

Architectures of Interoperability in Digital Trade: Toward a Technology-Agnostic Framework for Integrating Platforms, Distributed Ledgers and Regulatory Systems

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Introduction

The digitization of international trade is advancing through electronic trade documents, cross-border data platforms, distributed ledger technologies (DLT), digital identity systems and automated systems increasingly in use. Yet cross-border trade remains structurally paper-dependent. A typical international transaction still involves around 36 documents and 240 copies, while fewer than 1% of trade documents are fully digitized (Ganne & Nguyen, 2022). Around 4 billion paper-based trade documents are estimated to circulate through the trade ecosystem at any given time (ICC DSI, 2021). Even for the bill of lading, one of the most central documents in international trade, electronic adoption remains limited, where electronic bills of lading (eBL) represented only 5.7% of market uptake in January 2025, compared to 1.2% in 2021, which remains far short of the 100% adoption target set by DCSA member carriers for 2030 (DSCA, 2025; DCSA, 2023).

This gap is no longer mainly a question of technological availability, as most of the tools required for paperless trade already exist. However, the difficulty lies in their fragmented deployment and limited interoperability across the transaction chain. The 2025 UN Global Survey shows that general and digital trade facilitation measures have reached an implementation rate of 71%, while cross-border paperless trade still lags behind domestic paperless processes (UNESCAP, 2025). In practice, this means that trade data may be created digitally in one system but still require re-entry, reformatting, revalidation or manual checking in another because systems rely on different standards, identifiers, formats and trust mechanisms (ICC DSI, 2025a; WTO, UNESCAP, & UNCITRAL, 2023).

Legal frameworks are also evolving, but unevenly. UNCITRAL records 13 states or jurisdictions with legislation based on or influenced by the Model Law on Electronic Transferable Records (UNCITRAL, 2026). MLETR illustrates why legal reform matters: an electronic transferable record must be identifiable, its integrity must be preserved, and it must be subject to exclusive control if it is to function as the equivalent of a paper original (UNCITRAL, 2017). Similar requirements arise in border, single-window and banking environments, where electronic processes depend not only on legal recognition, but also on reliable mechanisms for identification, authentication, authorisation and verification.

The central bottleneck is therefore not the creation of electronic documents as such, but the alignment of the legal, semantic, technical and governance layers that allow the same data to be recognised, reused and relied upon across commercial, transport, customs and banking systems (Ganne & Nguyen, 2022; ICC DSI, 2025a). Digitization of trade documents is not achieved by converting paper documents into PDFs, however, it requires trade data to be created once, structured in a machine-readable form and reused securely throughout the transaction lifecycle, from order to payment.

This note develops a technology-agnostic interoperability framework for a documentary letter of credit (LC) transaction supported by an eBL. The LC–eBL transaction provides a useful test case because it brings together commercial ordering, transport documentation, customs clearance, banking examination, payment and release of goods. It also combines two areas where interoperability is particularly demanding, namely the documentary discipline of the LC and the legal and technical requirements of the eBL as a transferable digital document of title.

The paper proceeds in two stages. Part I develops the conceptual framework. It first frames the LC–eBL transaction as a transactional data system, using the UN/CEFACT Buy–Ship–Pay model to identify the main actors, documents and data flows. It then sets out a layered interoperability architecture covering legal and regulatory recognition, data and standards alignment, identity and trust mechanisms, and connectivity and governance. Within each layer, the analysis includes a non-exhaustive mapping of the principal standards, identifiers, trust mechanisms and exchange frameworks relevant to the LC–eBL chain. Part II then tests this architecture against implementation evidence, examining what has already been demonstrated in practice, where interoperability remains incomplete across the Buy–Ship/Border–Pay chain, and what design conditions are needed to move from fragmented digital initiatives toward a scalable cross-border interoperability framework. The paper concludes with recommendations to support a more coherent architecture for trusted cross-border paperless trade.

Research Gap and Analytical Approach

Existing literature provides substantial analysis of individual trade documents, trade finance digitisation and legal recognition frameworks such as MLETR, giving less attention to how these elements interact across the full lifecycle of a documentary trade transaction.

Three limitations are particularly relevant. First, much of the literature remains document centric: Purchase orders (PO), invoices, customs declarations, eBLs, and letters of credit are often analysed separately, whereas interoperability failures frequently emerge at the interfaces between these documents rather than within the documents themselves. Errors or inconsistencies introduced in the PO may propagate into the invoice, the eBL, the customs declaration, and ultimately the documentary presentation to banks (ICC DSI, 2021; ICC DSI, 2025a).

Second, technology-focused analysis often concentrates on specific solutions, such as blockchain platforms, DLT-based eBL systems or single-window infrastructures. However, these studies do not always address the fact that digital trade operates through multiple overlapping infrastructures rather than through a single platform, which makes the ability of these infrastructures to exchange and rely on data across different legal and institutional settings a key prerequisite for interoperability (UNECE/UN-CEFACT, 2023; WTO, UNESCAP, & UNCITRAL, 2023).

Third, legal analysis of electronic transferable records has often focused on formal recognition. However, legal validity alone does not ensure operational interoperability, as electronic trade documents still need to interact with platform architecture, including identity management, authentication, trust services, data standards, customs requirements, and banking compliance processes.

More fundamentally, the existing literature does not provide a framework that simultaneously addresses all four interoperability layers: legal recognition, semantic standards, identity and trust, and connectivity, across all three phases of the LC–eBL chain (Buy, Ship/Border and Pay) (ICC DSI, 2023). Most contributions address one or two layers within one phase; none maps the cross-layer conditions required for data to flow as a coherent, machine-readable chain from commercial ordering through transport, customs clearance and documentary examination to payment. This note addresses that gap by treating interoperability as an architectural condition for scalable paperless trade. Using the UN/CEFACT Buy–Ship–Pay model, it examines how legal, technical, and governance components must align to enable electronic trade

documents to function as a seamless cross-border data chain and identifies the cross-layer conditions required for the reliable circulation of trade data. The empirical cases examined in Part II were selected against three criteria: representativeness of the transactional phase concerned (Buy, Ship/Border or Pay); availability of sufficient public-source detail to support cross-layer analysis; and diversity of institutional configurations (bilateral trade corridors, multi-stakeholder consortia, sectoral standardization initiatives) (ICC DSI, 2025b; ICC UK, 2025). This combination of conceptual framing and targeted empirical grounding positions the paper within the established tradition of theoretically informed, empirically anchored research in the digital infrastructure governance and trade facilitation literature.

Part I: Framing Interoperability in the LC–eBL Chain

1. The LC–eBL Chain as a Transactional Data System

A letter of credit transaction supported by an electronic bill of lading should be understood not as a sequence of standalone documents, but as a transactional data system linking the Buy, Ship/Border and Pay functions of international trade (UNECE, 2019; Ganne & Nguyen, 2022). The purchase order and commercial invoice create the initial commercial dataset; the shipper’s instructions, packing list and eBL transform it into shipment and transport records; the customs declaration converts part of it into regulatory data; and the documentary presentation tests its consistency against the terms of the credit (UNECE, 2019; ICC, 2023).

This core data, covering parties, goods, quantities, values, locations, shipment references and payment terms, appears across the various documents involved. While each document has a distinct legal or operational function, the reliability of the transaction ultimately depends on the consistency of this data across systems and institutions (ICC & WTO, 2022).

The key interoperability question is therefore whether data created at the outset can remain structured, machine-readable, legally effective and trusted as it moves across commercial, transport, customs and banking processes throughout the LC–eBL lifecycle (WTO, 2022).

