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AI driven transformation in trade finance: A roadmap for automating letter of credit document examination

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ABSTRACT

International trade with unfamiliar stakeholders poses challenges of trust, payment security, and regulatory compliance. Letters of Credit (LC) help mitigate these risks but rely on manual, error prone processes that lead to delays, high costs, and limited scalability. This study proposes a roadmap for AI adoption in trade finance, specifically targeting the automation of LC document examination. Guided by the Technology-Organization-Environment (TOE) framework and complemented by individual-level insights from the Technology Acceptance Model (TAM), the research integrates organizational, technological, and behavioral factors to frame the adoption process. A literature-driven approach, supported by expert insights and case study analysis, was used to identify trade finance bottlenecks and the role of AI in addressing them. The findings highlight AI's potential in discrepancy detection, workflow optimization, and compliance improvement. However, full automation remains impractical due to regulatory and trust concerns. A hybrid AI-human approach is proposed as a practical and effective solution. This study contributes to bridging research gaps in AI-driven trade finance and provides strategic insights for implementing intelligent document examination systems.

1. Introduction

Cross border trade with unfamiliar parties is often fraught with challenges in terms of trust, payment security, and regulatory compliance, and trade finance can provide a viable solution. Trade finance is essential in facilitating global trade by creating trust among parties. According to the World Trade Organization (WTO), approximately 80 % to 90 % of world trade relies on trade finance instruments (Nguyen, 2022). Traditional trade finance faces significant inefficiencies due to its reliance on outdated, paper-based processes. These inefficiencies stem from the involvement of multiple parties and often across different countries and organizations, the dependence on labor intensive and time-consuming manual tasks, delays in processing, increased uncertainties, and limited traceability (Ibrahim & Truby, 2022). Artificial Intelligence (AI) adoption in trade finance is necessary to improve efficiency and establish robust and standardized frameworks. There are strategic, tactical and operational phases to be followed to achieve this crucial digital transformation (Rueckel et al., 2020). This shift towards automation and AI integration is part of a broader trend of digital transformation, which Vial (Vial, 2019) defines as “a process that aims to improve an entity by triggering significant changes to its properties

through combinations of information, computing, communication, and connectivity technologies.” In the context of trade finance, this transformation involves rethinking document processing, compliance workflows, and customer engagement models to align with emerging digital capabilities.

Numerous banks and other financial institutions have acknowledged the imperative for digital transformation and have subsequently redefined their strategic objectives to align with this paradigm shift. In contrast, certain early adopters have proactively partnered with AI solution providers, such as Conpend and Tradystream, and have progressed to the tactical or operational stages of implementing this transformation (Beaulieu & Bentahar, 2021). The majority of financial firms that are yet to align their strategic goals with digital transformation, or are in the early stages of this journey, often face significant barriers to initiating and advancing the implementation of digital solutions in trade finance. These barriers include workforce resistance, uncertainty in selecting appropriate technologies, difficulty in defining an optimal implementation strategy, and concerns regarding regulatory compliance and cybersecurity (Jaloliddin, 2023).

While trade finance encompasses a broad range of financial products and services designed to facilitate international trade, the Letter of

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Credit (LC) is a specific instrument within trade finance that play a significant role in international trade by mitigating risks for buyers and sellers (Khalil et al., 2021). Sellers are guaranteed payment upon meeting the LC terms, while buyers gain assurance that compliance is met before payment, reducing noncompliance risks. LCs provide a secure and standardized payment mechanism that promotes credibility and trust, especially in cross-border trade with unfamiliar partners.

As a result, there is a need for structured, detailed frameworks to effectively address these multifaceted issues. Hence, the main objective of the paper is to develop a comprehensive roadmap for AI adoption in trade finance, addressing critical gaps in research and application. Although there is some research in related areas, there is a significant lack of studies that combine trade finance, LC examination, digitalization, and AI adoption. This knowledge gap was one of the initial challenges we encountered in developing a roadmap for AI adoption in trade finance which was tackled by drawing insights from related fields, such as AI applications in digitizing business processes, legal document verification, and banking. Based on literature driven knowledge reinforced by expert domain opinions, we present a future focused roadmap for automating the LC document examination process.

The paper is organized as follows: Section 2 outlines the bottlenecks in traditional trade finance and highlights AI's role in driving positive change, establishing the research background. Section 3 presents a systematic literature review to identify gaps and motivate the research objectives. Section 4 details the methodology for developing the proposed roadmap. Section 5 discusses AI's role in LC examination, addressing discrepancies and decision making. Section 6 explores insights from case companies undergoing digital transformation, leading to the roadmap presented in Section 7. Section 8 and 9 present the efficacies and challenges. Finally, Sections 9 and 10 provide managerial insights, future research recommendations and conclusions.

2. Background

There are several payment methods in international trade as per Fig. 1, varying in risk allocation between buyers and sellers. Open account trade is a payment method where goods are shipped and delivered to the buyer before payment is made where the seller provides credit to the buyer, allowing the buyer to pay for the goods at a later agreed upon date (Carton et al., 2021). Conversely, payment in advance minimizes seller risks but shifts financial risk to buyers. Documentary collection offers a middle ground but involves delays as documents are physically processed by banks. LCs, while secure and widely used, are expensive and documentation heavy, making them the most reliable option for many corporates (Ruslan, 2022). The ICC Trade Register Summary, 2023 noted that LCs accounted for 25 % of trade finance transactions in 2021.

The basic LC process involves multiple steps and parties, including buyers, sellers, and two or more banks, as illustrated in Fig. 2. It enables the seller and buyer to initiate the trade contract, exchange shipment, and payment, followed by the seller presenting the required trade documents to banks for validation and payment commencement. Governed by the Uniform Customs and Practice for Documentary Credits (UCP-600) (International Chamber of Commerce (ICC), 2025), the process

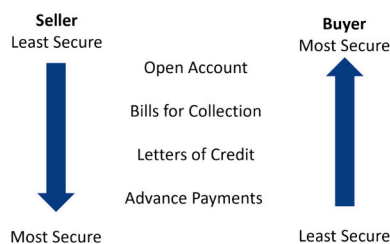


Fig. 1. Trade payment methods and risk.

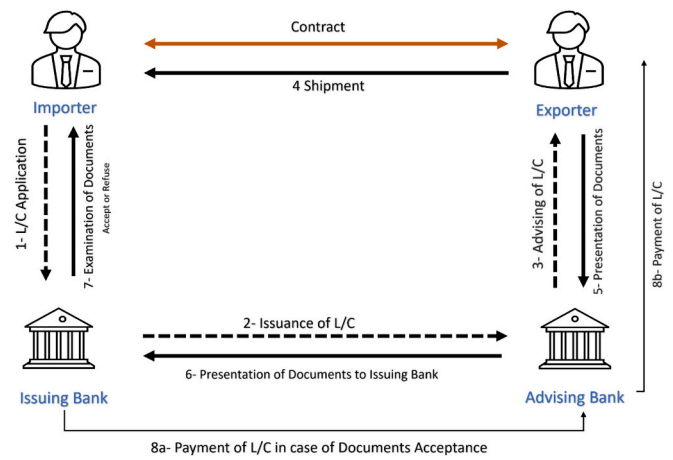


Fig. 2. Traditional Letter of Credit (LC) process workflow.

requires compliance verification before payment (Rafique & Duraisingam, 2023). However, these traditional paper-based operations dominate current practices and often result in inefficiencies (Yap, 2025).

Trade finance inefficiencies stem from the reliance on paper-based processes and the physical circulation of documents, which require significant human intervention and workforce involvement (Toorajipour et al., 2022). These inefficiencies introduce delays, increase uncertainty, and reduce traceability within the system (Chang et al., 2020; Toorajipour et al., 2022). Addressing these challenges is vital to improve the overall efficiency and reliability of trade finance practices in a rapidly evolving global trade environment.

2.1. Bottlenecks in traditional trade finance

Traditional trade finance is inefficient, as it often involves over 20 parties, creating thousands of interactions between data fields. According to the Boston Consulting Group (BCG), each transaction can involve up to 5000 data fields (Ramachandran et al., 2017).

The document examination phase in LC process, aligned with steps 5, 6 and 7 of the LC flow (Fig. 2), is a critical yet traditionally inefficient component of trade finance. This phase involves banks meticulously reviewing all the trade documents presented, such as invoices, bills of lading, and certificates of origin, to ensure compliance with the LC terms and conditions. Compliance verification directly influences the success of the transaction, as errors, discrepancies, or deviations can result in payment delays, document rejection, or disputes, posing significant financial and legal risks on all parties in the supply chain. Historically, this process has relied on skilled human professionals to perform thorough manual checks, a labor intensive and time consuming task prone to inefficiencies.

Another critical bottleneck arises from the complexities involved in reviewing and verifying the accuracy of documents submitted by multinational companies engaged in international trade. These documents often originate from different countries, are prepared according to varying standards, and may involve multiple languages, formats, and regulatory frameworks, making manual examination even more laborious, error-prone, and time-consuming. Multinational transactions, by nature, amplify the complexity and risk in document verification due to inconsistencies in documentation practices and the need for adherence to jurisdiction specific requirements (Khalil et al., 2021).

AI can significantly help resolve or mitigate this challenge. AI technologies, particularly those leveraging NLP and ML, can standardize and interpret diverse document formats and languages, enabling a consistent compliance verification process across multinational submissions (Ibrahim & Truby, 2022). AI can automatically classify, extract, and cross validate data fields from complex and varied document types,

ensuring that discrepancies related to international standards, terminology variations, and format differences are identified quickly and accurately.

(Pahari et al., 2023). This automation reduces the dependence on manual expertise for handling multinational documents and ensures a higher level of consistency, speed, and reliability in the examination process, while maintaining compliance with local and international trade regulations (Conpend, 2025).

2.2. Artificial intelligence (AI)’s role in trade finance

Advancements in AI are transforming business processes across various domains, including trade finance. While not yet widely applied to LC document examination, AI holds the potential to significantly impact this area in the future by automating labor intensive operations (Pahari et al., 2023). Technologies such as Machine Learning (ML), Natural Language Processing (NLP), and Optical Character Recognition (OCR) enable AI systems to read, extract, and analyze information from trade documents, verifying compliance and regulatory standards (Prasanth et al., 2023). These AI-powered solutions address inefficiencies by significantly reducing the time and manual effort required for document review while maintaining accuracy (Khalil et al., 2025). Fintech companies have developed specialized software to replace traditional manual document checks, offering a streamlined, automated alternative to ensure compliance (Conpend, 2025).

Despite the transformative potential of AI, its adoption comes with challenges. While AI enhances efficiency, it does not offer absolute accuracy. Banks remain accountable for document examination outcomes, regardless of whether the process is manual or automated (Richey et al., 2023). Relying on AI for decisions involving high value transactions poses risks, especially in cases where the system fails to identify critical discrepancies. To mitigate these risks, industry experts recommend a hybrid approach that integrates human judgment with AI-driven processes. Human validators review and confirm AI-generated decisions, ensuring a balance between efficiency and accuracy (Jones, 2023). As mentioned earlier, trade finance encompasses various financial products, with LC being a subset. The focus of this paper is the integration of AI into LC verification specifically, which is much more nuanced and yet to be explored.

2.3. AI and ML techniques for real time document verification in trade finance

AI and ML techniques are increasingly leveraged to automate real-time document verification in trade finance, particularly within the LC examination process. Techniques such as NLP, OCR, and supervised and unsupervised ML models are at the forefront. OCR facilitates the digital extraction of data from scanned trade documents, enabling subsequent processing by AI systems, while NLP empowers the interpretation and classification of the extracted information (Khalil et al., 2025).

Supervised learning models like Support Vector Machines (SVMs) and Random Forests are widely employed for detecting discrepancies and classifying document types, whereas unsupervised methods such as clustering algorithms help in anomaly detection where labeled datasets are unavailable (Dunsin et al., 2024). Advanced frameworks combining AI and optimization models specifically tailored for LC document examination processes show great promise in enhancing operational efficiency and up to 68.3 % in risk reduction (Khalil et al., 2025). These systems enable automated checks against trade compliance standards, such as UCP 600 and ISBP guidelines, reducing manual effort while improving accuracy (Khalil et al., 2025).

Nonetheless, the application of AI and ML in real time document verification is not devoid of limitations. One primary constraint is data quality: OCR accuracy significantly drops when document scans are of poor quality or contain handwritten annotations (Lv et al., 2022). Furthermore, biases inherent in machine learning algorithms, if not

properly addressed, can result in systematic errors in classification and anomaly detection (van Giffen et al., 2022). A comprehensive analysis of AI and ML roles in financial services points to challenges such as model opacity (lack of explainability), regulatory compliance issues, and operational risks associated with over-reliance on automated systems (Dunsin et al., 2024).

