivery of goods to the receipt of documents by the issuing bank.

The analysis suggests that even partial implementation of electronic documentation in projects could yield considerable and recurring financial gains for the case company. Furthermore, the results are conservative in nature, as the estimates were based on moderately cautious assumptions on parameters. As such, the actual impacts may be greater than estimated in cases where the reduction in process lead time is close to the number of days estimated in the interviews. However, it should be noted that the estimates only capture the benefits of implementation. In other words, the calculations do not include the amount of initial investments or operating costs, as these could not be reliably estimated within the scope of this study. Therefore, the results of the scenario analysis indicate potential benefits, but not the total net benefit of implementation.

6.2.6 Barriers to Implementation

E1 notes that the L/C process cuts across a company's core operations, including logistics and financing processes, making end-to-end digitalization challenging, as development would need to take place simultaneously at multiple points through collaboration. I4 reinforces this view by arguing that even if the case company were able to streamline its processes through automation to a certain extent, the ecosystem is lagging in terms of digitalization. Hence, regardless of whether the case company implements effective innovations, their value will not be realized unless stakeholders are involved in the development. Similarly, E1 emphasizes that although digital solutions yield obvious benefits, the investments are difficult to justify if transaction volumes are low. When the operations are marginal, the potential savings may not offset the system costs. Technology has not been a barrier to digitalization for years, but rather the lack of users (E1).

Consistent with Kim et al. (2022), several respondents emphasized that interoperability is a key prerequisite for digitalization, but the L/C process and the broader ecosystem are currently fragmented. E2 reports that in past years, there was limited information and several platform providers, which hampered investments and prevented consolidation. In line with Takahashi (2016), E3 indicates that this created separate digital islands, with only stakeholders operating within the same platform capable of benefiting from the given solution. E4 further notes that large companies are not agile in implementing new tools, limiting their ability to adapt processes quickly.

The existing regulatory environment was seen as a key constraint. Several respondents argued that legislative uncertainty and delays hinder the adoption of electronic documents (E1, E2, E4, E5). Until MLETR is in place, banks are uncertain regarding the adoption (E2). However, regulation was also seen as an enabler that would create the conditions for the use of electronic documents in the long term (E1, E4). This duality suggests that although the technical capabilities are achievable, the implementation is not feasible without an established legal framework. E3 adds that although eUCP has long been available, few banks have expressed intentions to apply it to the L/C process.

Respondents indicate that digitalization is not progressing at an equal pace geographically, but rather that development and limitations vary significantly across regions. Singapore was frequently cited as a pioneer in digitalization (E2, E4). In this region, many participants have transitioned to digital processes, and the markets are driving development forward. Moreover, China was frequently highlighted as a key driver of digitalization. E1 and E3 emphasize that China's commitment to developing and expanding electronic documentation is accelerating digitalization not only in maritime transport but also in land, rail, and air transport. E1 believes that as China's imports shift to the use of electronic documents, banks' willingness to accept and use electronic documents as collateral will increase, which would be quickly reflected in the export market.

In many countries, the use of physical documents remains deeply rooted. F1 notes that physical documents are still legally required in Brazil and Argentina, whereas F2 adds that eB/L has long been used in parts of South America, placing the region ahead of Europe in some aspects. Thus, developments vary greatly, making regional generalizations difficult. Respondents do not consider Europe to be a particularly easy region to digitalize. E5 argues that EU regulations and divergent practices hinder harmonization, while E3 adds that in the Nordics, long-established systems limit flexibility despite technical capability. Hence, developing countries may have a more favorable baseline for digitalization, as they can adopt innovations more swiftly once the legislation is in place.

The analysis indicates that the barriers to L/C digitalization are not solely technological. In many cases, the technical capabilities are established, but their implementation is limited by the fragmentation of the ecosystem, regulatory lag, investment uncertainty, and varying capabilities. The results show that the interdependence of stakeholders is becoming more important ahead of digitalization. A single organization may be highly invested and competent, but if the other parties are not involved in the digitalization, the benefits will remain rather limited. Hence, a broad transition to digital means requires commitment of the entire value chain, a supportive legal framework, and clear standards.