2. Interoperability as a layered architecture

Interoperability in the LC–eBL chain is not a purely technical matter. It depends on the alignment of multiple layers that enable data and documents to be recognized, exchanged and relied upon across systems and jurisdictions (ICC DSI, 2025a; ITC, 2025). This section approaches interoperability as a layered architecture structured around four interdependent components: legal and regulatory recognition, data and standards alignment, identity and trust mechanisms, and connectivity and governance arrangements. Together, these layers define the conditions under which trade data can circulate as a coherent and reliable cross-border data chain. Using the UN/CEFACT Buy–Ship–Pay framework, the following analysis examines how these layers operate across the main stages of the transaction and the key documents involved, from commercial ordering to transport, customs clearance and payment.

a. Legal and regulatory layer

The legal and regulatory layer determines whether electronic records used in the LC–eBL chain can produce legal, commercial, regulatory and banking effects equivalent to their paper counterparts (ICC DSI, 2026). It

covers key elements such as functional equivalence, validity of electronic records, electronic presentation, transferability, authentication, retention, customs submission, documentary examination, payment, enforcement and release of goods (UNCITRAL, 2017). For documents that perform more than an evidentiary function, such as the eBL, bills of exchange or promissory notes, the central issue is not simply digitisation, but the preservation of the legal function of the instrument, including, singularity, control, transferability, presentment and enforceability (UNCITRAL, 2017; UNCITRAL, 1988; Frosinini, 2026).

Following the Buy–Ship–Pay framework, the Buy phase focuses on the legal recognition and evidentiary value of the purchase order and commercial invoice (UNECE, 2019; Ganne & Nguyen, 2022). These documents mainly raise issues of authenticity, evidentiary reliability, retention and legal acceptance as electronic records, rather than transferability or control (ITC, 2025). The purchase order records the agreed commercial terms, while the invoice supports payment, customs valuation, tax treatment and, where relevant, presentation under a letter of credit. In the LC context, UCP 600, eUCP and ISBP 745 govern the examination of invoices, and whether the electronic record can be authenticated and relied upon (ICC, 2007; ICC, 2013). The practical difficulty is that invoices may be digitally generated or exchanged through e-invoicing systems but still be examined by banks as documents rather than as reusable data objects (Yap, 2018; Ganne & Nguyen, 2022). This confirms that LC practice remains document-based, and electronic presentation only works if the electronic record can be authenticated and examined for compliance (Yap, 2018; ICC, 2019).

In the Ship and Border/Clear phases, the SLI and packing list mainly have operational and evidentiary value, while the eBL has a stronger legal function because it must operate both as a transport record and as the digital equivalent of a transferable document of title. The core legal reference is MLETR, which requires an electronic transferable record to satisfy functional requirements such as identification, integrity and exclusive control (ICC DSI, 2026). The eBL should therefore not be treated as a mere dataset or platform entry; but as a legally recognizable instrument capable of being transferred, verified and relied upon beyond the platform that issued it. Otherwise, legal validity may become dependent on membership in a closed system or on access to a particular registry, which recreates the platform lock-in problem that digital trade should overcome (Frosinini, 2026).

Sectoral frameworks, such as, DCSA eBL standards, FIATA eFBL, & BIMCO eBL, can support implementation, but legal effectiveness still depends on broader legal recognition, contractual rulebooks and bank acceptance at presentation (UNCITRAL, 2017; ICC DSI, 2026; DCSA, 2023; FIATA, 2026; BIMCO, 2024). At the border, the legal framework is defined by WCO and WTO instruments (Revised Kyoto Convention, Trade Facilitation Agreement, Customs Valuation Agreement, HS Convention and the Single Window Compendium) enabling electronic customs submission and single-window processing (WCO, 2006, 2017, 2019; WTO, 2017). However, the main issue is not the lack of frameworks, but their national scope: while customs systems may accept electronic declarations domestically, cross-border reuse of invoice, packing list and eBL data remains limited due to differing requirements across jurisdictions (WTO, UNESCAP, & UNCITRAL, 2023; WTO & WEF, 2022).

In the Pay phase, legal interoperability is critical because payment, acceptance or negotiation depends on documentary compliance (ICC, 2007; ICC, 2019). UCP 600, eUCP and ISBP 745 govern the issuance, presentation and examination of documents under the letter of credit (ICC, 2007; ICC, 2013). While eUCP enables electronic presentation, it does not make the process data-driven: the credit must specify the

format and place of presentation, and the records must be capable of authentication and examination (ICC, 2019). As a result, although SWIFT and banking channels digitize message transmission, supporting documents often remain PDFs, scans or platform uploads, and documentary credits continue to operate on document examination rather than structured data (Yap, 2018; ICC, 2023).

Where collections, forfaiting or negotiable payment instruments are involved, additional frameworks become relevant: URC 522 and eURC for collections, URF 800 for forfaiting, the UNCITRAL 1988 Convention for bills of exchange and promissory notes and ITFA's electronic Payment Undertaking and dDOC specification for digital negotiable instruments including bills of exchange and promissory notes that cannot simply be scanned or converted into electronic files, because their legal effect depends on negotiability, presentment, transfer, control and enforceability (ICC, 1995; ICC, 2013; UNCITRAL, 1988; ITFA, 2021, 2023). Their digital form must therefore preserve the instrument's legal function, not merely reproduce its information content (Forsinini A., 2026).

The main interoperability problem at this layer is therefore the uneven alignment between legal recognition and operational reliability (WTO, UNESCAP, & UNCITRAL, 2023; ICC DSI, 2026). Electronic records may be legally valid but fail in practice if they remain platform-bound, cannot be reused across customs systems, or cannot be authenticated and examined by banks, or if SMEs and market participants lack practical pathways for adoption (Qadir, 2025; ITC, 2025; ICC DSI, 2025b). An eBL may circulate within one platform but fail to operate as a transferable document of title across jurisdictions.

Finally, legal recognition also depends on supporting trust mechanisms. Electronic signatures, seals, timestamps and validation systems enable verification of authenticity, integrity and control across systems, making legal reliance operational. These mechanisms are addressed in the identity and trust layer.

b. Data and standards layer

1. Semantic Alignment: what the data mean

Semantic interoperability concerns whether the same transaction data retain the same meaning as they move across the Buy, Ship/Border and Pay phases of the LC–eBL chain (Ganne & Nguyen, 2022; WTO & WEF, 2022; Atkinson & Becha, 2025). In an eBL-based letter of credit, this is essential because core data—parties, goods, quantities, values, locations, shipment references and documentary conditions—must remain consistent from the purchase order and invoice to the eBL, customs declaration and documentary presentation.

In the Buy phase, the purchase order and commercial invoice establish the initial commercial dataset (UNECE, 2019). Their semantic baseline relies on frameworks such as UN/CEFACT CCL and BSP-RDM, UBL/ISO 19845 and GS1 business vocabularies, with document-specific standards including UN/CEFACT ordering for PO and invoice models and, where relevant, Peppol BIS Billing and EN 16931 (OASIS, 2024; European Commission, 2026; OpenPeppol, 2024; ISO/IEC, 2015). The main issue is inconsistent data definitions across ERP systems, e-invoicing platforms, EDI networks and banking workflows, which prevents reliable reuse of purchase-order data in invoices, LC processes and downstream transport documents (ICC DSI, 2025a).

Document-level standards build on this baseline across the main documents in the Ship and Border/Clear phases. For the packing list, the UN/CEFACT Export Packing List structures goods, packaging, quantities and

weights. For shipping instructions (SLI), FIATA Forwarders Instructions and the UN/CEFACT Multimodal Shipping Instruction define shipment data such as parties, locations and cargo descriptions. For the eBL, DCSA provides the reference for container shipping, FIATA eFBL for multimodal use, and BIMCO for bulk trades (DCSA, 2024; BIMCO, 2022; FIATA, 2026). These standards should, where possible, be mapped to UN/CEFACT reference models. Additional alignment is reinforced by UN/CEFACT BRS and ISO 5909 work on DLT-based eBLs, which structure eBL processes, linking data elements and authorized data flows across issuance, endorsement, transfer and surrender (UN/CEFACT, 2026; ISO, 2026a).

For customs declarations, the WCO Data Model is the core regulatory semantic baseline and should be mapped to UN/CEFACT CCL and BSP-RDM to enable reuse of invoice, packing list and eBL data across systems. The main issue is not the absence of standards, but their partial misalignment. Key data, such as goods descriptions, packaging structures, quantities, weights, locations, parties and shipment references, are often defined inconsistently or captured as free text across packing lists, shipping instructions, eBLs and customs declarations. This prevents reliable reuse and leads to re-entry or reinterpretation across logistics, border and banking processes (ICC DSI, 2025a; ITC, 2025).