In terms of ethical risks, various biases such as sampling bias, algorithmic bias, and evaluation bias have been systematically classified in recent research, underscoring the critical importance of bias mitigation strategies when deploying AI models in sensitive domains like trade finance (van Giffen et al., 2022). Furthermore, systematic reviews discuss effective approaches to manage these biases and ensure responsible and trustworthy AI deployment (D. V. P.S, 2023). In addition, industry evaluation standards highlight the necessity for stringent validation procedures to ensure the reliability, robustness, and compliance of intelligent technologies with financial industry requirements (Lv et al., 2022).

Therefore, while AI and ML offer significant opportunities to streamline and enhance real time document verification in trade finance, a fully autonomous model is neither practical nor advisable at this stage. A hybrid human AI approach, which combines the computational efficiency of AI with human judgment for oversight and final decision making, remains the most reliable framework for the foreseeable future (Khalil et al., 2025; Prasanth et al., 2023).

3. Literature review

Table 1 presents the Scopus search results using relevant keywords, enhanced with wildcard entries such as finan*, letter*, credit*, and digit* to capture variations like finance, financial, finances, letters, credits, digital, digitized, digitization, and digitalization, ensuring comprehensive coverage of related terms.

The search resulted in 5 articles, two articles deals with blockchain for smart contracts and electronic LCs (e-LCs) (Nezhad et al., 2024; Phuc et al., 2023), while others are irrelevant. The search results in Table 1 clearly indicate a lack of research focused solely on the automation of LC processes.

It is important to note that a traditional LC and an e-LC are fundamentally different. An e-LC involves a fully digitized process for issuance, exchange, and verification. Integrating AI into the LC process does not automatically transform it into an e-LCs but automates specific components of the broader trade finance ecosystem.

Therefore, this paper focuses on AI integration to document examination within the existing LC framework, addressing the immediate and practical challenges of traditional LC processes, which remain more widely used and relevant than the fully digitized e-LCs in many regions.

Due to the scarcity of articles specifically addressing the automation of document examination in LC processes using AI, we reviewed related areas, as discussed in this section. Fig. 3 illustrates the broader scope explored to gain insights. The literature on digital solutions in trade finance is reviewed in Section 3.1, with a focus on AI as a key driver. AI

Table 1
Scopus database search results for articles on roadmap, conducted on 01/01/2025.

Search Query	("Trade Finance" OR "Commercial Finance" OR finan*) AND (digit* OR "Artificial Intelligence" OR "AI" OR "Machine Learning") AND ("Letter* of Credit*" OR "Letter of Credit" OR "L/C" OR "LC") AND (roadmap OR framework)
Filters	None.
Results	5 articles and 1 erratum were found.
Identified articles	1. AI for mitigating phishing attack, (Zhang et al., 2017) 2. AI for geospatial monitoring, (Mardani et al., 2019) 3. AI for healthcare, (Van Woensel et al., 2021) 4. Blockchain for smart contracts, (Phuc et al., 2023) 5. Blockchain and AI for e-LCs, (Nezhad et al., 2024)

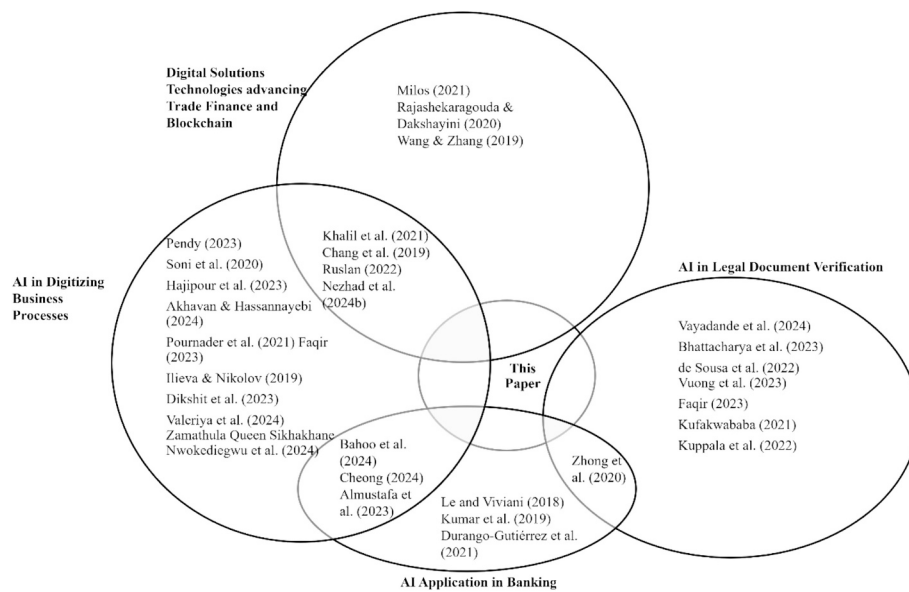


Fig. 3. Overview of literature review in domains related to LC examination.

applications in business processes, legal document verification, and banking are discussed in Sections 3.2–3.4. Research gaps in these domains are analyzed in Section 3.5, leading to the formulation of research objectives in Section 3.6 to guide the development of a strategic roadmap for AI integration into the LC process.

3.1. Advancing trade finance with digital solutions

Researchers and organizations like the ICC and WTO have explored various digital solutions to improve trade finance, introducing technologies such as Blockchain, Bank Payment Obligation (BPO), SWIFT for Corporates, and e-LC. The BPO, developed by SWIFT and the ICC, automates data matching for open account transactions, enhancing transaction speed, transparency, and security while reducing manual errors and processing times. Despite its advantages, the BPO has distinct characteristics and limitations that make it unlikely to fully replace the traditional letter of credit (Milos, 2021). These constraints have likely contributed to its slower than anticipated adoption in international trade transactions. Similarly, SWIFT for Corporates (MT798) standardizes communication between corporations and banks, allowing businesses to manage e-LCs and guarantees through a secure messaging platform with limited capabilities. While it reduces paperwork and improves efficiency, adoption remains costly for smaller businesses due to infrastructure and training requirements (Khalil et al., 2021). The e-LC digitizes the traditional LC process, streamlining transactions, enhancing accuracy, and supporting sustainability by reducing the carbon footprint of paper-based operations. However, its global adoption hinges on standardized regulations, hence automating document examination of LC process (Steps 5 and 7 in Fig. 2) within existing framework is a more practically feasible option.

Blockchain technology has the potential to revolutionize trade finance by improving transparency, reducing fraud, and eliminating the need for paper documents (Nezhad et al., 2024). Blockchain's decentralized network allows for secure, real-time verification of documents. Studies, such as those by (Chang et al., 2019; Khalil et al., 2021; Rajashekaragouda & Dakshayini, 2020), suggest that blockchain could greatly benefit LC processes, although challenges remain in integrating traditional documents into a fully digital framework. When linked with smart contracts, blockchain can offer transparency, security, and auditability in trade finance. The core characteristic of a smart contract is its ability to execute automatically based on predefined conditions. Therefore, when the terms and conditions of the contract are established

and recorded on the blockchain, smart contracts enable transactions to occur without the need for intermediaries to enforce or mediate the agreement (Yang et al., 2024). Smart contracts codify the agreement between buyers and sellers into a decentralized blockchain network, automatically executing upon meeting the predefined terms. Chang et al., (Chang et al., 2019) demonstrated blockchain's capability to streamline LC processes, but integration challenges persist, particularly in ensuring that all parties adhere to a uniform digital protocol. In the life cycle of the LC including issuance, amendments, document presentations, and payment involves a lot of paperwork which implies that more people are involved as well as institutions. This in turn has a corresponding increase in the resources needed and time (Wang & Zhang, 2019). Blockchain's integration into trade finance faces significant challenges, including regulatory uncertainty due to the need for standardized international frameworks and interoperability issues with existing legacy systems (Saihi, 2021). Data privacy concerns, such as compliance with various regulations, further complicate adoption (Agarwal et al., 2023). Resistance from stakeholders, particularly smaller banks or those unfamiliar with blockchain, adds to the barriers. High initial implementation costs and the reliance on robust digital infrastructure present additional hurdles which requires more research (Upadhyay, 2024). Legal challenges surrounding smart contract enforceability (Yeoh, 2017) and a lack of standardization across the industry create inconsistencies, while the high energy consumption of some blockchain platforms raises sustainability concerns (Guerin, 2023).

3.2. AI in digitizing business processes

AI technologies such as ML, NLP, and robotic process automation (RPA) are at the forefront of digitizing business processes across industries (Soni et al., 2020) and enhancing data-driven decision-making (Akhavan & Hassannayebi, 2024) by automating repetitive tasks, optimizing workflows, and providing predictive analytics, leading to increased accuracy and reduced operational costs (Zhao & Zhang, 2022). In supply chain management, for instance, AI driven tools can predict demand, optimize inventory, and detect inefficiencies in real time, allowing businesses to respond more agilely to market changes (Pournader et al., 2021). AI's ability to process vast amounts of unstructured data allows for enhanced customer insights (Hajipour et al., 2023), which in turn facilitates the personalization of services, driving customer satisfaction and retention. Baziyad et al., (Baziyad et al., 2024)

provided a comprehensive analysis of IoT and CPS integration in digital supply chains, offering a practical roadmap for businesses through strategic planning, phased implementation, and employee training. While Susitha et al., (Susitha et al., 2024) bridges the gap between management and technology disciplines by employing bibliometric methods to analyze the interplay between supply chain agility and digital technologies.

Moreover, AI is revolutionizing financial processes, particularly in areas like invoicing, auditing, and fraud detection (Pendy, 2023). AI powered systems can automatically reconcile invoices, flag anomalies, and even predict cash flow issues, allowing businesses to optimize their financial health with minimal human intervention (Almustafa et al., 2023). These systems not only speed up transaction times but also reduce human errors, making the digitization of these processes both cost effective and reliable. In the legal and compliance sectors, AI tools help in reviewing contracts and ensuring regulatory compliance by analyzing and flagging potential risks, saving countless hours of manual review (Faqr, 2023). Despite its transformative potential, AI adoption poses challenges, particularly around data privacy and the ethical use of automated decision making (Vayadande et al., 2024). Businesses must ensure robust governance frameworks and transparency in AI usage to mitigate these risks (Cheong, 2024).

The integration of AI in digitizing business processes aligns with broader digital transformation trends (Ilieva & Nikolov, 2019), particularly in improving sustainability. AI can optimize energy usage (Dikshit et al., 2023), reduce waste, and enhance resource allocation, contributing to environmental sustainability efforts (Valeriya et al., 2024). However, the full potential of AI in business process digitization is contingent on the availability of high-quality data and the implementation of scalable, adaptable AI solutions (Nwokediegwu et al., 2024).

Vial (Vial, 2019) provides a comprehensive framework for understanding digital transformation, highlighting the interplay between digital technologies, organizational change, and value creation. This perspective is highly relevant to trade finance, where AI adoption not only enhances process efficiency but also necessitates cultural shifts, new skillsets, and redefined roles across financial institutions. Our proposed roadmap aligns with these principles by outlining strategic, tactical, and operational changes required to embed AI within the LC document examination process.

Furthermore, recent studies have expanded the application of AI and ML beyond operational automation to critical areas such as cybersecurity risk detection within digitized business environments. AI and ML technologies enable intelligent monitoring systems that detect abnormal behaviors, identify anomalies in user activities, and flag suspicious transactions in real time, addressing risks from both external cyber threats and internal actors, including current and former employees.

Jada et al. (Jada & Mayayise, 2024) highlight AI's role in automating threat detection, enhancing cyber defense, and addressing challenges such as adversarial attacks and data quality issues. Kirimhan (Kirimhan, 2023) emphasizes the integration of ML in anti-money laundering systems to promptly flag and recover stolen assets. Similarly, Roshanaei et al. (Roshanaei et al., 2024) discuss AI strategies for detecting insider threats through the analysis of access anomalies and behavioral deviations.

3.3. AI in digitizing legal document verification

As previously noted, there are no specific studies directly addressing the application of AI in LC document verification. Therefore, comparisons are drawn from research on AI in legal document verification. Recent case studies highlight the adoption of AI to improve law enforcement and enhance legal processes (Bhattacharya et al., 2023; de Sousa et al., 2022; Vuong et al., 2023). In this area, the integration of AI is primarily explored under two main categories: (1) methods to improve document processing and scalability, and (2) fraud detection

and prevention. The task of AI tools is to help process large volumes of documents quickly, ensure authenticity, and detect anomalies or forgery attempts, if any, to reduce the risk of fraud (Faqr, 2023; Vayadande et al., 2024; Zhong et al., 2020). Studies by Kufakwababa and Kuppala et al., (Kufakwababa, 2021; Kuppala et al., 2022) identify key attributes that are essential for legal document verification, including digital signatures, metadata, timestamps, rhetorical role labeling (such as identifying facts, arguments, and judgments), and mechanisms for retrieving supporting legal cases to ensure document accuracy and relevance.