7 Discussion

This section interprets the main results in relation to previous literature and research questions. The study aimed to identify the key inefficiencies in the L/C process, identify technological solutions supporting digitalization, evaluate their implications for the exporter's efficiency, and identify the key barriers that have hindered implementation. The results consist of findings from qualitative and quantitative analysis, which enable a comprehensive examination of the topic.

In many respects, the results support the findings of previous research but also provide new empirical evidence from the perspective of export companies. In line with previous literature, manual work, errors, and delays emerged as key process challenges (Kim et al., 2022; OECD, 2021). However, the data indicated more precisely at which stages bottlenecks typically arise and how they affect cash flow and costs. Moreover, while different technologies were strongly emphasized in the data, their perceived connection to efficiency differed to some extent from the literature. This suggests that there remains a great deal of uncertainty surrounding adoption, and that certain benefits emphasized in an academic context do not appear as straightforward in operational activities.

The quantitative text analysis conducted in the study revealed the frequency and correlation of key themes, highlighted differences between stakeholders, and indicated that the positive sentiment of bank respondents explains the digital adoption. This finding supports previous literature, which has identified banks as an important driver of digitalization (Grassi et al., 2022; ICC, 2023a). The results suggest that digitalization opens a significant opportunity to streamline the existing L/C process, but the complex ecosystem complicates the transition which requires the involvement of all stakeholders.

7.1 Interplay of Inefficiencies

The results show that the main inefficiencies in the case company's L/C process stem from paper-based documentation, manual repetitive work, delays, and errors. Document preparation was described as laborious, with some instances requiring several hours. The reliance on original transport documents often creates bottlenecks, while delays in L/C issuance by the issuing bank further extend process time and weaken the exporter's cash flow. Consequently, the process is labor-intensive and ties up the capital for longer than alternative payment methods. These findings align with previous literature, which shows that manual, paper-based, and fragmented systems sustain high process costs and hinder digitalization (Kowalski et al., 2021; Kim et al., 2022). Moreover, complex regulation and incompatible platforms increase inefficiency (OECD, 2021).

The quantitative text analysis further confirmed the identified inefficiencies. Themes related to manual work, delays, and errors were the most frequently recurring challenges in the data. Moreover, individual negative words such as challenge, delay, mistake, and problem appeared repeatedly. However, the results revealed stakeholder-specific differences. Whereas the quantitative analysis showed that exporters and banks emphasized manual work, the qualitative analysis provided deeper insights. Exporters highlighted document preparation and labor costs, while banks considered document errors and the resulting rework to be the greatest challenge. This reflects that the cost structure of the process is not equally distributed, with each stakeholder experiencing distinct challenges.

The results highlight the structural challenges of L/C. Respondents emphasized that the UCP 600 rules and established paper-based practices sustain a slow and error-prone process. These views support E3's argument that the role of L/C is threatened in the long term unless it can be modernized through digital tools. Literature reinforces this perspective, as Takahashi (2016) emphasizes that the adoption of eB/Ls will remain limited without a supportive legal system, while the ICC (2024) similarly highlights that the digitalization of L/C requires standardization and legal reforms. Hence, the inefficiencies reflect structural constraints that extend beyond the operational level.

Overall, the findings demonstrate that the process is inefficient on multiple levels, with challenges arising partly from factors that reinforce each other. Manual processes increase the risk of errors, errors increase the burden of revision, and delayed document submissions, combined with paper-based processes, tie up the exporter's capital. Deep-rooted structural challenges make L/C a difficult instrument to modernize, meaning that in most cases, individual technological solutions will not suffice. Instead, creating broad value requires comprehensive changes and cooperation across the entire supply chain.