In the Pay phase, semantic alignment must connect the LC terms, banking examination rules and the data contained in the documents presented under the credit (ICC, 2007; ICC, 2013; ICC, 2019). UCP 600, eUCP and ISBP 745 provide the documentary baseline, while ISO 20022 trade-finance concepts and UN/CEFACT models support alignment between LC conditions and structured data from invoices, eBLs, packing lists and other presented records (UN/CEFACT, 2025a, 2025b). Where bills of exchange or promissory notes are used, MLETR, the UNCITRAL 1988 Convention, URC/eURC, URF 800, ITFA's ePU and dDOC provide the relevant references for preserving negotiability, presentment, transfer and enforcement in digital form (UNCITRAL, 1988; ICC, BAFT, & TTP, 2026). The main semantic problem is that LC terms may be digitally transmitted through banking channels, while the underlying documents and payment instruments remain insufficiently structured or aligned with the data needed for automated examination, comparison and reliance (Yap, 2018). The priority is therefore to map LC conditions to structured trade data and to represent negotiable instruments as legally meaningful data records, rather than as PDFs or platform-specific files (Law Commission, 2022; ICC DSI, 2025a)

Across all Buy–Ship–Pay phases, consistent interpretation of recurring data relies on common code lists and classification standards. Key fields such as country, currency, date and units of measure depend on shared references (ISO 3166-1, ISO 4217, ISO 8601 and UN units), while goods classification relies on the Harmonized System, particularly to align customs declarations with invoice and shipment data. Location and transport references are supported by UN/LOCODE for places and ISO 6346 for containers, which are used across packing lists, shipping instructions, eBLs and customs declarations. Although UN/LOCODE and ISO 6346 also perform an identification function for locations and containers, that these references are not all identifiers in the strict sense, where their uneven use, replacement by free text or inconsistent implementation creates ambiguity and prevents data from being reliably reused or validated across the LC–eBL chain (Ganne & Nguyen, 2022; UNECE, 2024).

Therefore, semantic alignment requires a common mapping between commercial, transport, customs and banking data models. The objective is not to replace existing standards, but to make them interoperable, linking UN/CEFACT (commercial and transport), WCO (customs), DCSA/FIATA/BIMCO (eBL-related

transport) and ICC/ISO 20022 (trade finance). Without this semantic bridge, documents may be digital in isolation but cannot function as a coherent, reusable and machine-readable data chain (ICC DSI, 2024).

2. Syntactic alignment: how the data are structured and exchanged

Syntactic interoperability concerns the way trade data are structured, formatted and exchanged once their meaning has been defined. In the LC–eBL chain, the issue is not the absence of machine-readable formats, but the coexistence of multiple XML, EDI, JSON/API and banking-message formats without sufficiently governed implementation profiles (WTO & WEF, 2022; ICC DSI, 2025a). Without such profiles, even semantically aligned data cannot move automatically between ERP and e-invoicing systems, logistics and eBL platforms, customs gateways and banking channels (WTO, UNESCAP, & UNCITRAL, 2023).

In the Buy phase, purchase orders and invoices are shared through structured XML and EDI environments (e.g., UBL XML, UN/EDIFACT, ANSI X12, GS1 XML or EANCOM, and, where relevant, Peppol-based infrastructures) (OASIS, 2024; OpenPeppol, 2025). Purchase orders typically use UBL Order XML, EDIFACT ORDERS and ANSI X12 850, while invoices rely on UBL Invoice XML, EDIFACT INVOIC, X12 810 and Peppol BIS / EN 16931-aligned profiles. The issue is fragmented implementation across ERP systems, EDI networks, e-invoicing platforms and corporate workflows, which disrupts straight-through reuse: purchase-order data may not flow cleanly into invoices, and invoice data may require conversion or manual checking before reuse in shipping instructions, customs declarations or LC presentation (Yap, 2018). The priority is therefore to rely on governed syntax profiles and mappings across these environments so Buy-phase data can serve as structured upstream input for the rest of the LC–eBL chain.

In the Ship and Border/Clear phases, packing lists, shipping instructions (SLIs), eBLs and customs declarations rely on structured formats, but their implementation remains fragmented across documents and platforms. For packing lists, formats such as UBL XML, UN/CEFACT XML and UN/EDIFACT are used, but often coexist with non-standard layouts and PDFs. For shipping instructions, UN/CEFACT, EDIFACT, UBL and increasingly DCSA-aligned JSON/API structures are used, yet no widely adopted implementation profile has emerged (DCSA, 2025). For the eBL, implementation is converging toward JSON, REST and OpenAPI profiles, particularly under DCSA, with FIATA eFBL and BIMCO, while UN/CEFACT BRS / ISO 5909 also supporting eBL business-process and data-interchange structuring in DLT-based environments (UN/CEFACT, 2026; ISO, 2026a). For customs declarations, the main formats include WCO Data Model XML, national XML/EDI profiles, UN/EDIFACT CUSDEC and GOVCBR, and UBL customs documents (WCO, 2019; Ganne & Nguyen, 2022). Again, the matter is not the lack of formats, but their inconsistent and system-specific implementation. As a result, packing, shipment, eBL and customs data often require mapping, conversion or manual intervention before reuse across logistics, border and banking processes ((WTO & WEF, 2022; ICC DSI, 2025a).

In the Pay phase, LC workflows rely on structured banking formats, mainly SWIFT MT Category 7 messages for issuance, amendment, advice, refusal and reimbursement, together with SWIFT MT 798, FileAct and, where implemented, ISO 20022 trade-finance profiles (ICC DSI, 2024). These formats enable secure and structured communication between banks, but do not make the documentary presentation machine-readable. LC terms may be transmitted in structured messages while invoices, eBLs, packing lists or other presented records still arrive as PDFs, scans or portal uploads (Yap, 2018; ICC, 2021). The syntactic gap lies in this disconnect between structured LC messaging and unstructured document formats examined under

the credit, which prevents automated comparison between LC conditions and presented data (ICC, 2023; Yap, 2018). For promissory notes and bill of exchange, initiatives such as ITFA dDOC and JSON/API representations provide emerging approaches, but also not widely adopted interoperable syntax yet supports digital presentment, transfer and enforcement (ITFA, 2023; Frosinini, 2026). The priority is therefore to move toward governed SWIFT and ISO 20022 profiles, structured e-presentation channels and interoperable schemas for digital negotiable instruments, so that payment-side processes can rely on reusable data rather than document PDFs (Law Commission, 2022).

Overall, the syntactic challenge is not to develop new formats, but to discipline the implementation of existing ones. Buy-phase documents should rely on governed UBL, EDIFACT, X12, GS1 and Peppol/EN 16931 profiles; Ship/Border documents on UN/CEFACT-aligned XML, JSON/OpenAPI and WCO Data Model profiles; and Pay-phase workflows on controlled SWIFT, FileAct and ISO 20022 formats, complemented where needed by structured e-presentation and schemas for digital negotiable instruments. The objective is not to impose a single syntax across the LC–eBL chain, but to ensure that formats are implemented through consistent profiles, mappings and validation rules, so that data can move seamlessly across the end to end supply chain.

C. Identity and trust layer

The identity and trust layer determines whether the actors, objects, documents and control events in the LC–eBL chain can be reliably identified, authenticated and verified across systems. It complements the data and standards layer: even where information is structured and machine-readable, it cannot support cross-border interoperability unless parties, goods, shipments, documents and electronic records can be matched and trusted throughout the transaction lifecycle (WTO, UNESCAP, & UNCITRAL, 2023; ITC, 2025).

In the Buy phase, identity issues concern the identification of buyers, sellers, invoice parties, products, locations and commercial references. While purchase orders and invoices may contain structured data, interoperability is limited if these elements cannot be matched consistently across ERP systems, e-invoicing platforms, banks, logistics systems and customs environments (Ganne & Nguyen, 2022; ICC DSI, 2021; WTO & WEF, 2022). Key identifiers include LEI (ISO 17442) for legal entities, GLN for business locations, GTIN for products, and ISO/IEC 15459 for unique object identification (ICC DSI, 2024). Their consistent use enables reliable reuse of commercial data across downstream processes.