3.4. AI in digitizing banking

AI is reshaping banking by streamlining risk management, fraud AI is transforming the banking industry by enhancing critical functions such as risk management, fraud detection, and customer relations (Fares et al., 2023). In risk management, AI's application through machine learning and neural networks significantly improves credit scoring accuracy and the predictive ability of financial instabilities. For instance, many studies demonstrate the effectiveness of using Support Vector Machines (SVMs) and random forests to better predict credit risks ahead of traditional models (Bahoo et al., 2024). Additionally, Le et al., (Le & Viviani, 2018) discuss the efficiency of AI in predicting bank failures, though they caution about the need for greater transparency in AI models (Citterio, 2024).

Recent empirical evidence from Indonesia further reinforces the relevance of the Technology-Organization-Environment (TOE) framework for AI adoption in financial institutions. In a study by Ikhsan et al. (Ikhsan et al., 2025), the researchers examined how banks in Indonesia adopt AI technologies, highlighting key influencing factors across technological, organizational, and environmental domains. Their findings indicate that perceived usefulness, top management support, and regulatory environment play critical roles in AI adoption decisions. This study supports our application of the TOE framework, as similar drivers technology readiness, leadership engagement, and compliance pressures are evident in trade finance, particularly in the context of automating LC document examination.

In terms of fraud detection and improving customer service, AI's role is equally transformative. Kumar et al., (Kumar et al., 2019) explore how AI-enhanced systems can identify fraudulent transactions by analyzing anomalous spending patterns. Durango-Gutiérrez et al., (Durango-Gutiérrez et al., 2023) combine AI with traditional logistic regression to provide deeper insights into banking operations, thus aiding in more informed decision-making. Tarkocin et al., (Tarkocin & Donduran, 2024) highlight how AI driven decision support systems in banks can help prevent financial crises by providing early warnings of liquidity stress using market-based indicators. These advancements not only streamline banking processes but also significantly improve customer experience, thereby boosting satisfaction and ensuring financial security (Bahoo et al., 2024). Based on the literature review Table 2 summarizes various AI capabilities and their areas of application in banking.

3.5. Ethical implications of AI in LC review

The integration of AI into the document examination process under LCs introduces critical ethical considerations, particularly in the areas of data privacy, decision-making transparency, and bias risks (Khalil et al., 2025). AI systems require access to sensitive client data to perform document validation tasks, which increases the risk of potential data breaches or unauthorized access, especially in online environments. Strict compliance with international and local data protection regulations, alongside secure storage and transparent data usage practices, is essential to mitigate these vulnerabilities.

Moreover, the transparency of AI decision-making remains a vital ethical concern (Cheong, 2024). The inherent complexity of AI algorithms can obscure the rationale behind discrepancy identifications or document acceptance decisions, making it difficult for trade finance

Table 2
Artificial Intelligent (AI) capabilities and their applications in banking.

AI Capability	Area/Sub-Area of Application	Relevant Studies
Document Automation	Document examination, transaction processing	(GTR, 2025a; Conpend, 2025; Traydstream, 2025; Yap, 2025)
Risk Management	Fraud detection, compliance monitoring	(Bahoo et al., 2024; Durango-Gutiérrez et al., 2023; Faqir, 2023; Kumar et al., 2019; Tarkocin & Donduran, 2024)
Workflow Optimization	Trade finance operations, process automation	(Almustafa et al., 2023; Conpend, 2024; Traydstream, 2025)
Compliance Management	Regulatory checks, compliance validation	(Bécue et al., 2021; Jones, 2023; Raffique & Duraisingam, 2023)
Data Analysis	Pattern recognition, predictive analytics in trade trends	(Durango-Gutiérrez et al., 2023; Fares et al., 2023; Tarkocin & Donduran, 2024)
NLP	Analyzing and processing trade documents, improving customer interaction	(Bhattacharya et al., 2023; Kufakwababa, 2021; Zhong et al., 2020)
AI-Driven Platforms	End-to-end trade finance process management	(JPMorgan Chase & Co, 2025; Citigroup Inc, 2025; Traydstream, 2025)
Decision Support	Operational decision making, credit assessments	(Bahoo et al., 2024; Tarkocin & Donduran, 2024)
Predictive Analytics	Risk forecasting, financial instability detection	(Citterio, 2024; Le & Viviani, 2018)
Customer Relations	Chatbots, AI-powered client systems, automated assistance	(Akhavan & Hassannayebi, 2024; Maseke, 2024)

professionals to fully interpret outcomes. To address this, AI software should be trained on international best practices such as UCP 600, ISBP guidelines, local regulatory frameworks, and historical case data to ensure standardized, consistent, and globally acceptable results.

Nevertheless, ethical concerns also extend to the risk of AI perpetuating or exacerbating existing biases embedded in historical data. If not carefully managed, AI systems could unintentionally replicate inefficiencies or discriminatory practices, particularly affecting documents from emerging markets or industries with non-standardized formats (D. V. P.S, 2023).

Insights from our expert interviews underscored these concerns, highlighting the importance of maintaining strong human oversight to ensure that AI recommendations are reviewed critically, especially for transactions involving non-traditional or jurisdiction-specific documentation.

The hybrid LC examination process, which combines AI-enabled document checking with human checker validation, offers an essential safeguard to uphold accountability, mitigate error propagation, and correct any bias-related issues. Additionally, developing transparent evaluation checklists, maintaining robust audit trails, and standardizing assessment criteria enhance the overall reliability and scalability of the examination process (Goodman & Trehu, 2022). Addressing regulatory compliance variations, minimizing potential biases in AI training, and proactively adapting to evolving legal requirements are critical to deploying AI systems that ensure security, transparency, fairness, and operational efficiency in LC document examination.

3.6. Critical synthesis of the literature

While the previous sections provide a descriptive overview of research across areas related to trade finance, this section aims to critically synthesize the key themes identified in the literature review. Table 3 summarizes how these themes connect to broader academic debates and where critical gaps remain. This synthesis also clarifies the specific ways in which the current study builds upon existing knowledge to offer original contributions in the context of LC document examination and AI integration.

Table 3
Critical synthesis of key themes in LC and AI literature.

Theme	Insights from Literature	Critical Synthesis
Researched Areas in LC	Studies focus on legal compliance, blockchain for e-LCs, fraud prevention, and credit scoring.	Fragmented research. These studies do not address operational document examination within traditional LC workflows. While relevant, existing work does not explore how these AI capabilities can be tailored to the regulated LC document examination process.
AI's Success in Related Fields	AI has been adopted in legal document review, banking, and supply chain automation.	Reveals a major gap. Most research overlooks AI's specific role in examination of LC documents
Lack of AI Studies in LC Document Examination	There is a notable lack of academic studies specifically focused on LC document examination	Indicates need for comparative studies between traditional and AI-enabled LC processes to demonstrate value.
Lack of Evidence on Digitization Benefits in LC	Claims of improved efficiency exist, but without structured measurement frameworks.	

This synthesis highlights that while foundational work exists in related domains, significant research gaps persist in applying AI to LC document examination. These gaps form the basis for the research objectives outlined in the next section.

3.7. Research gap and aim of this work

Fig. 3 highlights the current state of research, uncovering underexplored areas that warrant future focus for research and practical advancements. The following Table 4 discusses the key gaps identified through the review of the existing literature. Addressing these gaps can foster innovation, improve operational resilience, and facilitate the adoption of AI driven solutions in this critical industry.

Table 4
Research gaps.

Research Gap	Description
Integration of AI in Letter of Credit (LC) Document Examination	Researchers have not extensively explored hybrid AI models that validate AI as a comprehensive digital solution for automating the LC process, especially in document examination. While existing studies have mainly focused on legal issues, compliance, cybersecurity, and blockchain technologies, there remains a gap in deploying AI for digitizing document checks comprehensively. There is a lack of experimental or quantitative research to substantiate the effectiveness of AI solutions as viable replacements for human reviewers in LC document examination.
Experimental Validation of AI	There is a noticeable gap in research publications that specifically explore classical optimization methods and procedures for optimizing various elements of trade finance including processes like LC document examination in the operational management perspective. While there is ongoing research in adopting AI solutions for automation and efficiency, studies focusing on the application of traditional optimization techniques to systematically enhance trade finance operations remain scarce.
Optimization of Trade Finance Processes	The majority of research in this area has been qualitative, highlighting a significant gap in quantitative data-based research that could demonstrate the efficiency gains from digital solutions in trade finance.
Empirical Evidence of Digital Enhancements	

3.8. Research objectives

As highlighted in Section 3.5, researchers are yet to extensively explore hybrid AI models as comprehensive solutions for automating the LC document examination process. Existing studies primarily focus on legal issues, compliance, cybersecurity, and blockchain, leaving a gap in efficient utilization of AI for digitizing documents. Hence, we align our objectives to address this gap by analyzing the current LC document examination process, identifying necessary changes, and proposing actionable solutions. Fig. 4 outlines six steps derived from literature-based knowledge, supported by expert domain opinions, for developing the proposed roadmap for adopting AI in the LC document examination process. These steps result in specific objectives that guide the subsequent sections of this paper.

1. Evidence collection for consolidating status quo from publications.
2. Gap identification for consolidating research and practical gaps for the integration of AI in the digital examination process. This step will help determine the specific changes needed to facilitate the AI adoption in LC document examination.
3. Explore case studies to learn from the experiences of the early adopters in related fields.
4. Propose a roadmap for AI adoption based on existing document examination process.
5. Managerial insight will be provided on the strategic, tactical, and operational steps for the proposed change, drawing lessons from case studies, literature, and expert opinions.
6. Provide future research recommendations based on an overall assessment of the findings and implications.

The focus is on introducing a hybrid approach, where AI is integrated to digitize LC documentation examination process, rather than fully automating all processes in trade finance. Full digitization may not be always feasible due to standardization barriers, making this targeted hybrid model a practical and effective solution.

4. Methodology

This research adopts a qualitative methodology to investigate the AI in trade finance, focusing on the exploration of technological advancements and the assessment of expert opinions. The guidelines described in (Beaulieu & Bentahar, 2021; Martin & Daim, 2012) for development

of road map have been followed to shape the methodology of our study.

4.1. Theoretical framework: TOE as a Lens for AI adoption

To provide a theoretical underpinning for the proposed roadmap, we adopt the TOE framework (Depietro et al., 1990), which has been widely used in information systems research to study technology adoption. The TOE framework contextualizes technology implementation through three lenses: technological capabilities, organizational readiness, and environmental factors. Our roadmap addresses these dimensions explicitly through activities such as AI vendor selection and integration (technological), stakeholder engagement and training (organizational), and regulatory compliance (environmental). Additionally, we reference Vial's [4] model of digital transformation to position our approach within broader organizational change literature. This dual-framework integration ensures that the roadmap is not only practically grounded but also theoretically aligned with existing scholarship.

The selection of TOE framework is reinforced by recent empirical studies in the financial sector. Ikhsan et al. (Ikhsan et al., 2025) demonstrated the applicability of TOE in the Indonesian banking industry, showing that technological factors (e.g., ease of use), organizational support (e.g., executive sponsorship), and environmental conditions (e.g., regulatory incentives) significantly influence AI adoption. These dimensions directly parallel the challenges and enablers we observed in trade finance, thereby validating our use of TOE to underpin the roadmap proposed in this study.

In addition to TOE, we also integrate insights from the Technology Acceptance Model (TAM) to capture individual-level drivers of technology adoption. While TOE explains macro level factors such as infrastructure readiness and regulatory pressures, TAM focuses on how users perceive and accept new technologies. This dual theoretical approach ensures that our framework reflects both organizational dynamics and user behavior. In particular, Ikhsan et al. (Ikhsan et al., 2025) extended the TAM model by introducing perceived trust as a moderating variable in the context of AI adoption in Indonesian banks. Their empirical findings suggest that perceived usefulness and trust significantly influence the willingness of banking professionals to adopt AI technologies. By incorporating TAM alongside TOE, we enrich our theoretical foundation and provide a more comprehensive understanding of AI adoption in trade finance across institutional and individual dimensions.