7.2 Collective Value and Diverging Priorities

The results suggest that L/C digitalization primarily centers on electronic documentation, system integration, and automation. These components were considered concrete solutions to manual work, discrepancies, and delays. Exporters highlighted eB/L and electronic documentation as solutions to the slow transfer of documents. Respondents estimated that lead times could be reduced from weeks to days or even hours, consistent with previous eB/L pilot findings (Plomaritou & Jeropoulos, 2022). However, the data revealed that legal uncertainty and a lack of standards are hindering the implementation of electronic documentation. This aligns with the ICC (2024), which suggests that the technical capability is already in place, but the full potential will only be realized once the regulatory framework is strengthened.

Integration and system compatibility were particularly emphasized by bank respondents. The interviews revealed a need to consolidate the internal systems into a unified back-office environment and to ensure seamless data exchange between stakeholders. Integration was seen to accelerate payment processing and improve visibility throughout the supply chain. These findings align with previous literature, which highlights API-based integration as a key enabler of L/C digitalization (Carr & Ramezani, 2022; ICC, 2023b). Although respondents did not always explicitly link technology to liquidity, interoperable systems were seen as enabling a more predictable and smoother payment process.

Automation was recurring theme among exporters and banks. AI-based document review and OCR were estimated to reduce manual work and errors in the most intensive process stages. However, the role of automation remained abstract, as the respondents approached it cautiously, noting that the benefits will be gradual and that human involvement will remain essential. Similarly, previous literature shows that AI can significantly accelerate work related to manual documentation and reduce operational risk (Ozturk, 2024; Khalil et al., 2025). However, the literature has suggested that the value of AI depends on data standardization and ecosystem capabilities (Baviskar et al., 2021).

Finally, the results indicate that electronic documentation and integration typically depend on platform environments that facilitate data exchange among stakeholders. Accordingly, platform solutions emerged as a key enabler. They were considered to enhance transparency and enable real-time information exchange. However, this study identified a limitation previously found in literature. Typically, platforms are closed and poorly scalable, which restricts their ability to generate value on a large scale (Takahashi, 2016). This tension was further reflected in the sentiment analysis, with platforms raising positive sentiments, but thematic analysis revealing concerns regarding the functionality.

The results suggest that the value of digitalization emerges collectively from interoperable solutions. Electronic documentation eliminates postage and bottlenecks, automation reduces manual work and errors, and integration enables seamless information flow across stakeholders. This layered architecture is consistent with previous literature, which suggests that the benefits of digitalization are realized through the interoperability of technologies, systems, and ecosystems (Patel & Ganne, 2021; OECD, 2021; ICC, 2024). Moreover, the results revealed that each actor prioritizes solutions differently based on its role and objectives. Exporters viewed eB/L as the most promising solution due to its direct impact on faster throughput and cash flow, whereas banks prioritized integration and the resulting interoperability. Automation and AI were seen as promising, but their benefits were expected to be realized in the long term.

7.3 Incentives through Financial Impacts

The results indicate that the primary benefits of digitalizing a company's L/C process are realized through cash flow effects and improved operational efficiency. The data particularly highlighted the acceleration of the process and the reduction in manual work and errors. The operational benefits were seen as direct, whereas streamlining of cash flow was more of an implicit consequence. In other words, digital solutions were perceived to enhance everyday process activities, and the cash flow effects were less visible to respondents, despite their evident presence.

Quantitative text analysis supports this observation, as discourse on efficiency and system interoperability received a distinctly more positive sentiment than discourse on cost savings or cash flow. This suggests that respondents focused on the concrete process improvements enabled by digitalization. However, the findings of the scenario analysis deepen this perspective, showing that an estimated 93% of the benefits of electronic document presentations are ultimately realized through cash flow effects. In other words, faster document flow between stakeholders directly leads to the exporter's capital being tied up in the process for a shorter period. This finding aligns with previous literature, which highlights that digitalization is not merely a matter of seeking efficiency but also a financial strategy for companies (González et al., 2023).

