Deliverable D 2.1

Specifications for the implementation of blockchain technologies and smart contracts in intermodal transport

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1 Executive Summary

This document is Deliverable 2.1 (D2.1) of Work Package 2 (WP2) within the ESEP4Freight project. The aim of this deliverable is to develop a conceptual framework and a potential architecture for intermodal transport using blockchain technologies and smart contracts.

The deliverable first analyses how smart contracts can play a crucial role in a door-to-door intermodal environment. To this end, a comprehensive study was carried out on how smart contracts are considered in intermodal transport and what their general functionalities are, as well as identifying their current challenges in intermodal contractual frameworks and their benefits.

This was followed by a more detailed analysis of smart contracts and the main existing solutions for the intelligent management of transport documents, in particular consignment notes (CMR, CIM), including solutions on the market that offer comprehensive solutions covering not only smart contracts but also document management and integrated solutions for intermodal transport.

In addition, blockchain technology has been analysed, as it is based on a number of fundamental principles that make it particularly suitable for creating secure and transparent contractual frameworks. The main applications of this technology in different modes of transport were analysed, with a particular focus on rail and how it can improve processes in the rail freight industry.

The project partners, with the support of the Stakeholders' Group (SG), carried out a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of the use of these technologies in an intermodal context. The aim of this analysis was to assess the potential for simplifying the implementation of these technologies by focusing on emerging digitalisation technologies, such as the intelligent container, in the context of intermodal transport. The SWOT analysis allowed the collection of requirements for the different use cases, taking into account the perspectives of the different actors in intermodal transport.

In addition, a complete analysis of the standards and regulations required for the implementation of blockchain and smart contracts in intermodal transport was also carried out.

Defining the architecture of the smart contract was the next step, with the aim of improving the engagement of multimodal transport contracts in a more secure and paperless way. For this reason, two sets of specifications for the implementation of smart contracts have been proposed and developed, one set for an information layer and a second one for a contract layer, applied to both c-CMR and blockchain.

This deliverable then served to provide the conceptual framework and potential architectural specifications of two possible smart contract implementations (e-CMR and blockchain), in both the information and contractual layers. These specifications will be incorporated into the module developed in WP3 and piloted in WP4.

Keywords: Intermodal transport, Rail freight, Blockchain, e-CMR, Smart contracts, Transport market.

2 Abbreviations and Acronyms

Abbreviation / Acronym	Description
AI	Artificial Intelligence
APIs	Application Programming Interfaces
B4CM	Blockchains for Condition Monitoring
BIEs	Business Information Entities
CCL	Core Component Library
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation Électrotechnique
CIM	International Convention concerning the Carriage of Goods by Rail (Convention Internationale concernant le transport des Merchandises par chemin de fer)
CMR	Consignment Note. Convention on the Contract for the International Carriage of Goods by Road (Convention relative au Contract de transport international de Merchandises par Route)
D2D	Door to door
DLT	Distributed Ledger Technologies
EBSI	European Blockchain Services Infrastructure
eCMR, e-CMR	Electronic Consignment Note.
ERP	Enterprise Resource Planning
ESEP4Freight	European Shift Enabler Portal for Freight
ETA	Estimated time of arrival
ETD	Estimated time of departure
ETSI	European Telecommunications Standards Institute
EU-RAIL MAWP	Europe's Rail-Multi-Annual Working Programme
EVM	Ethereum Virtual Machine
FA	Flagship Area
FMS	Fleet Management System
GDPR	General Data Protection Regulation
GHG	Greenhouse gases
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technologies
LCC	Life Cycle Cost
LSPs	Logistics service providers
MaaS	Mobility as a Service
MMT RDM	Multi Modal Transport Reference Data Model
P2P	Peer-to-peer

PoET	Proof of Elapsed Time
PoS	Proof of Stake
PoW	Proof of Work
RU	Railway Undertaking
SaaS	Software as a Service
SG	Stakeholders’ Group
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TMS	Transport Management Systems
TRL	Technology Readiness Level
UN/CEFACT	United Nations Centre for Trade Facilitation and Electronic Business
WMS	Warehouse Management Systems