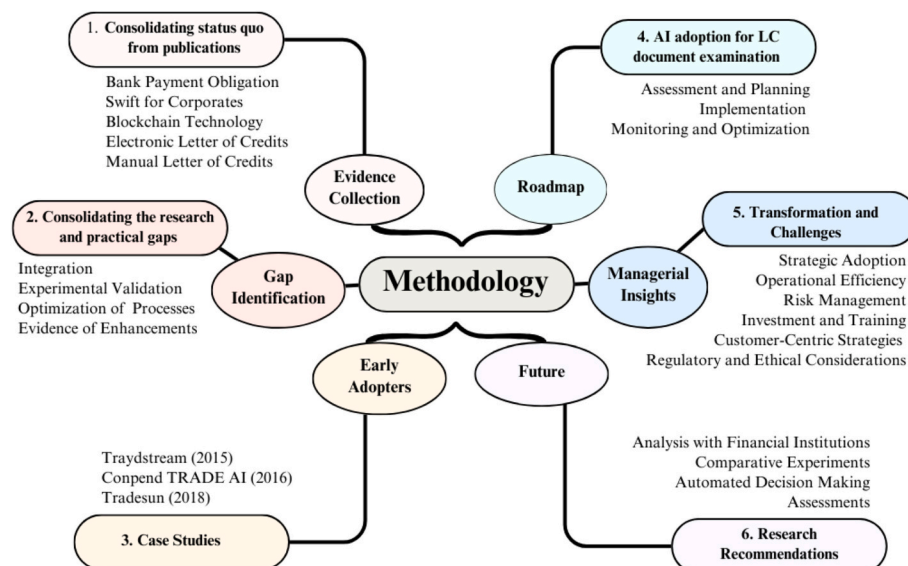


Fig. 4. An Overview of Research Methodology.

4.1.1. Expert interview protocol

To reinforce literature based knowledge and ground the roadmap in practical realities, expert opinions were collected and analyzed as part of the methodological framework. Five domain experts were consulted, three from leading international banks with established trade finance operations and two from digital solution providers specializing in AI integration in financial services. One banking expert was actively associated with the International Chamber of Commerce’s Digital Standards Initiative, ensuring a globally aligned perspective.

Experts were selected based on their active involvement in AI capability assessment, regulatory compliance, and digital transformation within trade finance ecosystems. Data collection was conducted through semi-structured interviews, either via virtual meetings or written exchanges, allowing for in-depth, open-ended responses. The interview guide was designed around key themes such as AI readiness, human-in-loop practices, document verification standards, regulatory challenges, and system integration.

Interview responses were transcribed and subjected to a qualitative thematic analysis to identify recurring patterns, points of divergence, and actionable insights. Themes were refined iteratively, and coding was conducted manually to maintain interpretive fidelity to each expert’s input. This expert validation stage provided an empirical grounding to the roadmap development process, ensuring that strategic, tactical, and operational insights were not solely theoretical but informed by practice-led knowledge. The insights derived from this process are presented and critically analyzed in [Section 4.3](#).

4.2. Approaches and methods analysis

The outcome of the first two steps mentioned in the research objectives and [Fig. 4](#), namely evidence collection and gap identification, are detailed in [Sections 3.1 to 3.4 and 3.5](#), respectively. Approaches and methods followed for evidence collection, gap identification, and development of roadmap are discussed in this section.

The initial phase involves a comprehensive review of approaches to establish a theoretical foundation and critically assess existing scholarly works on AI applications in trade finance. This comparative analysis of methods will help identify key technologies, theoretical gaps, and areas where AI has been or can be applied effectively within the domain. It will cover sources from academic journals, industry reports, and case studies that discuss the integration and implications of AI technologies in financial institutions.

Step 4: assessment and planning: we propose a hybrid approach to address compliance concerns, focusing on digitizing only the LC document examination process while incorporating the human in the loop concept, instead of opting for end-to-end digitization. Identify and address barriers related to technology, regulations, and operations for AI adoption, while highlighting how AI improves efficiency, accuracy, and reduces risks compared to current methods. Additionally, find the right balance between AI automation and human oversight to ensure reliable and compliant processes.

4.3. Expert insights and analysis

The expert interviews yielded several recurring themes and divergences that directly informed the development of the roadmap and hybrid AI-human model. Key insights are summarized in [Table 5](#) below:

Qualitative thematic analysis was employed to examine the expert inputs. The analysis focused on identifying consensus areas (e.g., the need for human oversight), divergences (e.g., differing views on automation readiness between banks and FinTech firms), and practical recommendations related to AI deployment in LC document examination. These insights were not only used descriptively but were critically integrated into several components of this study including the development of the AI adoption roadmap ([Section 5](#)), the proposed hybrid human-in-loop model ([Section 4.3.2](#)), and the identification of

Table 5
Expert insights.

Theme	Expert Insight Summary
Need for Human Oversight	All five experts emphasized that a hybrid model is necessary to mitigate risks in high-value trade finance transactions. AI is seen as a tool for first-level screening, with final decisions requiring human validation. Experts expressed concerns about regulatory inconsistencies across jurisdictions, which may hinder full automation. One noted, “Until regulators standardize expectations, banks will hesitate to rely entirely on automated outcomes.”
Regulatory Challenges	FinTech experts highlighted the challenge of API integration between legacy trade platforms and AI systems. Operational silos and lack of interoperability were flagged as bottlenecks.
Technology Integration Gaps	Bank representatives were more cautious about AI’s readiness, while FinTech stakeholders showed greater confidence in current capabilities, highlighting an industry divide.
Variation in Automation Readiness	

regulatory and operational barriers ([Section 5](#)).

This dual approach combining a literature-driven foundation with real-world expert validation ensures the proposed framework is both theoretically grounded and practically relevant. The expert insights also directly informed the comparative analysis between the existing LC examination process and the proposed AI-integrated model presented in [Sections 4.3.1 and 4.3.2](#), respectively.

4.3.1. Existing LC document examination process

Our study focuses on the stages of the LC process where both the nominated and issuing banks conduct a detailed examination of submitted documents to ensure compliance with the terms and conditions specified in the LC, laws, and regulations, subsequently authorizing payment to the beneficiary (see [Fig. 2](#)). Since an LC serves as a financial institution’s commitment to disburse payment upon the presentation of compliant documents, precise compliance verification is a critical aspect of the process. This verification is traditionally performed through manual, visual inspections by trained and certified professionals (Certificate for Documentary Credit Specialists (CDCS)) ([LIBF, 2025](#)) to ensure adherence to the established criteria. Document examination is a specialized function requiring meticulous attention, as it is essential to assess and address discrepancies accurately. However, scalability remains a significant limitation, with banks constrained by the capacity of their document checking teams. Scaling this capacity to handle growing transaction volumes presents significant challenges due to the labor-intensive nature of the compliance examination process and the heightened risk of financial losses stemming from undetected discrepancies during the examination.

Many documents under an issued LC, including invoices, shipping documents, insurance certificates, and financial drafts, must be presented to the buyer’s bank to facilitate payment. Human expert checkers, who are experienced and certified, conduct extensive manual examinations of these documents. To maintain high standards, banks invest heavily in acquiring and training these professionals. However, the dynamic landscape of trade finance increasingly necessitates automation to replace manual, paper-based processes. Emerging technologies such as AI, ML, NLP, smart OCR, and blockchain are driving this transition. The failure of human checkers to identify discrepancies accurately and promptly can expose banks to significant legal, financial, and reputational risks ([Aujara, 2019](#)). To address these challenges, FinTech companies are developing AI driven solutions that offer greater accuracy and efficiency in document examination.

4.3.2. Proposed AI integrated LC document examination process

AI, with support from ML, NLP, and OCR, has been identified to have a significant part to play in effecting changes in how document

examination takes place in the forecasted trade finance area (ICC, 2021a). These technologies allow for text capturing and understanding from documents and then proceed to summarize key information and check them against the LC. This capability enables the AI to make decisions to accept the presented documents or refuse them and states all founded discrepancies. Because of the secrecy of the research that are directly studying the AI role in examination of the trade documents, we had to drive the conclusions and findings from Fintech websites, whitepapers, and trade organization's reports. According to (Kim & Kim, 2020) AI enhances decision making by providing faster, more accurate data analysis and insights, which improves the overall quality and efficiency of decisions made within organizations. Fig. 5 shows AI integration with the LC process.

A comparison of Fig. 2 with Fig. 5 clearly demonstrates the additional steps required to integrate AI into LC document examination process. AI technologies are proposed for use in the document presentation phase, particularly in Steps 5 and 7, to conduct the examination of documents submitted by the exporter to the advising bank, then to the issuing bank, and finally to the importer (buyer). However, due to the complexities associated with risks, compliance, regulations, and cybersecurity issues in this process, there is a lack of clear steps and guidance for implementing this change. This gap motivated the development of a detailed roadmap, as outlined in Section 5.

In this process, AI enabled software is used by the advising and issuing bank to streamline document examination against the LC terms and conditions. It can also be utilized by large exporters as a preliminary check to prevent the rejection of their submitted documents and to avoid delays in re-submission in case of discrepancies. The AI isolates unstructured data from physical documents and applies advanced rules and analytics to validate compliance with the LC requirements, related laws and regulations. This includes verifying document consistency, cross-checking individual documents like shipping, financial, and commercial documents, then identifying any discrepancies. If discrepancies are found, the AI flags them and lists specific discrepancies for rejection, allowing for a standardized and efficient document screening process. According to FinTech experts, this preliminary automation stage is critical for reducing manual effort while still enabling banks to retain final control.

By automating these initial checks, AI reduces the time and labor involved in manual document verification while enhancing accuracy. However, there is still a human-in-loop needed, and final approval still involves human decision at the issuing bank, providing an essential layer of risk mitigation before finalizing any transaction under the LC. This

hybrid approach leverages AI's efficiency while retaining human judgment for high value decisions, balancing speed with financial security (Khalil et al., 2025).

Incorporating AI for document examination also raises behavioral considerations. As highlighted by the TAM framework, user adoption is significantly influenced by perceived usefulness and trust in the system. These factors are particularly critical in hybrid models, where banking professionals must rely on AI recommendations but retain final decision-making authority.

4.3.2.1. How AI examines the trade documents. The AI software examines documents presented under the LC by ensuring compliance with the existing LC terms and conditions available in the bank system. So, it is crucial to integrate the AI checking software with the trade finance processing software of the bank. Then the AI performs two additional checks (See Fig. 6). First, against the uniform customs and practice for documentary credits (UCP) established by the International Chamber of Commerce (ICC) that governs the use of letters of credit in international trade. UCP provides a standardized framework for banks to follow when handling documentary credits, ensuring consistency and reliability in global trade transactions. Second, against the international standard banking practice (ISBP), which are set of guidelines published by the ICC to complement the UCP and provide detailed instructions and examples cover various aspects of document examination, such as the

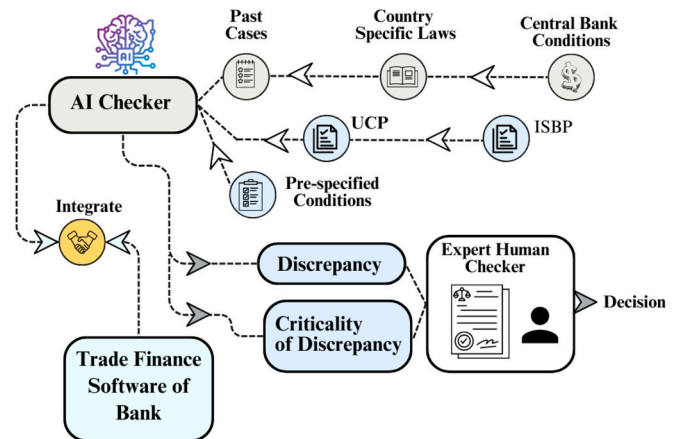


Fig. 6. Hybrid human-in-loop AI Integration.

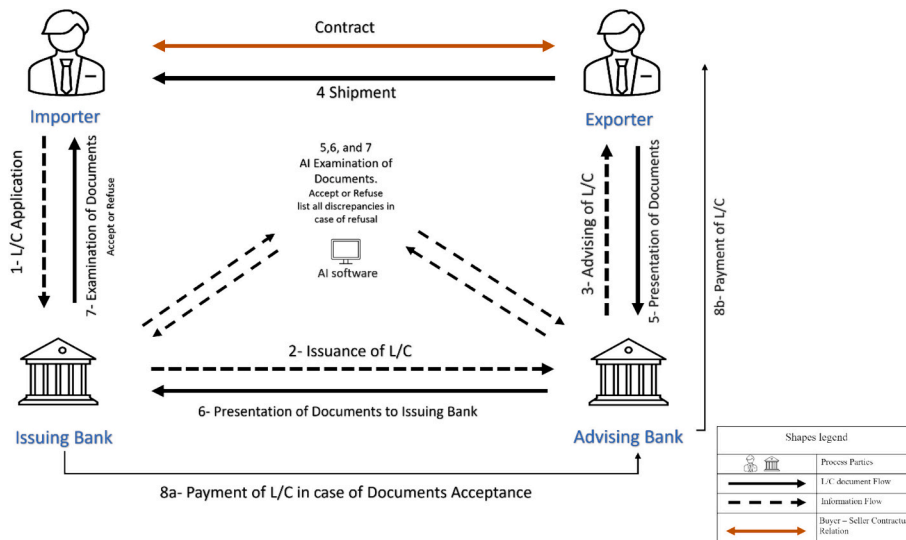


Fig. 5. AI integration with the LC process.

requirements for different types of documents (e.g., invoices, bills of lading) and the procedures for checking compliance with credit terms. Furthermore, AI is trained to reference past cases, country specific laws, and central bank conditions as necessary. According to the ICC Academy (ICC Academy, 2025), the most common discrepancies include conflicts of data, missing documents, late presentations, late shipments, expired LCs, unauthenticated alterations, missing endorsements, goods descriptions not matching the LC, incorrect ports of loading or discharge, insurance documents dated later than the shipment date, and incomplete or missing on-board notations. The AI software follows specific criteria to ensure thorough verification of the documents, including presentation validation checks, document consistency checks, and individual document checks for the bill of exchange, draft and commercial invoice. This multi layered approach ensures that all documents are meticulously vetted for compliance, thereby significantly reducing the risk of errors and discrepancies in international trade transactions.