The scenario analysis suggests that the introduction of electronic documentation can accelerate the L/C process lead time up to 32%. This translates into savings of several days, which releases capital faster and improves the case company's cash management. This is supported by previous literature, with Plomaritou and Jeropoulos (2022) reporting that an eB/L pilot carried out by Maersk achieved time savings of 40%. Moreover, several respondents in this study referred to successful industry projects where the reported time savings have reached hundreds of percent. Freight forwarders also highlighted concrete cost savings, reporting that digital document transmission via a platform has reduced the cost of a single transaction by up to 86%.

Khalil et al. (2025) estimate that AI-based document verification can reduce the operational risk of a given work step by up to 68% while reducing the intensity and costs of the process. Similarly, respondents pointed out that automation is a valuable tool for reducing manual work and errors in the process. Furthermore, prior literature emphasized the capabilities of OCR, reporting savings of up to 50-80% in manual work depending on the process phase (Dab et al., 2016; Alshaleel, 2024). Hence, automation can significantly reduce the recurring costs associated with the process and speed up payments. These figures align with this study's results, indicating that reduced lead times and errors translate into improved cash flow.

The data revealed several key mechanisms through which digitalization affects cash flow and improves the operational efficiency of exporters. As previously discussed, electronic documentation eliminates paper and postage, significantly streamlining the process by enabling payment conditions to be fulfilled sooner. Secondly, API integrations increase system interoperability and improve supply chain visibility. Thirdly, automated document verification reduces document discrepancies, which contributes to processing speed and eases the workload. Finally, digital identity and electronic signatures facilitate the use of digital tools and reduce friction associated with banks' KYC processes, thereby accelerating the overall transaction flow. Together, these mechanisms support TCT's perspective, as reducing uncertainty and delays lowers the cost of capital commitment.

Thus, the implications of digitalization for operational efficiency and cash flow are interlinked but appear differently across stakeholders. Operational benefits are relatively easy to observe in individual stages of the process, whereas cash flow effects are realized indirectly through the faster release of capital. This observation complements previous literature by highlighting the perspective of an exporting company. Although cash flow effects are not prominently featured in the respondents' discourse or in prior literature, they constitute the most significant business benefits of digitalization according to the quantitative analysis.

7.4 Adoption Dynamics

The findings indicate that L/C is a complex trade instrument whose position is at risk unless it can be modernized. The largely paper-based and manual process is intensive, slow, and prone to errors. Without digitalization and standardization, the instrument faces increasing competition from lighter payment methods such as OA or bank payment obligations. This is problematic for exporters, as L/Cs contain key provisions related to risk management and obligations that provide security for cross-border trade. Consequently, OA payment methods may become more common in standard transactions, while L/C increasingly evolves into an instrument for complex trading.

The results show that the main obstacles to digitalization stem from the fragmentation of the ecosystem, regulatory lag, and differences between stakeholders' ability to invest in innovative solutions. Respondents emphasized that while the technological capabilities exist, widespread adoption requires standardization and strong commitment from banks. Moreover, respondents stressed that investment uncertainty is a key constraint. There is no inclination to commit to a given solution unless legal certainty and sufficient scalability have been achieved. This concern aligns with prior literature, which suggests that gaps in the legal framework and lack of interoperability between platforms are the most significant barriers to the digitalization (OECD, 2021; Kim et al., 2022).

Moreover, the regression analysis supports these findings by showing that positive sentiment among bank respondents explains the likelihood of adoption-related discourse. In other words, banks expressing a more positive attitude towards digitalization are more likely to engage with topics related to digital implementation. This finding provides empirical evidence underscoring the central role of banks in advancing digitalization. By contrast, the sentiment of exporters was more cautious and less related to adoption. These findings support previous literature, which identifies banks as key investors and promoters of digital transformation in trade finance (Grassi et al., 2022; ADB, 2019; ICC, 2023a; Deutsche Bank, 2024).