In the Ship and Border/Clear phases, identity extends from commercial parties to logistics and regulatory objects. Packing lists, shipping instructions (SLIs), eBLs and customs declarations require stable identifiers for locations, goods, packages, logistics units, shipments, consignments, containers, vessels and customs actors (WTO & WEF, 2022; ICC DSI, 2021). Key references include UN/LOCODE and GLN for locations, GTIN for products, SSCC for logistics units, GSIN, GINC and UCR for shipments or consignments, ISO/IEC 15459 for object identification, ISO 6346 for containers, IMO identifiers for vessels, and national trader identifiers such as TINs for regulatory processes (IMO, 2017; WCO, 2019). The issue is that these identifiers are often used unevenly, confined to sector-specific systems or replaced by free text, preventing the same shipment, consignment or logistics unit from being recognized consistently by carriers, platforms, customs authorities and banks (WTO, 2022).

For the eBL, identity and trust requirements are more stringent, as it must function as a digital original rather than a copy. It must be uniquely identifiable, integrity-protected, controlled by one party at a time, and capable of verified transfer or surrender (ICC DSI, 2026). This requires lifecycle standards and trust infrastructures, such as DCSA frameworks, event-based records, audit trails and, where relevant, TradeTrust or OpenAttestation-type mechanisms, so that its authenticity, status and control can be verified across systems and jurisdictions (DCSA, 2024; ICC DSI, 2023).

In the Pay phase, identity and trust are required to verify banks, applicants, beneficiaries and, where relevant, holders of negotiable instruments. BIC (ISO 9362) remains the core identifier for banks, while LEI (ISO 17442) supports consistent identification of corporates and financial institutions across systems. For letters of credit, trust depends on the ability to authenticate electronic records under eUCP-compliant presentation before examination for compliance (ICC DSI, 2024; GLEIF, 2024). For bills of exchange and promissory notes, identifiers such as GDTI or ISO/IEC 15459 may identify the instrument, but trust ultimately depends on whether transfer, endorsement, presentment and control can be evidenced in a verifiable digital environment (UNCITRAL, 1988; Law Commission, 2022; ITFA, 2023). The main issue is the absence of such mechanisms in practice: payment instruments often remain paper-based, scanned or platform-bound, with no reliable way to prove uniqueness, holder entitlement, transfer history or enforceability across systems (Law Commission, 2022; ICC, BAFT, & TTP, 2026).

This layer also includes the trust services that make identification operational, such as digital signatures, seals, timestamps, certificate validation and PKI-based authentication, secure connectivity and, where relevant, long-term validation standards such as ISO 14533 (ITC, 2025; WTO, UNESCAP, & UNCITRAL, 2023). These mechanisms enable verification of authenticity, integrity and control across systems. In practice, they are implemented differently across environments: DCSA relies on PKI/TLS and message-signing for transport documents; eUCP requires authentication of electronic records for LC examination; and customs systems use national authentication and certification frameworks for regulatory submissions (DCSA, 2024; WCO, 2019).

The main challenge is therefore not only assigning identifiers but also ensuring that identity and trust mechanisms are interoperable across the LC–eBL chain, where parties, goods, shipments and documents must be consistently identifiable, and electronic records must provide verifiable proof of authenticity, integrity and control across systems. Without this, structured data may circulate digitally but cannot serve as reliable evidence for customs clearance, documentary compliance, payment or transfer of rights, or release of goods (ICC DSI, 2025a).

d. Connectivity and governance layer

The connectivity and governance layer determines whether the structured and trusted data described above can actually move across the systems involved in the LC–eBL chain. It covers the exchange channels, messaging protocols, platform interfaces, implementation profiles and governance arrangements that allow commercial platforms, carriers, eBL providers, customs systems and banks to interact without relying on manual uploads, PDFs or closed bilateral connections. Its function is therefore to operationalise the previous layers, and support them by governed channels for exchange, validation and reuse (ICC DSI, 2023; ITC, 2025).

In the Buy phase, purchase orders and invoices may be exchanged through EDI networks, APIs, Peppol infrastructures, e-invoicing platforms or enterprise systems (OASIS, 2024; OpenPeppol, 2025; Ganne & Nguyen, 2022). However, exchange remains fragmented: while large corporates rely on integrated flows, many SMEs still depend on email attachments or PDFs, breaking data continuity at the start of the process (WTO, UNESCAP, & UNCITRAL, 2023). In the Ship phase, connectivity involves multiple actors and systems, including ERP/TMS platforms, freight forwarders, carriers and eBL providers. DCSA-aligned APIs, JSON/OpenAPI structures, and platform-to-platform exchange models support interoperability, but fragmentation persists where systems operate as silos without aligned APIs, rulebooks and control mechanisms (DCSA, 2024; Ganne & Nguyen, 2022; WTO & WEF, 2022). FIATA eFBL and BIMCO sectoral approaches also need to connect with this wider API-based ecosystem. In the Border/Clear phase, customs declarations are exchanged mainly through national customs systems, regulated gateways, single windows, EDI channels and, increasingly, APIs. Although the WCO Data Model supports structured exchange, interoperability remains limited by national implementation differences, restricting cross-border reuse of trade data (WCO, 2019; WCO, 2017).

In the Pay phase, connectivity is based on SWIFT, FileAct, bank platforms and, where implemented, ISO 20022. While these channels enable secure transmission, supporting documents for the LC are often still exchanged as PDFs or uploads, limiting interoperability. Moving toward structured e-presentation and API-based exchange is therefore essential to enable data-driven processing (ICC, 2023; ICC DSI, 2025a). For bills of exchange and promissory notes, future connectivity may also require registry-based, API-based or wallet-based infrastructures capable of supporting digital presentment, transfer and control.

Governance aligns these channels into a scalable system. It requires common implementation profiles, conformance testing, shared security baselines, contractual rulebooks, platform-interoperability commitments and coordinated adoption by market actors. Where DLT is used, ISO/TS 23516:2026 provides a reference for interoperability between DLT systems and with external systems, without making DLT a prerequisite for the overall architecture (ISO, 2026b). The objective is not to create a single global platform, but to govern a network of interoperable systems across the LC–eBL chain, covering EDI/API exchanges in the Buy phase, interoperable eBL platforms in the Ship phase, single-window and customs gateways in the Border/Clear phase, and structured e-presentation and banking channels in the Pay phase. Without such governance, data may be standardized and trusted within individual systems but remain confined to platform, sectoral or national silos, limiting end-to-end interoperability (Ganne & Nguyen, 2022).

Taken together, these four layers show that interoperability in the LC–eBL chain is not achieved by digitising individual documents or connecting isolated platforms. It depends on the combined alignment of legal recognition, data standards, identity and trust mechanisms, and governed exchange channels across the Buy, Ship/Border and Pay phases (UNECE/UN-CEFACT, 2023). Part II moves from conceptual architecture to practical implementation and explores how to transition from fragmented pilots to a scalable cross-border interoperability framework.

Part II: From Architecture to Implementation: Empirical Evidence and the Path Toward a Global Interoperability Framework

Building on the four-layer framework developed in Part I, this section will examine what has already been demonstrated in the LC–eBL chain, in which layers interoperability remains incomplete, and what conditions are needed to move from fragmented pilots toward a scalable cross-border framework. The analysis first reviews selected implementation evidence, then proceeds with interface gap analysis across the Buy, Ship/Border and Pay phases, before outlining the sequencing logic and outlining priorities for a wider adoption of a global interoperability framework.

1- Demonstrated Interoperability: what has been achieved?

Recent implementation experience shows that interoperability in the LC–eBL chain is no longer purely theoretical. Several initiatives have demonstrated that electronic trade documents, platform-to-platform exchange and end-to-end documentary workflows can operate in practice where standards, legal rulebooks, trust mechanisms and governance arrangements are aligned. However, these achievements remain uneven. Progress is most advanced in the Ship phase, especially around the eBL, while Buy-phase commercial data, customs reuse and Pay-phase documentary examination remain less mature. The purpose of this section is therefore not to restate the standards architecture developed above, but to identify what has already been operationalised and what this evidence reveals about the remaining path to scale (DCSA, 2025; ICC DSI, 2025a).

1.1. eBL standardisation as the most mature implementation anchor

The electronic bill of lading is the document around which the greatest degree of semantic convergence has been achieved. Three bodies of work have converged to populate the Semantic Layer and the Code List Layer of the Part 1 architecture for the Ship phase.