4.3.2.2. AI driven data processing and document examination. The AI driven document examination process illustrated in Fig. 7 begins with uploading the trade documents presented under the LC. Advanced OCR and NLP technologies which will be part of the AI checker (See Fig. 6) are then applied to digitize and classify the data, enabling efficient handling of both structured and unstructured inputs (ICC, 2021a).

Next, data extraction captures thousands of relevant attributes from various document types, ensuring comprehensive coverage for further analysis. Following this, the system proceeds with accessing the LCs and their related amendments. When integrated with a trade processing system, the AI directly retrieves and validates the LC and amendments, ensuring compliance with the specified terms and conditions. In the absence of such integration, users manually upload the LC and associated documents into the system.

The AI checker then performs compliance and consistency checks, rigorously evaluating the extracted data against over 400,000 permutations of international trade rules (Traydstream, 2025), including UCP 600 and ISBP guidelines. These checks ensure the data aligns with regulatory and organizational standards, while cross-document verification identifies inconsistencies across related documents in the transaction set.

Additional validations ensure adherence to specific LC terms, the incorporated amendments, internal banking practices, and global trade regulations. Discrepancies and anomalies are flagged during this process, with a detailed discrepancy report generated for human review, allowing professionals to focus on resolving specific issues rather than manually reviewing entire datasets.

To ensure seamless processing, API (Application Programming Interface) integrations in digital channels maintain the digital nature of

the data throughout the workflow. APIs facilitate data sharing and standardization, which could indirectly support document verification by automating and validating business interactions and transactions across regions (Heshmatisafa & Seppänen, 2023). These integrations facilitate the incorporation of diverse data sources, such as SWIFT messages and shipping documents, from both digital and non-digital inputs. This end-to-end process provides a robust and efficient approach to document examination, significantly reducing errors, enhancing compliance, and streamlining trade finance operations.

4.3.2.3. Discrepancies. In the context of an LC, discrepancies refer to inconsistencies, errors, or deviations from the terms and conditions outlined in the LC documents submitted by the seller to the buyer's bank. These discrepancies can pertain to mismatches between the presented documents and the LC terms or inconsistencies within the documents themselves.

Typical discrepancies observed during the LC document review include, but are not limited to, differences in quantity or description, pricing, shipping schedules, presentation timelines, incomplete documentation, and discrepancies in shipping documents. When the seller submits documents to the buyer's bank for review, the bank examines them against the LC terms to verify compliance. If any discrepancies are identified, the bank may reject the documents or request amendments or clarifications from the seller.

The LC often mandates that the issuing or advising bank must complete its examination and issue any necessary notices regarding discrepancies or their resolution within a specified timeframe, frequently stated as "within five working days" or a similar duration. If discrepancies are detected, the bank communicates them to the seller for resolution as per the LC terms. Meeting this deadline is essential to ensure a seamless and timely LC transaction for both the seller and the buyer.

It is important to note that if the document examiners at the bank fail to identify and report a discrepancy accurately and within the stipulated time, this lapse can expose the bank to substantial risks. These risks may include legal, financial, and reputational consequences. To address these challenges, FinTech companies have introduced AI-driven technologies designed to enhance accuracy and efficiency in the process (Conpend, 2025). However, these solutions do not entirely replace human involvement. Thus, the LC review process can be characterized as a hybrid model integrating AI and human expertise.

4.3.2.4. Decision. Once the AI system completes its compliance and consistency checks and generates a detailed discrepancy report, the bank must decide whether to accept the AI results as final or escalate the flagged documents for human verification. Both ways have implications for risk management, process efficiency, quality of examination, and

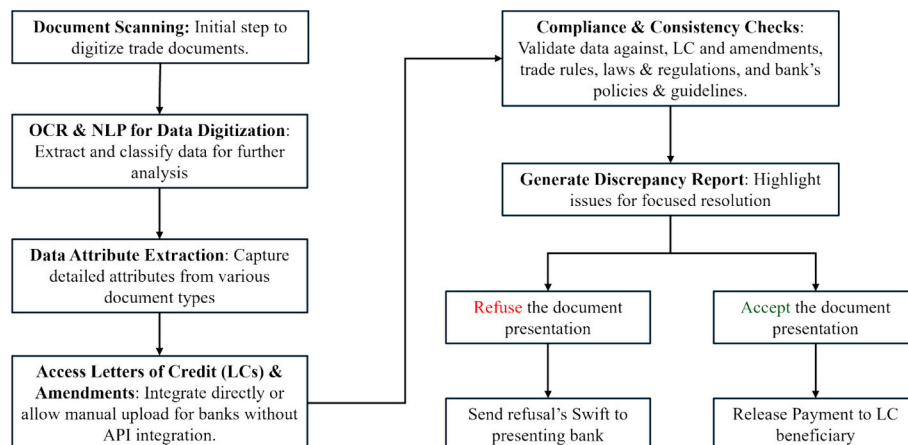


Fig. 7. AI driven data processing and document examination.

resource allocation.

In cases where the bank decides to accept the AI results as final, it can capitalize on the efficiency and accuracy provided by the AI driven examination process. This decision eliminates the need for manual intervention, enabling faster processing and cost savings. However, the risk associated with this approach lies in the possibility of AI misinterpreting nuanced or context sensitive elements of the LC terms or associated documents (Khalil et al., 2025). AI provides practical, case specific examples of document examination and compliance evaluation, showcasing its potential to streamline processes and reduce manual effort. However, these examples are inherently limited in scope and context, making it unsuitable to use AI outcomes as the sole basis for generalizing conclusions across all scenarios (Ozturk, 2024). Errors in AI decision making could lead to the wrongful acceptance or rejection of documents, posing potential legal, financial, and reputational risks for the bank.

Alternatively, if the flagged discrepancies are forwarded for human verification, the bank introduces an additional layer of scrutiny. Trade finance professionals review the specific issues highlighted by the AI, focusing on complex or ambiguous cases where human expertise is invaluable. This approach ensures robust risk mitigation and enhances the quality of the document examination process. However, it increases operational costs and may slow down processing times, particularly in high volume scenarios. The need for skilled human resources to verify discrepancies adds further pressure on staffing and may diminish the efficiency gains achieved through AI automation.

AI is typically utilized for tasks with lower complexity, while high complexity tasks are better suited for human experts (Fares et al., 2023). Banks can adopt a risk-based strategy, where the decision to escalate flagged discrepancies depends on the transaction's complexity, value, and associated risks. Straightforward cases or minor discrepancies could rely solely on the AI generated results, while complex or high value transactions warrant human intervention. This hybrid approach combines the efficiency and accuracy of AI driven processes with the contextual judgment and expertise of human reviewers, ensuring a robust, compliant, and resource-optimized examination workflow.

4.4. Case studies

This section delves into real world case studies and illustrations of impactful digital transformation initiatives driven by AI technology within trade finance. The discussion highlights adopting banks, challenges faced, obstacles encountered, implemented solutions, and the specific purposes for which AI is applied, as outlined in the case studies (Tables 6–7). The roadmap for AI adoption is developed based on the insights and lessons derived from these real-world case studies, combined with the knowledge and expertise of professionals in this field, to guide effective implementation strategies (see Fig. 4).

In the landscape of trade finance, Traydstream came into existence in 2015, Conpend in 2016, and TradeSun in 2018 (Cbinsights, 2025a; Cbinsights, 2025b; PitchBook, 2025). These AI driven solutions distinctly focus on the specialized task of LC document checking, which is a crucial aspect of ensuring compliance and operational efficiency in financial transactions. These platforms leverage sophisticated AI algorithms to scrutinize, validate, and automate the processing of LC, a critical component not directly addressed by solutions like those from ClearView Trade, Monetago, and PrimaTrade. The latter companies, while also utilizing AI, apply their technologies more broadly across different facets of trade finance such as fraud prevention, export logistics, and supply chain management, without a concentrated focus on LC documents. This delineation highlights a targeted approach by Traydstream and its peers towards resolving specific challenges in LC transaction processing, contrasting with the broader scope of digital transformation pursued by the other firms.

In our research, we explored case studies of banks and fintechs adopting AI for LC document checking in trade finance. Traydstream and Conpend are highlighted as pioneering solution providers in this

Table 6

Banks and digital transformation: AI application in trade finance.

Bank	Solution Applied
ING Bank	Implemented Conpend's TRADE AI app to automate document checking, enhancing compliance and efficiency (GTR, 2025a)
Danske Bank	Adopted Conpend's TRADE AI app to digitize trade finance processes, improving efficiency and compliance (Conpend, 2024; Weisman-Pitts, 2025)
Bank of Africa	Selected Conpend's TRADE AI app via Finastra to digitize trade finance processes.
Commerzbank	Piloted Conpend's TRADE AI to automate compliance checks in trade finance transactions.
Scotiabank	Partnered with Conpend via CGI to implement intelligent process automation for trade finance transactions. (CGI Group Inc, 2025)
Bank of Montreal (BMO)	Participated in a pilot integrating Conpend's TRADE AI with CGI Trade360, enhancing trade finance efficiency. (CGI Inc, 2025)
National Bank of Canada (NBC)	Engaged in a pilot with Conpend and CGI to automate trade finance processes using TRADE AI. (CGI Inc, 2025)
JPMorgan Chase	Utilizing Cleareye.ai's advanced AI platform, ClearTrade, to automate document examination and reduce processing times in trade finance transactions (JPMorgan Chase & Co, 2025)
HSBC	Implementing AI-driven platforms with IBM to streamline trade finance processes and improve efficiency by automating and digitizing trade finance documentation. (GTR, 2025b)
Standard Chartered	Employing Traydstream AI to enhance risk assessment and fraud detection in trade finance activities and trade document matching services to the Bank's clients, delivering increased efficiency and transparency to document trade processing and improving the trade finance experience for buyers and suppliers globally (Standard Chartered, 2025)
Deutsche Bank	Leveraging Traydstream AI to automate document checking for their Trade Finance products and optimize trade finance workflows and improve client service delivery (Finextra, 2025)
Citibank	Partnered with Traydstream to automate trade-document processing, leveraging AI-powered solutions to enhance scalability and reduce manual process risks. This collaboration aims to streamline trade finance operations, optimizing document checking for letters of credit and collections (Citigroup Inc, 2025)

Table 7

Other applications of AI in trade, supply chain, and financial institutions.

Fintech Solution	Sector	AI Application and Usage
ClearView Trade	Export and Logistics	Automates document generation, streamlines export workflows, integrates with customs for efficient declarations, reducing manual processes and errors.
Monetago	Finance and Trade	Provides fraud detection with digital fingerprinting technology to authenticate trade-related documents and prevent duplication. Digitizes financial supply chains, manages supplier payments, automates supply chain finance (SCF) and dynamic discounting, verifies Environment, Social, and Governance (ESG) compliance at scale.
PrimaTrade	Trade Finance	

domain, each having formed substantial partnerships with globally recognized banks. These case studies exemplify varying levels of digital and AI maturity, emphasizing the strategic adoption of innovative technologies within the financial sector. This analysis seeks to understand the impact of digital transformation on traditional trade finance operations and the evolving landscape of regulatory compliance and operational efficiency.