As emphasized, the lack of regulation and standardization emerged as a major constraint. Specifically, respondents considered the large-scale implementation of MLETR and eUCP to be crucial in providing a legally compliant basis for the use of electronic documentation. In terms of standardization, the closed nature of platforms was perceived as an obstacle to large-scale value creation at the ecosystem level. Similar to the respondents, Takahashi (2016) stressed that without sufficient interoperability and open platforms, digitalization leads to fragmented islands, where stakeholders operate in isolation. Consequently, solutions fail to scale across the ecosystem, and the expected benefits remain largely unrealized.

When examining the L/C process digitalization through Rogers' (2003) diffusion of innovations theory, the results suggest that the ecosystem is currently transitioning from the early innovators stage to the early majority stage. FinTech companies, banks, and a few other stakeholders have piloted solutions, but widespread adoption awaits the formation of a majority. As emphasized, early adoption can be risky, but on the other hand, late adoption can reduce a company's competitiveness. In this regard, the position of banks as large and central institutions is pronounced. Their visible commitment can attract critical masses to engage in the transition. Hence, exporters should focus their cooperation on banks that have demonstrated a willingness to drive digitalization forward, as this increases the likelihood that solutions will scale toward broad adoption.

7.5 Theoretical Contributions

This study extends previous literature in three main ways. First, it provides empirical evidence from the exporter's perspective on the L/C process digitalization. Previous research has emphasized structural aspects of the ecosystem or the potential of individual technological solutions, but the entire process has not been systematically examined from the exporter's perspective at a pragmatic level. The research data was collected from the exporting company professionals and its closest stakeholders, which enabled

the compilation of detailed assessments of how digitalization affects the business performance. The chosen perspective expands on previous research by indicating where the current pain points are greatest and through which mechanisms the benefits of digitalization are realized.

Secondly, this study applies TCT to the L/C process, demonstrating that manual procedures, delays, and errors account for a significant share of transaction costs. Digitalization drives down costs by eliminating repetitive checks, minimizing errors, and reducing processing times. While previous literature has identified these mechanisms conceptually, this study provides quantitative evidence indicating that approximately 93% of the benefits of electronic documentation are realized through cash flow effects. Therefore, digitalization is a key component of an exporter's financing strategy.

Finally, the study contributes to the diffusion of innovations theory by analyzing the dynamics of digital adoption in L/Cs. The results complement the existing literature by indicating that banks' positive attitude is a key quantitative determinant of adoption. Furthermore, this study suggests that the trade finance ecosystem is currently transitioning from the early adopter phase to the early majority phase, but that a complete transition requires the active role of key players and the commitment of the entire value chain. Moreover, through a mixed-methods approach, this study conducted quantitative text analysis in parallel with thematic analysis, providing a unique tool for examining emphasis of data, stakeholder attitudes, and digital adoption. The chosen research design enabled a deeper examination of the occurrence of topics and correlations between themes. The setup combines deep qualitative observations with quantitatively measurable connections and attitudes, which contribute to revealing indirect causalities.

8 Conclusion

This study examined the L/C process digitalization, focusing on existing inefficiencies, supporting solutions, impact on business performance, and implementation barriers. By combining qualitative and quantitative analysis, the study provides a multidimensional view of how digital transition can streamline an exporter's process flow. In many respects, this study reinforces the findings of previous literature on the most prominent challenges but also explains how these issues emerge. Furthermore, the results indicate that stakeholders perceive digitalization differently. The incentives and advantages are asymmetrically distributed, shaped by each stakeholder's cost structure and objectives.

The inefficiencies arise from overlapping factors. A major challenge is the manual nature of the process, which increases the risk of errors and causes delays. Exporters found physical transport documents to be particularly prone to causing bottlenecks, while for banks the main difficulties arise from the review process and the cumbersome compliance requirements. Exporters identified electronic documentation as a key enabling solution. eB/L eliminates courier costs and ideally reduces idle times to a matter of hours. Banks emphasized system integration, as it enables process visibility and provides a foundation for comprehensive digitalization. Integration enables seamless connectivity across different systems, reducing investment uncertainty. Moreover, automation was seen as a support mechanism that could be used to partially transfer document review and manual work to AI agents. Automation was not expected to eliminate human involvement, but it can significantly reduce manual work and operational risk.