- a) The DCSA eBL standard v3.0 defines the operational data model for the containerised maritime eBL, adopted by the world's largest ocean carriers, and specifies the mandatory and conditional data elements governing issuance, transfer and surrender of the electronic bill (DCSA, 2023; DCSA, 2024).
- b) ISO 5909:2026, published by ISO/TC 154 in January 2026, establish a technology agnostic framework formalising the business process model and data requirements for DLT-based eBLs in explicit alignment with UN/CEFACT reference data models and UNCITRAL MLETR, structured around lifecycle segments B1 through B9. ISO 5909 operates at the level of the Business Ontology View (BOV) and the Functional Service View (FSV), specifying what must be recorded and how lifecycle transitions must be governed, without prescribing a specific distributed ledger infrastructure (ISO, 2026a).
- c) The ICC DSI Key Trade Documents and Data Elements (KTDDE) framework contributes a third, transversal dimension, mapping the data elements of the eBL against upstream commercial documents and downstream customs declarations and banking documents, supporting the "reuse, not recreate" principle (ICC DSI, 2024).

These initiatives show that the eBL ecosystem has moved beyond abstract standard-setting: the core data needed for transport-document interoperability are now substantially identifiable and increasingly standardised. The remaining challenge is not the absence of reference models, but their incomplete operationalisation across platforms and adjacent document ecosystems. UN/CEFACT BSP-RDM and

MMT-RDM provide the cross-domain semantic baseline, but mappings between those models and sectoral standards such as DCSA, FIATA eFBL, BIMCO eBL and the WCO Data Model still need to be formalised and deployed in production systems. This is the practical gap that future implementation work must address (UN/CEFACT, 2019; ISO, 2024; ICC DSI, 2024).

1.2. Platform-to-platform eBL transfer: from standardisation to operational exchange

The second major achievement is the move from eBL standardisation to live platform-to-platform exchange reached in May 2025, when DCSA announced the first live, standards-based interoperable eBL transaction between two distinct platform providers. The transaction involved HMM as the ocean carrier and Suzano as the shipper, with an eBL issued on the CargoX platform in compliance with DCSA eBL 3.0 and transferred in real time to EdoxOnline, a technically separate platform, without reverting to paper or requiring a bilateral integration agreement. This constitutes the first demonstrated operationalisation of the Messaging and Exchange Layer for the Ship phase (DCSA, 2025; CargoX, 2025; edoxOnline, 2025).

The technical infrastructure underlying this achievement rests on three components that collectively address the requirements of the Part 1: Governance Layer, the Trust and Authentication Layer.

- a) The Platform Interoperability (PINT) API defines a standardised interface enabling any conforming platform to exchange eBLs with any other conforming platform, realising the network logic that the Messaging Layer requires.
- b) The Multi-Stakeholder Platform Interoperability Agreement (MSPIA) provides the contractual basis for cross-platform transfers, addressing the liability, responsibility and recognition requirements of the Governance Layer (DCSA, 2025; Smart Maritime Network, 2025).
- c) The Control Tracking Registry (CTR) maintains a real-time record of which platform holds exclusive control of a given eBL at any moment, preventing double issuance and satisfying the uniqueness requirement that the Trust and Authentication Layer mandates for transferable electronic records under MLETR.

This progress remains concentrated in the Ship phase, proving that eBL transfer can be made interoperable and scalable where data standards, legal rulebooks, APIs and control-tracking mechanisms are aligned.

The GSBN (Global Shipping Business Network) provides a complementary example of operational deployment. By implementing DCSA eBL API v3.0 with major carriers, including ONE and IQAX, within a DLT-based infrastructure illustrates that platform-level adoption and API standardisation can coexist within a federated architecture. This matters not because the LC–eBL chain must rely on DLT, but because it shows that standardised interfaces can allow different infrastructures to interoperate without converging on a single platform (GSBN, 2025).

GSBN also illustrates the cross-DLT interoperability question that ISO/TS 23516:2026 addresses (ISO, 2026b). The standard defines three interaction modes:

- data transfer (state synchronisation between registries),
- asset transfer (movement of the authoritative record from one DLT to another)
- asset exchange (atomic swap across registries) providing the technical framework for the federated multi-registry ecosystem that the Part 1 architecture's Governance Layer implies without mandating convergence on a single infrastructure.

The announced pipeline of additional platform implementations such as Enigio, WaveBL, TradeGo and others progressively aligning with PINT, signals that the network effect of DCSA's interoperability framework is beginning to operate. Each new conforming platform extends the reach of the interoperable network without requiring bilateral agreements, consistent with the hub-free federated model that the Part 1 architecture.

1.3. End-to-end LC–eBL pilot: testing the Buy–Ship–Pay chain

If the DCSA interoperability milestone demonstrates platform-to-platform exchange within the Ship phase, the Siemens–Commerzbank–Fr. Meyer's Sohn–China pilot in 2025 provides a more advanced test of the full Buy–Ship–Pay chain. The transaction involved an end-to-end bilateral trade flow between Germany and China, connecting Siemens as exporter (Buy phase), Fr. Meyer's Sohn as freight forwarder and eBL issuer (Ship phase), Commerzbank as notifying bank and a Chinese issuing bank managing the LC presentation (Pay Phase), through Enigio's trace:original platform on the European Side and TradeGo on the Chinese side (Enigio, 2025; GTR Review, 2025; Smart Maritime Network, 2025).

The documentary set processed included a native digital eBL issued under trace:original's uniqueness and control model which does not require a blockchain but achieves the paper-equivalent properties of singularity and transferability through cryptographic controls alongside with the commercial invoice, packing list and the full letter of credit presentation set under eUCP rules. Interoperability between the two platforms was achieved through DCSA transport data standards. The outcome was a reduction in documentary processing time from approximately two weeks to under two hours (Smart Maritime Network, 2025).

Analytically, this pilot illuminates several structural features of the full interoperability challenge:

- a) First, it confirms that the bottleneck is not technical but institutional: the technology existed; the constraint was alignment between the carrier, forwarder, two banking institutions and the importer around shared data standards and mutually recognised legal frameworks (Enigio 2025).
- b) Second, it reveals the importance of the semantic and syntactic Layers that had played a critical enabling role: the structured data formats used by trace:original and TradeGo were sufficiently aligned on DCSA transport data standards to enable automated cross-platform processing without manual re-keying.
- c) Third, it demonstrates that the Pay phase — specifically the LC presentation and examination workflow — is the most institutionally complex segment: its digitalisation requires not only technical interoperability between banking platforms but the adoption of eUCP-compatible workflows by both the issuing and the notifying bank, a condition that remains far from universal (ICC, 2019).
- d) A fourth observation concerns legal scalability and its geopolitical underpinnings. The corridor connects two jurisdictions (Germany and China) that operate under distinct legal regimes with different legal positions toward MLETR, its success depended on contractual and rulebook-based recognition rather than on full legal interoperability of electronic transferable records. This observation foreshadows the most fundamental barrier to scaling the framework globally: the legal layer (UNCITRAL MLETR, ICC eUCP, ICC URF 800) is structurally incomplete without substantially broader national enactment (GTR Review, 2025; ICC DSI, 2026).

Taken together, these three milestones confirm that the Ship phase, and particularly the eBL ecosystem, is the most operationally mature segment of the LC–eBL chain, while the Buy, Border/Clear and Pay phases remain substantially less advanced, which is why the following section examines precisely where each layer breaks down in practice.

2- Interface gap analysis: where the architecture remains incomplete

The implementation evidence shows an uneven maturity pattern across the LC–eBL chain. The table below does not restate the standards architecture developed in Part I; it identifies where those standards are already operational, where they remain emerging, and where structural gaps still require coordinated legal, technical or institutional action. The main finding is clear: the Ship phase, especially the eBL ecosystem, is the most advanced segment, driven by DCSA standardisation, platform-to-platform exchange and operational deployments. By contrast, the Buy, Border/Clear and Pay interfaces remain less mature because commercial data, customs declarations and LC presentation workflows are not yet connected through reusable, trusted and machine-readable data flows (DCSA, 2025; ICC DSI, 2025a).