In examining the role of AI in the digitization of LC document

examination within trade finance, Conpend’s TRADE AI application serves as a critical technological advancement. TRADE AI automates processing of trade finance documents, including LC, invoices, and shipping documents to ensure accuracy and compliance by cross-referencing document data with predefined rules and regulations. This AI app checks against International Chamber of Commerce (ICC) rules and performs compliance checks based on Bankers Association for Finance and Trade (BAFT) anti-money laundering (AML) guidelines, as well as regulatory sanctions screening, including Office for Foreign Assets Control (OFAC). Prominent banks such as ING Bank, Commerzbank, UniCredit, Danske Bank, and BANK OF AFRICA have adopted this AI-driven tool to enhance the efficiency and compliance of their trade document processes. The integration of TRADE AI at Danske Bank, for instance, signifies a significant leap towards digital transformation, reducing reliance on manual processes and aligning operations with international regulatory standards.

Similarly, Traydstream’s adoption by Deutsche Bank (July 2021) and Citi (December 2023) (Citigroup Inc, 2025; Finextra, 2025) highlights another facet of AI’s impact on trade finance. The Traydstream platform employs machine learning to scrutinize trade documents, increasing transaction speed and accuracy. This technology supports Deutsche Bank’s strategic goal to enhance the digital capabilities of its trade finance operations globally. Additionally, Citi’s utilization of Traydstream aligns with efforts to scale operations efficiently while maintaining client service quality (Arif, 2025). HSBC’s Global Trade and Receivables Finance (GTRF) team handles over US\$500 billion in documentary trade each year, involving the manual review of more than 100 million pages. To streamline this process, HSBC and IBM have developed a cognitive solution designed to automate and digitize trade finance documentation, reducing labor-intensive tasks (GTR, 2025b). Furthermore, TradeSun’s recent collaboration with Wells Fargo introduces an advanced AI platform that streamlines trade document processing, reinforcing the trend towards digital solutions that enhance operational efficiency and compliance accuracy. This partnership is indicative of Wells Fargo’s commitment to adopting cutting-edge technologies that support robust digital strategies in trade finance. These case studies collectively demonstrate a significant shift towards more automated, efficient, and compliant trade finance operations, driven by sophisticated AI technologies that redefine traditional processes and set new industry standards.

5. Results and discussion

5.1. Roadmap for AI integration in trade finance: LC process

The adoption of AI in trade finance, particularly for the digitization and automation of the LC examination process, holds significant potential to revolutionize traditional practices. However, as outlined in Section 3.7, critical gaps remain in the literature and industry applications, including the integration of hybrid AI models with existing trade finance digital solutions, the lack of experimental validation of AI’s effectiveness, and the absence of quantitative evidence demonstrating operational efficiency improvements. Additionally, research has not sufficiently optimized trade finance processes through AI or addressed adoption barriers such as regulatory compliance and human-AI collaboration. Building on these identified gaps and the case studies presented in Section 4.4, this section provides a detailed decision roadmap (Table 8 and Fig. 8) for banks and financial institutions seeking to implement AI in LC processes. This roadmap is designed to guide stakeholders in overcoming challenges, enhancing operational efficiency, and fostering a future-ready trade finance ecosystem.

The findings of our roadmap align with broader patterns observed in the global financial sector. For instance, Ikhsan et al. (Ikhsan et al., 2025) highlight how organizational readiness and environmental constraints such as regulatory expectations and digital infrastructure shape AI adoption in the Indonesian banking sector. Similarly, our expert

Table 8 Roadmap for AI integration in trade finance: letter of credit (LC) process.		
Step	Description	Key Activities/Outputs
Align AI Adoption with Organizational Digital Transformation Goals	Ensure AI integration supports the organization’s broader digital transformation strategy, fostering innovation and competitive advantage. Experts highlighted that organizational alignment and staff readiness are among the most underestimated barriers to AI implementation, especially in legacy banking environments. Banks were more cautious than FinTech firms, indicating different organizational maturity levels.	Strategic Vision Alignment: Link AI adoption to the organization’s overarching digital strategy, focusing on enhancing customer experience, operational efficiency, and scalability.
		Cross-Functional Collaboration: Engage leadership and key business units to define AI’s role in achieving digital transformation.
Define Existing LC Examination Process	Analyze current workflows, identify inefficiencies, and establish baseline metrics.	Current Practices: Manual, paper-based processes prone to delays and errors. Baseline Metrics: Average LC processing times, compliance error rates, and manual operation costs. Evaluate customer journey and transaction flows for inefficiencies. Review regulatory compliance and risk control mechanisms in the current processes.
		Key Activities: Review internal workflows for bottlenecks in document verification, compliance checks, and turnaround times. Leverage Insights: Reference industry case studies to identify opportunities for digitization and automation.
Evaluate Current Processes and Identify Challenges	Assess existing LC processes, inefficiencies, and pain points to align with best practices.	Assess technology architecture for integration potential and missing tools. Evaluate staff training needs and organizational model requirements for AI adoption.
		Vendor Criteria: Assess AI solutions for document automation, compliance risk analysis, and integration capabilities.
Select and Evaluate AI Vendors	Identify and evaluate vendors based on their ability to meet trade finance-specific requirements.	Pilot Testing: Conduct proof-of-concept trials with shortlisted vendors to evaluate performance, scalability, and support services.
		Evaluate system options for customization, upgrades, or new solutions based on identified gaps.
Propose AI Integration in LC Examination	Design and pilot AI systems for automating document verification and compliance checks.	Hybrid AI Models: Implement machine learning and rule-based systems for document verification.

(continued on next page)

Table 8 (continued)

Step	Description	Key Activities/Outputs
		Integration: Ensure seamless connectivity with trade operation systems, sanctions and compliance checking systems, client trade portals, SWIFT, and APIs. Pilot Implementation: Test AI in specific LC processes and measure metrics like accuracy and processing time reduction. AI for Efficiency: Automate repetitive tasks such as data extraction and validation to reduce processing times and improve accuracy. Risk Mitigation: Use AI for anomaly detection, ensuring secure audit trails and compliance with international regulations. Technological Barriers: Invest in scalable AI systems integrating with legacy systems. Regulatory Hurdles: Collaborate with regulators to align AI solutions with compliance standards. Operational Readiness: Train staff to work alongside AI tools while maintaining oversight and reliability. Optimal Integration: Allocate routine and repetitive tasks to AI while focusing human expertise on critical decision-making. Feedback Loops: Use insights from human-AI interactions to refine algorithms and enhance system accuracy. Phased Approach: Start with pilots (6–12 months), evaluate results, and scale operations by Year 2. Plan for full AI integration by Year 5. Strategic Redefinition: Use AI insights for predictive analytics and decision-making. Long-term Goals: Transition to fully automated, real-time trade finance systems integrating blockchain, IoT, and other advanced technologies to enhance reliability and efficiency.
Address Efficiency and Risk Mitigation	Use AI to optimize workflows and mitigate risks related to fraud and compliance issues.	
Overcome Adoption Challenges	Address barriers such as technology readiness, regulatory compliance, and operational alignment. FinTech experts noted API incompatibility and siloed infrastructure as barriers to scaling AI tools.	
Enhance Human-AI Collaboration	Define roles for AI and humans, ensuring seamless integration and continuous improvement. Expert feedback aligned with these implementations, noting that early adopters found the highest value in AI tools that enhanced but did not replace human review processes	
Develop a Timeline for Adoption	Implement AI solutions in phases to ensure smooth transition and measurable progress.	
Future Prospects	Position AI as a transformative tool for trade finance, integrating emerging technologies for long-term goals.	

interviews and case studies emphasize the importance of organizational alignment and regulatory clarity in successfully integrating AI into LC document examination. This underscores the generalizability of our approach while also suggesting that national or institutional context may affect the pace and depth of transformation.

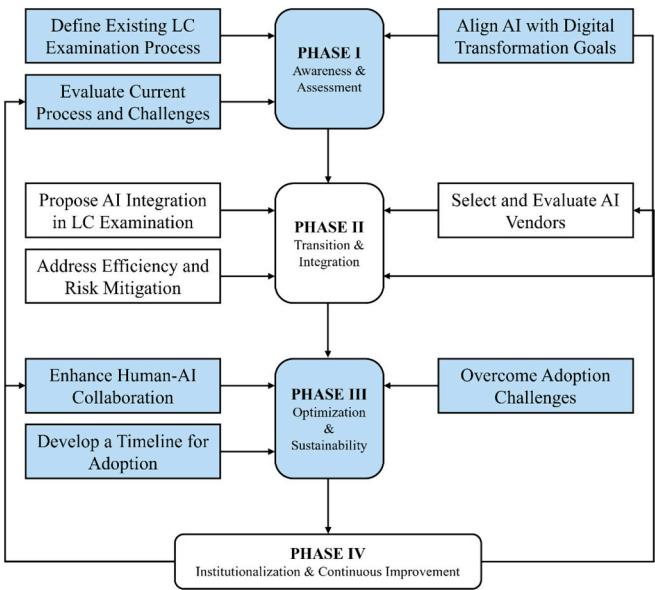


Fig. 8. Roadmap for AI integration in LC examination.

5.2. AI-driven efficiencies in trade finance

Current Trade Finance processes available to support the trade finance ecosystem are largely manual and paper driven. These produce over four billion pages of documents every year (Ramachandran et al., 2017). The automation of document examination under documentary credits highlights substantial efficiencies for all parties involved in the LC process. By reducing the need for manual labor, automation saves time and cuts costs significantly. Automated systems can handle larger document volumes efficiently, promoting scalability without requiring a proportional increase in human resources (ICC, 2021a). Additionally, automation minimizes human error, ensuring consistent application of rules and standards across processes (Khalil et al., 2021).

Enhanced accuracy and speed are key benefits, as automated systems streamline workflows by automating repetitive tasks. This allows experienced document checkers to focus on discrepancies and complex issues, optimizing the use of expertise.

Overall, the integration of AI, ML, and OCR technologies offers significant opportunities to enhance efficiency, reduce costs, and support sustainable practices while ensuring compliance and future proofing operations.

Table 9 below illustrates the comparative efficiencies between digital AI-integrated solutions and traditional paper-based approaches. It highlights the transformative impact of digital technology on transparency, workflow, security, cost, time, and customer satisfaction, emphasizing its potential to modernize the trade finance ecosystem.

In addition to AI, blockchain technology offers a promising pathway for enhancing real time verification of trade documents. Specifically, a permissioned private blockchain platform is proposed for use among banks, corporations, and other related entities. In such a platform, only authorized participants including issuing banks, advising banks, applicants, beneficiaries, logistics providers, and insurers would have access to submit, verify, and approve documents such as invoices, bills of lading, insurance certificates, and inspection reports. Smart contracts would automatically enforce pre-defined conditions, ensuring that document validation is conducted instantly and transparently. Real-world implementations such as Marco Polo Network and Contour Network demonstrate the feasibility of such permissioned blockchain platforms, providing secure, efficient, and tamper-proof handling of documentation across multiple jurisdictions.

However, despite its potential, the use of blockchain for real-time document verification also faces limitations (Ahmed & MacCarthy,

Table 9

Comparison of efficiencies between digital AI integrated and traditional paper based solutions.

Efficiency Factor	Digital AI Integrated Solution	Traditional Paper Based Solution
High Level of Transparency and Visibility	AI integration with Blockchain technology provides real-time document access for relevant parties, ensuring transparency and eradicating unauthorized alterations (Chen, 2023; Dutta et al., 2020)	Limited transparency, with delays in document access and potential risks of unauthorized changes.
Seamless Workflow and Time Savings	Transactions and processing time significantly reduced. Automates LC processes, reducing delays and completing tasks in hours or minutes (Khalil et al., 2021; Khalil et al., 2025)	Time-intensive processes with delays in approvals and document movement. Manual processes often result in bottlenecks, redundancies, and delays spanning days or weeks.
Enhanced Security Protocol	Reduces human errors and improves trust through automation and secure technologies like smart contracts (Taherdoost, 2023)	Higher risk of errors, inconsistencies, and document tampering due to manual handling.
Cost Savings	Significant cost reduction by eliminating manual tasks and improving resource allocation (Ozturk, 2024)	Higher operational costs due to labor-intensive processes and inefficiencies.
Error Reduction	Automation decreases errors, lowering associated costs (Conpend, 2025; ICC, 2021a)	Prone to manual errors, increasing costs and risks.
Customer Satisfaction	Faster, accurate, and transparent processes improve customer feedback and loyalty. (Akhavan & Hassannayebi, 2024)	Customers face frustrations due to delays and inconsistencies.
Operational Impact	Streamlines lifecycle processes, boosting productivity and scalability (Mah et al., 2022; Maseke, 2024; Wang et al., 2024)	Complex and resource-intensive, limiting scalability.
Challenges	Regulatory uncertainties and cybersecurity threats are barriers but can be managed (Bécue et al., 2021) Experts cited both regulatory ambiguity and institutional resistance as key inhibitors, particularly in banks with fragmented digital infrastructure. Quantum computers could break current encryption securing trade documents, risking data integrity and trust. However, AI can mitigate these risks by supporting the development of post-quantum cryptographic algorithms, adapting security protocols dynamically, and enabling continuous threat monitoring through intelligent cybersecurity systems	Resistance to change, high costs of adaptation, and vulnerability to physical document mishandling.