The benefits of digitalization are reflected in the company's operational efficiency and liquidity. The scenario analysis showed that faster receipt of L/C payments reduces the exporter's working capital needs and financing costs. Entirely electronic document negotiations can reduce the process lead time by approximately one-third, whereas eB/L combined with PDF documents can reduce it by nearly a quarter. At full utilization, the average cost savings per presentation amount to €2,018 and €1,461, respectively. Notably, up to 93% of the benefits of electronic documentation stem from cash flow effects.

Digitalization is limited by shortcomings in regulation, standardization, and ecosystem coordination. The main barriers are the lack of legal validity of electronic documents, the incapability of actors, and the prevalence of closed platforms. These factors cause investment uncertainty, which further delays digitalization. Consequently, few actors are willing to be early adopters due to the perceived riskiness, although pilots could yield competitive advantages. In conclusion, this study provides insights into the position of exporting companies within digitalization, indicating that the transition can reduce operational inefficiencies and support capital management. However, the results reinforce the view that digitalization is an ecosystem-wide shift, where stakeholder commitment and alignment of objectives are required for broad value creation.

8.1 Managerial Implications

Digitalization is a holistic transition affecting a company's financing and partnerships. The case company should align trade finance digitalization with its broader digital strategy and actively build internal expertise. It is essential to monitor market and regulatory developments, assess the digital capabilities of partners, and participate in pilots to gain experience. The company should monitor the legal framework, particularly the adoption of the MLETR, which establishes a legally robust foundation for the use of ETRs. As the law has already been implemented in countries such as the UK and France, the company should observe the progress and prepare to align its processes accordingly. Moreover, Singapore and China were identified as digitalization pioneers, so monitoring developments in these markets could offer valuable insights into the trajectory of early adopters.

As a first step, the case company should integrate its internal systems and processes to ensure interoperability and visibility. The data required for paperless transactions is often scattered across different systems and difficult to access. Establishing uniform data models and centralized solutions can enhance data management and enable the automated use of product data in documentation. These capabilities create a foundation for

digital twins, which can digitally verify a company, its representatives, and traded products. With high-quality API-based integrations and standardized practices, the company can facilitate digital information exchange with trading partners and financiers. Moreover, banks increasingly require digital connections to sanctions and sustainability registers to fund only companies that meet modern compliance requirements.

Based on the analysis, electronic documentation could proliferate within five years, increasing the need for proactive measures. Reported pilots indicate that eB/L transactions can already be executed under the MLETR when parties operate on a common platform. The company should evaluate the business case, identify a reliable service provider, and conduct limited pilots on selected trade routes to demonstrate impact and justify further investment. However, large-scale adoption requires the development of interoperable platforms and a supportive legal framework. Moreover, most advanced automation solutions are not sufficiently mature to be systematically utilized in the L/C process. AI agents are valuable in support functions, where they can assist in preliminary reviews, while deferring final approvals to trade finance professionals. Since AI benefits from standardized data, the company should enhance internal standardization by structuring its data and processes. The company can explore the use of AI in support processes, starting with small-scale trials and expanding the use as the technology matures.

Investment costs are not a key barrier to digitalization, but rather uncertainties related to the legal framework and service providers. Hence, proof of concepts are a cost-effective way to gain real-world experience and develop expertise. Through these projects, the company can assess which solutions are scalable and where the benefits materialize. However, qualified personnel and partners are needed to ensure that the projects do not fall short as isolated experiments without sustained value. Market research and system testing prior to investment decisions entail costs, yet inaction and missed business opportunities can be more costly. Ultimately, the company must be prepared for the complex and time-consuming process of implementing solutions, which requires careful preparation, particularly regarding security, data management, and IT compatibility.