Interoperability readiness assessment: Buy–Ship–Pay architecture

Layer	BUY	SHIP (incl. Border)	PAY
Semantic	Emerging — KTDDE maps invoice fields; BSP-RDM not yet operationalised cross-border	Operational — DCSA eBL 3.0 + ISO 5909 + WCO DM converging	Emerging — ICC UCP/eUCP rules in place; ISO 20022 TF advancing
Code Lists	Operational — ISO 4217, ISO 3166, UN/LOCODE broadly adopted	Operational — HS codes, ISO 6346, UN/LOCODE standardised	Operational — ISO 4217, ISO 8601 uniformly used
Identifiers (Parties)	Emerging — LEI/GLN available; vLEI adoption nascent	Emerging — LEI/TIN used; vLEI not systematically integrated	Operational — LEI/BIC standard in banking; partial in LC workflows
Goods, Logistics IDs	Operational — GTIN/SGTIN standard in retail/manufacturing	Emerging — SSCC/GINC/UCR used; cross-platform linkage incomplete	Structural Gap — Goods identifiers rarely linked to LC/BoE
Syntactic	Emerging — PEPPOL/UBL in EU; no global cross-border invoice format	Emerging — DCSA APIs operational; WCO XML partial; FIATA eBL emerging	Structural Gap — SWIFT MT7xx legacy; ISO 20022 TF migration slow
Master data sync	Emerging — GS1 GDSN operational in retail; rare in trade finance	Structural Gap — No cross-domain party/product sync with SHIP layer	Structural Gap — No systematic product data linkage to PAY instruments
Messaging / Exchange	Emerging — PEPPOL network live in EU; APIs patchy cross-border	Operational — DCSA PINT live; Single Window APIs in major ports	Emerging — SWIFT FileAct/APIs; ISO 20022 migration underway
Governance	Structural Gap — No global governed framework for cross-border invoice	Operational — DCSA MSPA; TradeTrust; WCO Revised Kyoto; WTO TFA	Emerging — ICC eUCP/ISBP; ITFA DNI/DLPC; MLETR partial adoption
Trust & Auth	Structural Gap — No equivalent of ISO 14533 for commercial documents	Operational — ISO 14533 series; national eIDAS/trust services	Structural Gap — Long-term validation of LC/BoE not standardised

Table 1: Readiness assessment by layer and Buy–Ship–Pay phase (referenced to the Part 1 architecture)^f

Legend	Operational	Emerging	Structural Gap
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Source: Authors' elaboration based on ICC DSI (2024), ICC DSI (2025a), and Ganne and Nguyen (2022), together with the standards and instruments listed in the table.

The assessment table highlights that the most important gaps do not stem from the absence of standards, but from the limited operational mapping between them. It shows that three interfaces remain particularly critical: the Buy-to-Ship interface, where invoice and product data are not yet reusable at scale; the Ship-to-Border interface, where eBL and customs data remain weakly connected; and the Ship-to-Pay interface, where LC examination still depends largely on document-based rather than data-driven workflows. These interface gaps explain why successful eBL pilots, although important, do not yet automatically translate into end-to-end LC–eBL interoperability.

2.1. Buy-to-Ship gap: commercial data are not yet reusable at scale

The first implementation gap lies upstream, where commercial data are created but do not yet operate as reusable inputs for transport, customs and banking processes. E-invoicing frameworks such as Peppol/EN 16931, UBL/ISO 19845, UN/CEFACT Cross Industry Invoice and national invoice mandates provide important building blocks, but they remain fragmented across jurisdictions, ERP systems and e-invoicing networks. A structured invoice issued in one environment does not automatically generate compatible data for the shipping instruction, eBL, customs declaration or LC presentation (ICC DSI, 2024; OASIS, 2024; UN/CEFACT, 2019).

The priority is therefore not to create another invoice standard, but to operationalise mappings between existing invoice, product-data, transport and customs models. KTDDE, UBL/ISO 19845, UN/CEFACT invoice models, GS1 master-data standards, DCSA eBL data models and the WCO Data Model already provide the relevant reference points. What is missing is a governed implementation profile capable of making invoice data reusable across the Ship, Border/Clear and Pay phases. Until this is achieved, commercial data will continue to be re-entered, converted or manually checked at each handoff, and the “create once, use many times” principle will remain only partially implemented (ICC DSI, 2024; WCO, 2019; Ganne & Nguyen, 2022).

2.2. Ship-to-Border gap: the customs interface as a critical bridge

A second implementation gap appears at the customs interface, where commercial, transport and regulatory data should converge. The issue is not customs digitalisation itself: the WCO Data Model, WCO Single Window Compendium and WTO Trade Facilitation Agreement already provide important regulatory and data foundations. The gap lies in the weak operational connection between customs systems and adjacent commercial and transport data sources (WCO, 2017; WCO, 2019; WTO, 2017).

Many data elements required for customs declarations, including shipper, consignee, goods description, HS code, country of origin, transport reference and value, already appear in the invoice, packing list and eBL. However, there is still no widely deployed mapping between DCSA/ISO 5909 eBL data, KTDDE-aligned invoice data and WCO Data Model declaration fields. Such a mapping would enable customs declarations to be pre-populated from structured trade and transport data, reducing manual re-entry and improving consistency at the Ship-to-Border interface (DCSA, 2024; ISO, 2026a; WCO, 2019).

The customs interface also raises a trusted-identification challenge. Customs authorities increasingly rely on structured data for risk targeting, compliance checks and post-clearance audit, but these functions require reliable identification of parties, shipments and consignments. The practical priority is therefore two-fold: publish and test cross-standard mappings for customs data reuse, and strengthen trusted identifiers across commercial, transport and regulatory systems. This would turn the customs interface from a point of re-entry into a bridge for end-to-end interoperability.

3- Toward a global interoperability framework: sequencing and enabling condition

The empirical achievements and gap diagnosis set out above define both the opportunity and the work programme for a global LC–eBL interoperability framework. The objective is not to create a single global platform or to replace existing standards, but to organise their implementation around a clear sequencing logic, cross-standard mappings, interoperable interfaces and common governance conditions (Ganne & Nguyen, 2022; ICC DSI, 2025a). This section therefore identifies the priority steps needed to move from isolated pilots and document-level interoperability toward a scalable, cross-border LC–eBL framework (ICC DSI, 2025b).

3.1. Sequencing logic

- a) The first sequencing principle is to begin with anchor records: documents that are legally sensitive, operationally central and already supported by relatively mature standards, rulebooks or normalised at the semantic and governance frameworks. The eBL is the natural anchor for the **Ship phase**, given convergence around DCSA eBL standards, ISO 5909 and platform-to-platform transfer mechanisms (DCSA, 2023; ISO, 2026a; DCSA, 2025). The **LC presentation set** is the natural anchor for the **Pay phase**, because it already rests on established ICC rules for issuance, electronic presentation and document examination, notably UCP 600, eUCP and ISBP 745 (ICC, 2007; ICC, 2013; ICC, 2019). The **commercial invoice** should become the anchor for the **Buy phase**, but only once a cross-border structured invoice profile is operationalised and mapped to downstream eBL, customs and banking data requirements, building on KTDDE, UBL/ISO 19845 and UN/CEFACT invoice work (ICC DSI, 2024; OASIS, 2024; UN/CEFACT, 2025a)
- b) The second principle is bundling extension and cross-document mapping rather than document-by-document digitalisation. Interoperability should focus on reusing the same core data elements across the invoice, packing list, eBL, customs declaration and LC presentation, instead of digitising each document in isolation. The ICC DSI KTDDE framework provides a practical starting point for identifying these common data elements, while UN/CEFACT BSP-RDM offers the cross-domain reference model needed to structure them consistently (ICC DSI, 2024; UN/CEFACT, 2019). Operationalising mappings between the main document and sectoral standards should bring together: KTDDE, UBL/ISO 19845 and UN/CEFACT invoice models upstream; DCSA/ISO 5909 eBL data downstream; and the WCO Data Model at the customs interface (DCSA, 2024; ISO, 2026a; WCO, 2019). This would allow invoice and transport data to pre-populate customs and banking workflows, reducing re-entry, conversion and manual checking. The Siemens–Commerzbank pilot illustrates this logic: the efficiency gain came not from digitising one document in isolation, but from connecting the eBL, commercial documents and LC presentation across the transaction chain (Enigio, 2025; Smart Maritime Network, 2025).
- c) The third principle is federated and technology-neutral convergence. The global framework should not mandate a single platform, a single DLT infrastructure, a single software architecture or a single national legal model. It should instead rely on open interfaces and reliable-system requirements that allow heterogeneous systems to interoperate. This approach is consistent with MLETR-inspired legal reforms, including the UK Electronic Trade Documents Act and recent French legal reform efforts, which do not prescribe a specific technology, but require reliable systems capable of ensuring identification, integrity, exclusive control and transferability of electronic trade documents (UNCITRAL, 2017; Law Commission, 2022; ICC DSI, 2026). However, legal reliability does not by itself guarantee technical interoperability; it must be complemented by open interfaces, implementation profiles, conformance testing and shared governance arrangements. PINT APIs, BSP-RDM mappings, MSPIA-type governance arrangements and ISO/TS 23516, where DLT is used, illustrate this federated approach (DCSA, 2025; ISO, 2026b; UN/CEFACT, 2019). The operational challenge is therefore to create an enabling technical environment — scalable, sector-compatible, technology-agnostic and based on open interfaces — while avoiding both platform consolidation and regulatory fragmentation.