2023). High initial implementation costs, interoperability challenges with legacy trade systems, regulatory uncertainties across different jurisdictions, and the need for widespread industry adoption remain significant barriers. Furthermore, concerns over data privacy, governance models, and the complexity of integrating smart contracts into traditional processes may slow down the pace of full-scale deployment. These challenges necessitate careful planning, collaboration among stakeholders, and continuous evolution of regulatory frameworks to enable blockchain's wider adoption in trade finance.

5.3. Challenges in AI adoption for trade finance automation

AI integration faces challenges such as data privacy and security concerns, ethical issues like bias mitigation, and navigating diverse regulatory frameworks. Additionally, technological disparities, workforce skill gaps, interoperability issues, and high implementation costs, complicate adoption (Ozturk, 2024).

While AI offers significant benefits for automating document verification, its adoption introduces new vulnerabilities that must be proactively addressed. One major concern is the risk of adversarial attacks, where malicious actors subtly manipulate document features (e.g., formatting, language structure, or metadata) to deceive AI systems into misclassification or false acceptance. Such attacks, well-documented in NLP and computer vision domains, could compromise the integrity of trade document checks if AI systems are not robustly tested against adversarial inputs (Biggio & Roli, 2018). Furthermore, model drift where the AI system's performance degrades over time due to evolving document formats, regulatory changes, or user behavior can reduce accuracy and reliability unless continuous retraining and monitoring mechanisms are implemented. These issues underscore the need for strong human in the loop oversight and adaptive model governance strategies.

Several challenges associated with the automation of document examination under documentary credits. Achieving high levels of automation necessitates accurate classification and extraction of data from varied document formats, which can be complex due to non-standard clauses and diverse document structures (ICC, 2021a). One of the significant barriers to AI adoption in LC document examination is the wide

variability of trade documents across different jurisdictions, industries, and financial institutions. Trade documents often differ not only in language and format but also in the interpretation of legal and commercial terms based on local practices. For instance, a bill of lading issued in Southeast Asia may follow different standards compared to one issued in Europe, affecting how AI models interpret terms such as "shipped on board" or delivery conditions. Multinational companies often generate complex document sets that combine elements from multiple legal systems, requiring AI to recognize, adapt, and validate a wide range of document structures and terminologies.

Training AI models to handle such heterogeneity requires large, high-quality datasets annotated by domain experts, which is resource-intensive and complicated by data privacy regulations. Moreover, discrepancies in terminology, document presentation, and regulatory compliance requirements across regions pose challenges that simple rule-based models cannot handle efficiently.

However, the Uniform Customs and Practice for Documentary Credits (UCP 600), established by the International Chamber of Commerce (ICC), provides a standardized set of rules that govern the issuance and examination of Letters of Credit worldwide. By setting common expectations for document formats, presentation standards, and examination procedures, UCP 600 significantly reduces cross-border variability and mitigates part of the legal and operational risks associated with international trade documentation. AI systems trained with UCP 600 as a baseline framework can better align with standardized practices globally, though local adaptations and compliance still necessitate human oversight.

Therefore, a hybrid model, where AI handles standard checks aligned with UCP 600 principles and human experts review ambiguous or jurisdiction-specific elements, offers a balanced and practical solution to mitigate these complexities in trade finance automation.

Additionally, the initial investment costs and the need for substantial financial and technical resources to implement these technologies pose significant challenges (Khalil et al., 2021).

A significant concern is the potential loss of human expertise and intuition. Experienced document checkers can identify red flags related to fraud or anti-money laundering (AML) that automated systems might initially miss.

Researchers focusing on AI in business highlight its promising transformative potential, driven by advancements in big data and high speed processing units. AI technologies are leading to increased efficiency (Bhowmik et al., 2024). However, they identify key advantages of AI, such as increased productivity, time and cost efficiency, and reduction of human error. (Soni et al., 2020) stated several challenges that impact the reliability of AI, including trust, ethics, bias, and software vulnerabilities. The researchers stress the importance of addressing these challenges to ensure the reliability and commercial viability of AI applications.

Another emerging challenge to consider is the potential impact of quantum computing on document verification and digital security frameworks. As quantum computing technology advances, it may become capable of breaking conventional encryption methods that underpin the security of automated document examination systems (Huang et al., 2022). This could expose sensitive trade documents to significant cybersecurity risks and undermine trust in digital verification processes. AI can play a critical role in mitigating this threat by supporting the development of post-quantum cryptographic algorithms. For instance, AI systems can help identify signs of cryptographic compromise, adapt encryption strategies in real time, and assist in deploying NIST-endorsed quantum-safe algorithms (Huang et al., 2022; The National Institute of Standards and Technology (NIST), 2025). Including quantum security readiness in the strategic roadmap will ensure the long-term resilience of automated trade finance systems. Addressing the risks associated with quantum computing will be essential for ensuring the long-term resilience and trustworthiness of AI-enabled trade finance automation.

Although there are significant benefits of going digital, there has been resistance to digitalising the checking of documents. Banks would not be able to resolve this issue on their own, but could take a different approach by focusing on improving current processes of current document examination. By engaging a highly skilled team, a bank could use its staff for more meaningful work.

5.4. Reliability of AI results

AI-based and Human in loop workflow is recommended for domains, where AI technology is used to review documents and provide results for decision makers such as law cases and media. The complexity and nuanced nature of legal systems pose a challenge for AI, yet the structured and explicit reasoning processes required in law can enhance the reliability of AI results in this domain (Rissland et al., 2003).

In the media domain, media outlets are encouraged to emphasize their reliability and transparency to foster public trust in AI generated content (Kim & Kim, 2020). This is important as media reliability is a critical factor and trust in the institution managing the AI being paramount. This trust surpasses the inherent reliability of AI technology itself, suggesting that organizational credibility significantly influences the perceived reliability of AI generated news articles.

Similarly, banks cannot solely rely on AI generated results for accepting or rejecting documents, as AI might miss or falsely state discrepancies, potentially leading to high financial risks. Such errors could force banks to settle document values without causing embarrassment to clients (buyers), highlighting the need for continued human review post AI examination to eliminate error risks, leading to double costs in technology and workforce. While AI holds significant promise, its reliable deployment requires careful consideration of systemic failure modes, transparency, and ethical concerns (Soni et al., 2020).

6. Managerial insights

The integration of AI into trade finance, particularly in examining LC documents, is transforming traditional banking operations by enhancing efficiency, ensuring compliance, and improving customer satisfaction. Utilizing AI technologies enables banks to perform more accurate

assessments (Yang & Masron, 2024). However, challenges such as high initial costs, system integration issues, accuracy concerns, and regulatory compliance must be addressed. Strategic management is essential to navigate these complexities, balancing innovation with operational feasibility. This section outlines actionable insights for banks to guide AI implementation, focusing on operational efficiency, risk management, customer engagement, regulatory compliance, and future-proofing to maximize benefits and mitigate risks.

6.1. Operational efficiency and risk management

AI solutions provide a pathway to significant gains in operational efficiency. By automating repetitive and error-prone tasks such as document verification and compliance checks, organizations can cut down on processing times and costs. This allows human resources to focus on higher-value tasks that require strategic judgment. AI also enables scalability by processing larger transaction volumes without requiring a proportional increase in staff, providing organizations with the flexibility to grow without bottlenecks.

Risk mitigation is a critical aspect of trade finance, and AI enhances this through advanced fraud detection and compliance monitoring. By analyzing vast amounts of data and identifying anomalies, AI helps in preventing fraudulent activities and ensuring adherence to international trade regulations. Employing a hybrid model where AI conducts preliminary checks and experienced personnel review flagged issues ensures that high risk transactions are handled with a balance of speed and caution, significantly reducing financial and reputational risks.

6.1.1. Cost benefit analysis of AI integration in LC document examination

To better assess the feasibility and return on investment (ROI) of AI adoption in the LC document examination process, a quantitative analysis of operational benefits is essential. Empirical and industry-based evidence from early implementations provides valuable insights into the potential gains. According to the Compend Trade Whitepaper (Compend, 2024), financial institutions that deployed AI-driven platforms such as TRADE AI reported significantly faster document processing times, although specific percentages were not disclosed. These solutions also yielded measurable reductions in error rates and led to notable improvements in operational efficiency, enabling institutions to reallocate staff to higher-value tasks and reduce manual bottlenecks.

Recent findings reported by Rajput et al. (Rajput et al., 2025) highlight the substantial benefits of AI-driven intelligent document processing in the banking sector. Specifically, their study demonstrates that the implementation of AI solutions led to a 70 % reduction in loan approval times, a 50 % improvement in fraud detection capabilities, and a 40 % decrease in compliance-related operational costs. Although these results originate from broader banking operations, the underlying processes particularly those involving high-volume, repetitive, and compliance-sensitive document verification are closely aligned with those in trade finance. Therefore, these quantitative gains provide a strong indication of the potential cost-efficiency and risk mitigation benefits that AI integration could similarly deliver within the LC document examination context (Rajput et al., 2025).

Taken together, these findings substantiate the argument that AI offers not only strategic and process-driven advantages but also tangible financial benefits. However, stakeholders must weigh these gains against the upfront costs of implementation, such as infrastructure upgrades, workforce training, regulatory compliance, and long-term system maintenance.

6.2. Strategic adoption of AI, investment and training

The integration of AI into trade finance should be approached incrementally to ensure seamless adoption and minimize operational disruptions. Managers must prioritize pilot programs to evaluate the technology's effectiveness before scaling across departments. AI's initial

application should target areas like document examination, where its accuracy and speed deliver immediate value. Additionally, integrating AI tools with existing trade finance systems is essential to ensure compatibility, enhance interoperability, and maintain operational efficiency without creating new silos.

Implementing AI in LC document workflows involves not just the purchase of software licenses but also substantial capital expenditure on backend infrastructure. This includes upgrading data servers, integrating with trade finance systems, and establishing secure cloud environments for document processing. For accurate cost estimations, industry sources suggest that expenses associated with AI deployment in banking can vary widely based on the project's scope and complexity. For instance, Business Ware Technologies (Business Ware Tech, 2025) notes that developing a basic AI document processing system can start at approximately \$7500, while more comprehensive solutions may exceed \$200,000. Additionally, a case study from CostPerform (Cost Perform, 2025) highlights that a bank's AI implementation led to a 20 % increase in data processing costs, amounting to an additional \$600,000 in annual expenses. These figures underscore the importance of phased implementation strategies and clear ROI models to avoid long-term financial strain particularly for mid-sized institutions that may lack the capital buffers of large multinational banks.

Adopting AI technologies requires substantial investments not only in the technology itself but also in the necessary infrastructure and workforce training. Managers should allocate resources to train staff in utilizing AI assisted processes and interpreting AI generated insights effectively. A robust change management strategy is also crucial to address resistance, communicate the long-term benefits, and foster an organizational culture that embraces technological advancements.

Drawing on interviews with trade finance experts and implementation case studies, managers are advised to treat AI not as a plug-and-play technology but as a transformational process requiring cultural, strategic, and structural shifts. A key insight from experts is the misalignment between operational teams and digital transformation goals particularly in traditional banks. Leaders must invest in change management initiatives that bridge these internal gaps and actively align digital innovation with compliance teams, front-line document checkers, and IT infrastructure. This alignment is essential for the successful execution of hybrid AI-human workflows.

As supported by the Technology Acceptance Model (TAM), successful adoption also depends heavily on how users perceive the system's usefulness and their trust in its outputs. Ikhsan et al. (Ikhsan et al., 2025) highlight that in the banking sector, perceived trust significantly moderates the relationship between AI functionality and user acceptance. Therefore, building trust through transparency, reliability, and proper training is essential for encouraging adoption among banking professionals.

The move towards AI-assisted document examination will not eliminate human roles but reshape them. Managers should anticipate the need to upskill experienced trade finance professionals to act as AI supervisors and discrepancy arbitrators, rather than manual document processors. This shift requires revised job descriptions, new performance metrics, and training programs co-developed with vendors. Experts also noted the need for cross-functional teams where compliance officers, AI developers, and document specialists collaborate in agile cycles to refine AI outputs and improve system reliability.

6.3. Regulatory and ethical considerations with managerial implications

The use of AI in trade finance must align with regulatory requirements and ethical standards. Ensuring data privacy, implementing robust cybersecurity measures, and addressing AI biases are paramount. Managers should prioritize building transparent AI systems that stakeholders can trust while developing governance frameworks to oversee ethical AI usage, mitigating risks associated with automated decision-making. AI's ability to process and analyze vast amounts of trade data

presents an opportunity to enhance decision-making. Managers should leverage AI extracted data to improve management reporting and develop actionable insights for strategic planning. Ensuring high-quality, comprehensive input data is critical for maximizing AI's effectiveness, as it directly impacts the accuracy and reliability of AI-generated results.