8.2 Limitations and Future Research Directions

The main limitations of this study stem from the narrow and context-specific nature of the data. As the study focuses on a single case company and its closest stakeholders, the findings are not fully generalizable to other markets or industries. Although insights were gathered from key participants, the scope of the ecosystem prevented a representation of all stakeholders. Moreover, the qualitative approach can entail subjectivity, as responses reflect individual experiences. Similarly, the quantitative analysis is limited by the small sample and the inherent constraints of text-based methods. As the sentiment analysis relied on lexicons and model applications, the results may include minor biases related to context, wording, and translation. Furthermore, the limited dataset size reduces the robustness of the statistical models, preventing firm conclusions on causality.

Although the topic is not unprecedented, available information remains very limited due to the lack of pilots and practical implementations. Consequently, the study's results rely on expert assessments, perceptions, and scenario-based estimates rather than long-term empirical data. The scenario analysis primarily focused on the monetary operational benefits and cash flow impacts, without considering the implementation costs. Furthermore, the analysis emphasized the exporter's operational perspective, meaning that legal and technical dimensions could only be addressed to a limited extent. While this supported the study's objectives, it left some aspects of digitalization less explored.

Future research could focus on specific technologies, solutions, or process stages while retaining the exporter's perspective. Expanding the scope to multiple companies, industries, and regions would enhance comparability and generalizability. Moreover, systematic use of transaction data from pilots could enable accurate modeling of economic impacts. Simultaneously, future studies should explore the cost-benefit perspective by considering the implementation and maintenance costs, providing a more reliable view of the payback periods. Finally, it should be investigated how regulation and standards shape digitalization. The global implementation of MLETR provides an opportunity to compare how different legal frameworks affect the adoption of ETRs.

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Appendices

Appendix 1. Interview Questions for Trade Finance

Main Question	Sub-Question
1. Briefly describe your team's role and main tasks in the L/C process.	
2. Does your company have a dedicated tool for handling L/Cs?	2.1. Does it encompass the entire process or only specific steps?
3. Which manual steps in the L/C process typically take you the most time?	3.1. Do you find that manual steps are prone to errors?
4. What are the most typical factors that delay payments or tie up working capital in the L/C process?	4.1. Are the delays common?
5. Estimate which L/C process factors incur the highest costs in your company.	
6. What are the most significant challenges in the current L/C process?	6.1. Does the process involve bottlenecks or certain inefficiencies?
7. Is the L/C process communication smooth internally across departments and with external stakeholders?	
8. Considering the challenges raised in the interview, evaluate which part of the L/C process your company should prioritize digitalizing.	8.1. Why?
9. What kind of digital solutions would best support the efficiency of your tasks in the L/C process?	
10. What factors do you think support and limit the adoption of digital solutions in your company?	

Appendix 2. Interview Questions for Export Documentation

Main Question	Sub-Question
1. Briefly describe your team's role and main tasks in the L/C process.	
2. Does your company have a dedicated tool for handling L/Cs?	2.1. Does it encompass the entire process or only specific steps?
3. Which manual steps in the L/C process typically take you the most time?	3.1. Do you find that manual steps are prone to errors?
4. What are the most typical factors that delay payments or tie up working capital in the L/C process?	4.1. Are the delays common?
5. What are the most common causes for discrepant document presentation?	5.1. How long does it typically require for a discrepant presentation to be corrected and approved?
6. Estimate which L/C process factors incur the highest costs in your company.	
7. Can you estimate the typical costs of managing paper documentation under an L/C? For instance, how much labor time does the processing consume, and what other costs are involved?	
8. What are the most significant challenges in the current L/C process?	8.1. Does the process involve bottlenecks or certain inefficiencies?
9. Is the L/C process communication smooth internally across departments and with external stakeholders?	
10. Considering the challenges raised in the interview, evaluate which part of the L/C process your company should prioritize digitalizing.	10.1. Why?
11. What kind of digital solutions would best support the efficiency of your tasks in the L/C process?	
12. What factors do you think support and limit the adoption of digital solutions in your company?	