3.2- Enabling Conditions for scale

These sequencing logics are technically achievable with existing standards and demonstrated technology, but its scaling depends on institutional conditions.

Condition 1: Legal reform and accelerated recognition of electronic trade documents. The first condition is to align national and international legal frameworks with the digitalisation of trade documents. MLETR provides the core legal basis for recognising electronic transferable records as functionally equivalent to paper instruments, by requiring identification, integrity, exclusive control and transferability, without relying on bilateral contractual workarounds (UNCITRAL, 2017; ICC DSI, 2026). However, adoption remains uneven across major trading economies and is still geographically limited, with early implementation concentrated in jurisdictions such as the United Kingdom, Singapore and Abu Dhabi (UNCITRAL, 2026). Legal reform should therefore combine accelerated MLETR adoption with broader alignment of digital trade laws, including its enactment in civil law jurisdictions such as Japan and, critically, China and other major trading economies. This is one of the most important legal enablers for scaling LC–eBL interoperability beyond pilot corridors.

Condition 2: Trusted identity, verification and data-exchange infrastructure. The second condition is to operationalise a trust system that allows parties, documents, shipments and control events to be reliably identified and verified across the LC–eBL chain. This should not be limited to LEI/vLEI integration alone, but should combine persistent identifiers, verifiable credentials, electronic signatures and seals, timestamps, certificate validation and secure data-exchange infrastructure (ICC DSI, 2023; WTO, UNESCAP, & UNCITRAL, 2023). Such a framework is essential for document authenticity, control verification, KYC reuse, sanctions screening, customs risk management and banking reliance on electronic presentations (ITC, 2025; ICC DSI, 2025a). The priority is therefore to define interoperable trust profiles that can be used across trade platforms, customs systems and banking workflows, so that electronic trade documents can be relied upon beyond the system in which they were originally issued.

Condition 3: Awareness, bank adoption and implementation capacity. Scaling LC–eBL interoperability requires stronger awareness of the operational gains of digitalisation among corporates, banks and trade-finance teams. For corporates, the value lies in reducing document preparation, re-keying, courier delays, discrepancy risks and working-capital frictions; for banks, scale depends on whether front-office innovation is matched by back-office readiness, particularly in document examination, compliance checks, sanctions screening and settlement processing (ICC DSI, 2025a; ICC DSI, 2025b; ITC, 2025). This requires dedicated investment in three areas: upgraded systems and infrastructure, including API-based e-presentation, eBL registry connectivity and integration with LC messaging channels; staff training for document checkers, compliance officers and trade-finance operations teams with the capabilities to work with digital trade documents and structured data; and organisational change to ensure that digitalisation commitments are embedded in daily transaction processing. Without this internal adoption layer, dedicated funding and change-management effort, interoperability will remain confined to high-profile pilots rather than becoming standard practice in documentary trade finance.

Condition 4: ISO-based alignment across the LC–eBL chain. The fourth condition concerns the coherent use of ISO standards as semantic, syntactic and identification anchors across the transaction chain. ISO/IEC 19845/UBL supports structured commercial documents; ISO 20197-1/BSP-RDM provides a Buy–Ship–Pay semantic reference; ISO 5909 structures DLT-based eBL processes; and ISO 3166-1, ISO 4217, ISO 8601, ISO 6346, ISO/IEC 15459, ISO 9362/BIC and ISO 17442/LEI provide common codes and identifiers (Ganne & Nguyen, 2022). Their value is not to impose a single format, but to create a common baseline for cross-layer data mappings. In the Pay phase, ISO 20022 should be accelerated because it offers richer structured trade-finance data than legacy SWIFT MT 7xx messages and can support document references, API connectivity and more data-

driven LC processing, especially when linked to structured e-presentation channels and upstream invoice, eBL and customs data (UN/CEFACT, 2025a; UN/CEFACT, 2025b; ICC DSI, 2025a).

Condition 5: Multilateral governance architecture and coordinated implementation. The federated framework described in this paper does not require a new global institution, but it does require a structured coordination mechanism capable of aligning the standards bodies, platform operators and the regulatory authorities around a shared implementation roadmap. The priority is to move from parallel initiatives to coordinated implementation: interoperable pilots, conformance testing, mutual recognition pathways and capacity-building for public and private actors (ICC DSI, 2025a; WTO, UNESCAP, & UNCITRAL, 2023). Existing initiatives such as ICC DSI can serve as coordination platforms spanning industry, standards bodies and regulators, provided the focus shifts from document-level standardization to cross-layer implementation. The objective is not to centralise governance, but to sequence legal reform, data mappings, technical interfaces and market adoption so that LC–eBL interoperability can scale beyond individual corridors and pilots.

4- Longer-term frontier: programmable settlement and tokenized payment

The framework described above addresses the documentary and messaging layers of international trade interoperability. A further frontier concerns the integration of programmable payment instruments into the framework’s trust and authentication layer. ISO/TS 23516 provides a relevant technical reference for interoperability between distributed ledger systems and external entities, including asset exchange mechanisms that could support synchronised exchange between a transferable record, such as an eBL or an LC claim, and a payment instrument (ISO, 2026). In trade-finance terms, this would approximate a digital equivalent of delivery versus payment, reducing the settlement gap between document acceptance and payment, during which the exporter may continue to bear credit, liquidity and settlement risk.

Several central bank digital currency programmes are approaching the technical threshold at which wholesale CBDC systems¹ could interoperate with private trade platforms and digital trade infrastructures, including where relevant through ISO/TS 23516-type interoperability mechanisms. The BIS Innovation Hub’s Project mBridge, the Banque de France’s wholesale CBDC experiments, and the MAS Project Ubin+ have each demonstrated components of this capability.

Project mBridge — involving the central banks and monetary authorities of China, Hong Kong, Thailand, the United Arab Emirates and Saudi Arabia under BIS coordination — reached minimum viable product stage in 2024 and has demonstrated multi-currency cross-border wholesale CBDC settlement across participating jurisdictions (BIS, 2024a). This should be read as evidence of technical progress rather than full commercial deployment.

Project Agorá has similarly explored how tokenised commercial bank deposits could be integrated with tokenised wholesale central bank money in a public-private programmable financial platform, which is relevant to future trade-payment interoperability (BIS, 2024b). Project Ubin+ has explored interoperability between digital currency networks and private-sector payment infrastructures, while Banque de France and Eurosystem experiments have tested tokenised central bank money and programmable settlement environments for wholesale financial transactions (MAS, 2023; Banque de France, 2021).

¹ A central bank digital currency (CBDC) is a digital form of central bank money. A wholesale CBDC is designed for use by financial institutions and market infrastructures, rather than by the general public, and is typically explored for interbank, securities or cross-border settlement.

Their integration with the document interoperability framework described in this paper — by connecting the eBL and LC presentation layers to programmable payment triggers — would represent a consequential medium-term extension of the LC–eBL architecture. It is not addressed in the current generation of pilots but should be incorporated into the framework’s design from the outset to avoid future architectural incompatibilities. What none of these programmes has yet achieved is end-to-end integration with the trade-document chain: for example, a DCSA-conformant eBL transfer or an eUCP-compatible LC compliance event automatically triggering an irrevocable CBDC or tokenised-payment instruction. This integration would require not only technical connectivity, but also a governance decision on which standards body, industry consortium or multilateral forum should define the interface protocol between the trade-document layer, banking examination workflows and the settlement layer. The answer to that question will determine whether programmable trade settlement becomes a coherent extension of the LC–eBL interoperability framework or a further fragmentation point.