From a compliance perspective, aligning AI tools with local and cross-border regulatory frameworks often requires legal consultations, internal audits, and updates to data governance protocols. These efforts add to the operational cost structure. For example, implementing an AI model that complies with EU's GDPR, U.S. AML laws, and ISO 27001 may require 6–18 months of legal review and platform adjustments, which can delay deployment timelines and raise compliance costs substantially (Nezhad et al., 2024).

In addition to these regulatory and ethical requirements, practical implementation of AI also depends on addressing internal organizational alignment and workforce readiness. Expert interviews highlighted that AI deployment is not merely a technology adoption task, but a transformation that affects how teams interact, how decisions are made, and how roles are defined. Several experts noted the risk of misalignment between digital transformation objectives and traditional trade finance operations, especially in legacy financial institutions. To address this, managers should engage key stakeholders across compliance, document processing, and IT teams to coordinate implementation and define responsibilities clearly.

Furthermore, the introduction of AI changes the role of human document checkers. Rather than fully replacing these professionals, AI transforms them into decision validators and discrepancy reviewers. Managers should provide upskilling opportunities to prepare staff for these responsibilities, incorporating training on AI interpretation, compliance validation, and exception handling. This shift also requires adjustments to performance metrics and operational planning, as task priorities evolve under a hybrid model.

Governance structures should be updated to reflect these operational changes. Institutions are encouraged to establish internal review boards or cross-functional oversight groups to monitor AI model performance, manage risk, and ensure alignment with trade compliance standards such as UCP 600 and ISBP. These bodies also help ensure that ethical issues, such as transparency and fairness, are addressed consistently during system updates and deployment cycles. Planning for longer-term risks, including the impact of quantum computing on document security, should also fall within these managerial responsibilities. As discussed earlier, this includes preparing to adopt post-quantum cryptographic protocols and integrating AI-driven anomaly detection tools into broader cybersecurity strategies.

7. Future research recommendations

As clarified in Fig. 3, extensive literature review and interaction with experts with over 15 years of experience in the field enabled identification of literature and practical gaps (see Section 3.5), based on this following research directions are suggested. The purpose of these directions is to offer broad guidance on what the adoption of AI in document examination means in terms of practical applications and inform further advancements in the field that improve the use and promising advancements of this technology.

7.1. Direction 1: Conduct comprehensive research analysis with financial institutions

Future research should focus on extensive investigations with banks and financial institutions that have adopted AI technology in their document examination processes. Collaboration with these institutions will enable researchers to perform in depth analyses of the issues that arise from the practical application of AI. By accessing the data generated by AI checks, alongside the corresponding cases, and systematically

tracking and categorizing these errors, researchers can identify common trends and pinpoint areas where AI performance can be improved.

A critical and specific aspect can be evaluating the quality of data generated by AI systems and the quality of the advanced OCR and NLP technologies applied to digitize and classify data. Assessing whether these technologies serve as practical tools for efficiently handling both structured and unstructured inputs is essential. The examination should encompass an analysis of their reliability, accuracy, and adaptability in diverse operational contexts, including specific document types and particular stages in the examination process where challenges are prevalent.

Furthermore, analyzing the context in which errors occur, such as document specific or workflow related issues, can yield valuable insights for enhancing AI systems. These findings can then be reported to Fintech developers and AI practitioners to facilitate the development of more robust algorithms and improved integration strategies. The ultimate goal is to enhance the accuracy and reliability of AI models, ensuring their effective application and seamless integration into real world operations.

7.2. Direction 2: Conduct comparative experiments between AI and human experts

Future studies should include controlled experiments that compare AI systems' performance with human experts in the document examination process. The input into the AI system are different near real LCs scenarios to get the output from AI software, and for the same cases, verification results from trade finance human experts with manual examinations can be collected and compared. By analyzing AI's and human examiners' strengths and weaknesses, researchers can identify areas where AI can enhance human capabilities and where human oversight remains crucial. Additionally, this comparative analysis can highlight the potential for hybrid approaches that leverage the strengths of both AI and human expertise to achieve better results.

7.3. Direction 3: Automated decision making

The suggested direction for further research hybrid LC review process consists of two primary stages, as depicted in Fig. 9. In the first stage, LCs scheduled for review are input into AI empowered software. This software performs a series of checks, including assessments against LC terms and conditions, validation of presentations, validation of document consistency, as well as individual document checks. Based on these examinations and validations, the software decides whether to accept or reject the LC documents and lists all discrepancies in case of rejection.

However, it is essential to acknowledge that decisions derived from AI software are not foolproof. Relying solely on AI to examine trade documents, leading to definitive determinations regarding document acceptance or rejection, increases financial risk for financial institutions. This is especially pertinent when dealing with significant transaction values and large transaction volumes. Consequently, AI developers recommend that banks incorporate at least one human checker into the process to review AI-generated decisions before finalizing the assessment.

This transition marks the commencement of the second stage, which is the post AI review of the LCs where the AI results along with the documents examined are assigned to available human checkers to validate the AI software's decisions. The assignment process itself is a complex decision that, if not executed efficiently, may negate the advantages gained from employing AI software.

Researchers can conduct mixed methods studies, integrating quantitative and qualitative data analysis, taking into consideration several key aspects: system performance, accuracy, risk mitigation, and efficiency to compare the effectiveness of the hybrid model with traditional models.

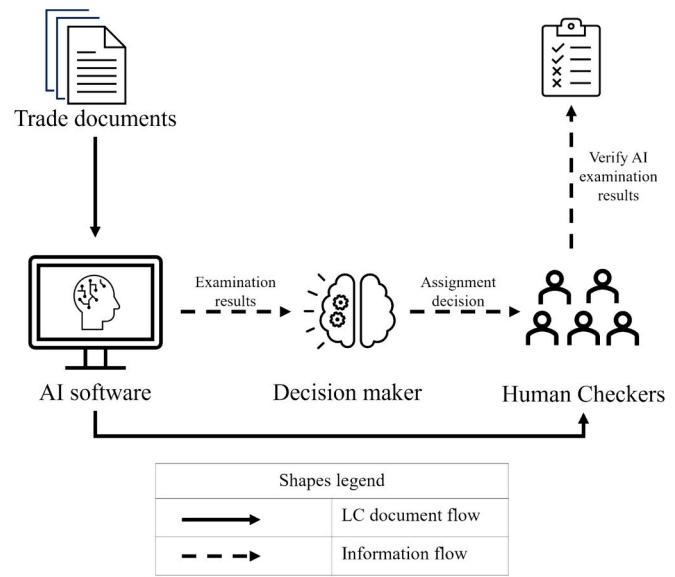


Fig. 9. Hybrid LC process with AI and assignment optimization.

7.4. Direction 4: Conduct comprehensive environmental assessment

The LC industry remains a cornerstone of international trade and finance. To enhance its efficiency, digital transformation is a crucial aspect (Murinde et al., 2022). Transitioning the trade finance and LC processes from outdated traditional methods to digital systems is not only a step towards operational improvement but also has the potential to yield positive environmental impacts. However, sustainable trade finance continues to face significant challenges, including the lack of standardized international frameworks. Despite these obstacles, various initiatives are actively being pursued to address these issues and promote a more sustainable and efficient trade finance ecosystem (ICC, 2021).

The study should examine the entire life cycle of the LC process, including initiation, circulation, verification, and finalization (Wang & Zhang, 2019). This will involve determining the new AI process's environmental performance compared to the current paper and manual based one. The study therefore seeks to show either the benefits or disadvantages associated with this change, focusing on less paper consumption and less manual physical activities and its consequences.

The research can provide useful knowledge that can help decision makers take environmentally sound decisions regarding the LC process and use of AI technology. Consequently, results from the research might be intended for public release as comparative assertions that promote transparency and accountability in respect of transformations.

8. Conclusion

This research provides a comprehensive analysis of the transformative potential of AI in the document examination process within trade finance, specifically for LCs. The study was formulated with the dual motivation of addressing inefficiencies in the traditional LC process and exploring how AI technologies can enhance operational efficiency, compliance, and risk management.

The existing LC processes are heavily manual, labor intensive, and error prone, leading to significant delays, high costs, and reduced scalability. These inefficiencies underscore the urgent need for a paradigm shift towards digitized and automated systems. This need for change forms the foundation of the research, which seeks to evaluate AI's role in addressing these challenges while maintaining compliance with international trade regulations.

The literature review systematically explores existing digital

solutions and AI applications across various domains, identifying critical gaps that hinder broader AI adoption in trade finance. These include the lack of experimental validation, limited empirical evidence on operational efficiencies, and insufficient research into hybrid AI human models. Based on these gaps, the research formulated targeted questions to explore how AI can enhance efficiency, mitigate risks, address adoption barriers, and redefine strategic frameworks for trade finance.

The study employed a robust methodology combining literature analysis and expert feedback. It examined AI's capabilities, including ML, NLP, and OCR, to automate document verification and compliance checks. By integrating AI into the LC process, the study demonstrated how banks can streamline operations, reduce errors, and improve turnaround times. The AI-driven solutions were explored in detail, outlining how they extract, analyze, and validate data against international standards such as UCP 600, ISBP guidelines, and other specific laws and regulations.

Real-world case studies, such as the adoption of Conpend's TRADE AI, Traydstream, Cleareye.ai's AI platform, ClearTrade, and IBM by leading financial institutions, were integral to this research. These case studies provided concrete evidence of how AI has been successfully implemented to address compliance challenges, reduce processing times, and enhance customer satisfaction. By presenting these examples, the study not only validates the practicality of AI in trade finance but also bridges some research gaps identified in the literature. Additionally, a cost-benefit analysis based on recent industry data was included to illustrate AI's operational value and support its feasibility for real-world implementation.

The research also proposed a detailed roadmap for AI integration in trade finance. This roadmap offers a step by step framework for financial institutions to transition from manual to AI driven systems. It emphasizes evaluating current inefficiencies, selecting and piloting AI solutions, and gradually scaling up adoption while addressing barriers such as regulatory compliance, workforce readiness, and technological integration. The roadmap is supported by a theoretical foundation using the Technology-Organization-Environment (TOE) framework, ensuring structured alignment with organizational readiness and environmental conditions. Insights from the extended TAM model and digital transformation theory further reinforced the strategic dimension of this framework.

While the benefits of AI are substantial, the study also acknowledges challenges such as data privacy concerns, ethical issues, and the limitations of AI in handling nuanced decision making. To address these challenges, the research emphasizes the importance of a hybrid approach that combines AI's efficiency with human expertise to ensure accuracy and mitigate risks. In particular, the roadmap incorporates emerging risks such as adversarial attacks, model drift, and data manipulation, and recommends robust monitoring mechanisms to ensure sustained model performance. It also highlights the long term threat posed by quantum computing and calls for post quantum cryptographic awareness to safeguard digital trade documents.

From a managerial perspective, the research highlights actionable insights to guide AI adoption in trade finance. These include strategies for pilot testing, resource allocation for workforce training, fostering organizational readiness, and leveraging AI to gain competitive advantages. Drawing from expert interviews, the study emphasizes the need for structural and cultural alignment across departments, the redefinition of human roles in AI-supported environments, and investment in cross-functional collaboration to ensure successful implementation of hybrid workflows. Furthermore, blockchain-based solutions were explored as complementary mechanisms for real-time verification and secure data exchange.

Lastly, the study provides future research recommendations, including conducting experimental comparisons between AI and human expertise, exploring the environmental impacts of digitization, and optimizing hybrid models for decision-making. Furthermore, the inclusion of quantum computing risks and the role of post-quantum

cryptographic readiness highlights the need for long-term resilience in AI-based document verification systems. These recommendations aim to further refine AI applications and address remaining gaps in knowledge, ensuring that the integration of AI into trade finance continues to evolve in alignment with industry needs and regulatory standards.

In conclusion, this research positions AI as a transformative force in trade finance, offering a comprehensive framework for its integration into the LC process. By addressing inefficiencies, leveraging practical insights from case studies, and proposing a strategic roadmap and research recommendations, the study provides a valuable resource for policymakers, financial institutions, and researchers. It serves as a foundation for advancing AI adoption and realizing its potential to modernize global trade finance systems.

CRedit authorship contribution statement

Mounaf Asaad Khalil: Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Regina Padmanabhan:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Majed Hadid:** Writing – review & editing, Visualization. **Adel Elomri:** Writing – review & editing, Supervision. **Laoucine Kerbache:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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