Appendix 3. Interview Questions for Treasury

Main Question	Sub-Question
1. Briefly describe your team's role and main tasks in the L/C process.	
2. Does your company have a dedicated tool for handling L/Cs?	2.1. Does it encompass the entire process or only specific steps?
3. Do you find that the current L/C process involves a lot of manual steps?	3.1. Do you consider that manual steps are prone to errors?
4. What are the most typical factors that delay payments or tie up working capital in the L/C process?	4.1. How significant is the impact of L/C payment delays on the company's cash flow?
5. Estimate which L/C process factors incur the highest costs in your company.	
6. What are the most significant challenges in the current L/C process?	6.1. Does the process involve bottlenecks or certain inefficiencies?
7. Is the L/C process communication smooth internally across departments and with external stakeholders?	
8. Considering the challenges raised in the interview, evaluate which part of the L/C process your company should prioritize digitalizing.	8.1. Why?
9. Which digital solutions would best support the efficiency of the L/C process?	9.1. Are any of the solutions mentioned particularly valuable from a cash flow management perspective, for example, to accelerate the cash conversion cycle or minimize costs?
10. What factors do you think support and limit the adoption of digital solutions in your company?	

Appendix 4. Interview Questions for Forwarders

Main Question	Sub-Question
1. Briefly describe your role and responsibilities.	
2. Describe how the bill of lading (B/L) is processed between you and the exporting company.	
3. How long does it typically take to prepare and deliver the B/L to the exporting company?	3.1. What are the main challenges of this process?
4. How often do documents need to be corrected or resubmitted?	
5. What causes the most significant delays or bottlenecks in B/L processing?	
6. What are the costs of processing paper-based transport documents? How high are these costs?	
7. How do you feel about electronic documents? Do you think that a transition to purely electronic documentation is realistic soon?	
8. Have you used or would you consider using an electronic B/L (eB/L)?	8.1. What are the technical requirements for using eB/L?
9. How would you evaluate the feasibility of eB/L in different customer segments or geographical areas?	
10. How significant a time saving would you estimate eB/L will enable compared to processing a paper version?	
11. How do you estimate the impact of eB/L on costs and errors?	
12. How could an exporting company promote digitalization in cooperation with you?	

Appendix 5. Interview Questions for Banks

Main Question	Sub-Question	Sub-Question 2
1. Describe your background with letters of credit (L/Cs) and trade finance digitalization.		
2. What do you consider to be the main challenges of the L/C process today?		
3. How would you describe the development of the L/C process digitalization over the past five years?	3.1. How do you see things developing over the next five years?	
4. What digital solutions does your organization use in the L/C process?		
5. What do you consider to be the most promising digital solutions for reducing the manual and paper-based aspects of the L/C process?	5.1. Are these solutions realistically implementable in an exporting company in the short term?	5.2. How do you estimate that these solutions will affect the speed and costs of the process for the exporter?
6. Are you aware of any projects where a company has successfully implemented electronic documents or automated its L/C process?	6.1. What benefits have been achieved?	
7. What measures can exporters take to promote the L/C process digitalization over the next five years? Which solutions require input from the entire value chain?		
8. What are the most significant obstacles limiting the adoption of digital solutions in the L/C process?		
9. What role do regulations, standards, and rules play in digitalization?	9.1. Are certain geographical areas relatively easier or more challenging to digitalize?	
10. Are banks now or soon prepared to accept and use electronic documents?	10.1. Would partially electronic document presentations be feasible?	10.2. What does the transition to fully electronic documentation require?
11. What kind of investments and costs does the introduction of electronic documentation require from a company?		
12. How much could electronic documentation save in terms of labor and standard document costs?		
13. Can you estimate how much time could be saved by introducing eB/L compared to paper B/L?	13.1. How much could an entirely electronic document presentation accelerate the bank's processing time?	
14. The L/C process incurs significant labor costs for exporters due to manual drafting, verification, and documentation. Are AI or robotics already viable solutions for automating the process steps?	14.1. Does their reliable and seamless operation require standardized data?	14.2. How significant efficiency gains can be achieved with them?