Conclusion: from available building blocks to scalable governance

The central finding of this paper is asymmetric. The main legal, data, trust and connectivity building blocks for LC–eBL interoperability are increasingly available. ISO 5909, DCSA eBL standards, ICC DSI KTDDE, the WCO Data Model, ISO 20022, ISO/TS 23516, PINT APIs and trusted identity mechanisms each address critical parts of the Buy–Ship/Border–Pay chain. The implementation evidence reviewed above — including live cross-platform eBL transfers, end-to-end LC–eBL pilots and commercial platform deployments — confirms that these standards and infrastructures can operate in practice when legal rulebooks, data models, APIs and trust mechanisms are aligned.

What remains incomplete is not the architecture itself, but the governance and implementation capacity needed to scale it. MLETR-style legal recognition remains uneven across major trading jurisdictions; cross-standard mappings between invoice, eBL, customs and LC data are not yet operationalised at scale; a cross-border structured invoice profile remains unresolved; ISO 20022 migration in trade finance remains incomplete; and trusted identity, verification and data-exchange mechanisms are not yet systematically embedded across trade platforms, customs processes and banking workflows.

The transition from advanced pilots to a scalable global framework is therefore not primarily a question of technological feasibility. It is a question of coordinated implementation under conditions of institutional fragmentation. The next phase should focus on a limited set of operational priorities: accelerating legal recognition of electronic trade documents, publishing and testing cross-standard mappings, connecting invoice, eBL, customs and LC data, defining interoperable trust profiles, supporting corporate and bank adoption, and aligning ICC, ISO, UN/CEFACT, DCSA, WCO, SWIFT, platform operators and public authorities around a shared implementation roadmap.

In this sense, the core challenge is not to invent a new architecture, but to make the existing one executable at scale. The future of LC–eBL interoperability will depend on whether existing standards, legal reforms and platform initiatives can be sequenced into a coherent implementation pathway. Designing the coordination mechanism capable of sustaining this alignment, whether through an extended ICC DSI mandate, multilateral digital trade corridor agreements, or a dedicated implementation body. This remains one of the most important institutional questions for the future of trusted cross-border paperless trade.

Annex 1. Buy–Ship–Pay Interoperability Mapping across the LC–eBL Chain

Layer	Interoperability Function	BUY	SHIP (INCL. BORDER)	PAY
Semantic Layer	Provide a common business meaning	UN/CEFACT CCL; BSP-RDM; Cross Industry Ordering; Cross Industry Invoice; GS1 EDI Business Terms; GPC; UNSPSC (United Nations Standard Products and Services Code); OASIS UBL / ISO/IEC 19845(structured business semantics for commercial documents) UBL/ISO 19845 <i>Documents: Purchase Order; e-Invoice</i>	UN/CEFACT Export Packing List; Multimodal Shipping Instruction; FIATA Forwarders Instructions; UN/CEFACT MMT-RDM; DCSA eBL; FIATA eFBL; BIMCO eBL; WCO Data Model; WCO DM Information Packages; UN/TDED <i>Documents: Packing List; SLI; eBL; Customs Declaration</i>	ICC UCP 600; ICC eUCP; ISBP 745; ISO 20022 Trade Finance; ICC URC 522/eURC; ICC URF 800; UNCITRAL MLETR <i>Documents: Letter of Credit; Bills of Exchange; Promissory Notes</i>
Code-List Layer	Standardised coded values	ISO 3166-1; UN/LOCODE; ISO 4217; ISO 8601; UN Units of Measure; ISO 639 <i>Documents: Purchase Order; e-Invoice</i>	ISO 3166-1; UN/LOCODE; ISO 4217; ISO 8601; UN Units of Measure; ISO 6346 (containers); HS Code <i>Documents: Packing List; SLI; eBL; Customs Declaration</i>	ISO 4217; ISO 8601; ISO 3166-1 <i>Documents: Letter of Credit; Bills of Exchange; Promissory Notes</i>
Identifier Layer (Parties & Locations)	Identify legal entities, parties, and locations	LEI (ISO 17442); GLN; W3C DID; BIC (for invoice-to-payment linkage) <i>Documents: Purchase Order; e-Invoice</i>	LEI; GLN; W3C DID; TIN; UN/LOCODE mappings <i>Documents: Packing List; SLI; eBL; Customs Declaration</i>	LEI; BIC/ ISO 9362; GLN; GDTI <i>Documents: Letter of Credit; Bills of Exchange; Promissory Notes</i>
Goods & Logistics Identifiers	Identify goods, shipments, consignments, logistics units	GTIN; SGTIN; LGTIN; ISO/IEC 15459 <i>Documents: Purchase Order; e-Invoice</i>	SSCC; GSIN; GINC; GDTI; UCR; IMO Ship Number; GTIN; ISO/IEC 15459 <i>Documents: Packing List; SLI; eBL; Customs Declaration</i>	GLN; GTIN; ISO/IEC 15459; GDTI <i>Documents: Letter of Credit; Bills of Exchange; Promissory Notes</i>
Syntactic Layer	Machine-readable structured formats	UBL XML; UN/EDIFACT; ANSI X12 850; GS1 EANCOM; GS1 XML; Peppol BIS Ordering/Billing; EN 16931 <i>Documents: Purchase Order; e-Invoice</i>	UN/CEFACT XML; UN/EDIFACT; UBL; DCSA APIs; FIATA eFBL JSON/API; BIMCO structured datasets; WCO DM XML; UN/EDIFACT GOVCBR; UN/EDIFACT CUSDEC; UBL Customs Declaration <i>Documents: Packing List; SLI; eBL; Customs Declaration</i>	SWIFT MT 7xx; SWIFT MT 798; ISO 20022 Trade Finance; ITFA ePU; ITFA dDOC; UN/CEFACT transferable-records JSON; Verifiable Credentials <i>Documents: Letter of Credit; Documentary Credit Application; Bills of Exchange; Promissory Notes</i>
Master Data Synchronisation	Synchronise product & party master data	GS1 GDSN <i>Documents: Purchase Order; e-Invoice</i>	—	—
Messaging / Exchange Layer	Secure machine-to-machine exchange	EDI; APIs; AS2; ISO 15000 series / ebXML; ebMS; AS4; ebMS; Peppol network; national e-invoicing platforms <i>Documents: Purchase Order; e-Invoice</i>	EDI; APIs; logistics platforms; DCSA APIs; national customs systems; Single Window environments; ISO 15000 series / ebXML; ebMS; AS4, especially for B2G, customs, logistics and single-window exchanges <i>Documents: Packing List; SLI; eBL; Customs Declaration</i>	SWIFT rails; FileAct; bank APIs; eUCP-compatible channels; registries and wallets <i>Documents: Letter of Credit; Bills of Exchange; Promissory Notes</i>

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Layer	Interoperability Function	BUY	SHIP (INCL. BORDER)	PAY
Governance Layer	Governed exchange frameworks	Peppol governance; national clearance/reporting rules; governed EDI/API profiles <i>Documents: Purchase Order; e-Invoice</i>	DCSA frameworks; TradeTrust; OpenAttestation; ISO 14533; WCO Revised Kyoto Convention; WTO Trade Facilitation Agreement; HS Convention; WCO Single Window Compendium <i>Documents: SLI; eBL; Customs Declaration</i>	ICC eUCP; ISBP 745; SWIFT governance; UNCITRAL MLETR; ICC URC 522/eURC; ICC URF 800; ITFA DNI; ITFA DLPC; TradeTrust; OpenAttestation; ISO 14533 <i>Documents: Letter of Credit; Bills of Exchange; Promissory Notes</i>
Trust and Authentication Layer	Protect authenticity, integrity, long-term verifiability	—	ISO 14533 series (long-term validation of electronic signatures); national authentication frameworks; cross-platform trust services <i>Documents: Customs Declaration</i>	—

Source: Authors' elaboration based on ICC DSI (2024), ICC DSI (2025a), and Ganne and Nguyen (2022).

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