3 Background

The present document constitutes the Deliverable D2.1 “Specifications for the implementation of blockchain technologies and smart contracts in intermodal transport” in the project European Shift Enabler Portal for Freight (ESEP4Freight). Funding body is the EU-RAIL in the call HORIZON-ER-JU-2022-02 in the framework of the Exploratory Research activities as described in the EU-RAIL MAWP (EU-RAIL, 2022).The project will support a simple, cost-effective and sustainable modal shift of freight flows to rail and contribute to the European Union’s target of reducing greenhouse gas emissions by 55% by 2030 compared to 1990 levels and decarbonising transport. The overall objective of ESEP4Freight is to contribute to the provision of open, high quality and user-friendly information for all actors in the supply chain and to test innovative new tools to promote modal shift to rail.

The creation of the Web Platform in WP3 is expected to primarily contribute, at a high-level, to the second cluster of the Flagship Area 5 (FA5), “Seamless rail freight” of the Multi-Annual Working Plan (MAWP). The Web Platform is developing an online portal providing relevant information on the European rail freight system. The goal is to position the Web Platform as the reference tool for stakeholders in the logistics chain seeking high-quality information on the possibilities of modal shift to rail. Information about rail schedules, potential transport flows between regions, and information about the available infrastructure are expected to play a central role in targeting the appropriate audience. The Web Platform would serve in this manner as gateway to promote and facilitate the use of advanced tools developed in the “Seamless rail freight” cluster from FA5, such as multimodal journey planner with dynamic information or booking features.

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This report will comprise the outputs of T2.2 and will include the specifications of 1) The informative layer, consisting of a set of specifications for the use of information exchange on event in the supply chain) and of 2) the contractual layer, consisting of a set of specifications for the intermodal trade clauses and milestones including recommendations on rights and duties amongst actors of the supply chain.

4 Objective/Aim

The objective of this document is to develop a conceptual framework and a potential architecture for intermodal transport using blockchain technologies and smart contracts.

To this end, the project partners will carry out a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of the use of these technologies in an intermodal context and, with the support of the Stakeholders' Group (SG), a market survey of existing solutions and/or implementations. The objective of this analysis is to evaluate the potential for simplifying the implementation of these technologies by focusing on emerging digitalisation technologies, such as the smart container, within the context of intermodal transport. Furthermore, a catalogue of existing platforms (e.g. for the electronic exchange of documents) will be created and evaluated according to a set of pre-selected criteria. This will serve to evaluate smart contract implementations.

This section begins with an examination of the main characteristics of the business model and legal framework as identified in T2.1. It then considers the technological components that could be involved in supporting the business model. Based on this analysis, the Smart Contacts conceptual framework and potential architecture for implementation tailored to the sector's own characteristics will be proposed. In order to ascertain the most appropriate solution, two possible implementations will be evaluated. The first is based on e-CMR and the second on blockchain.

This task will serve as a specification for the smart contract integration, with the aim of creating an informative layer that will facilitate the construction of a decentralised network. This network will be capable of collecting freight trains with common factors and adapting to their characteristics. Companies dedicated to freight transport may also become involved in the network, with the network providing them with information regarding the costs and the path of their goods from the shipment of the cargo until it reaches its desired destination.

A contractual layer will also be established, comprising a general set of terms and clauses. This will be achieved by integrating well-known APIs for blockchain and e-CMR into the web tool. The objective is to assess the potential of these tools in facilitating contractual relations between parties.

In conclusion, this task will provide the conceptual framework and potential architectural specifications of two possible smart contract implementations (e-CMR and Blockchain) in both the informative and contractual layers. These specifications will be incorporated into the module developed in WP3 and piloted in WP4.

Task 2.2 started in month one and the outputs of these tasks are included in this document. The following Table 1 gives the direct match of the task definition from the proposal with the output and a link to the section where more details can be found.

Table 1 Task descriptions and related output in the report

Task 2.2 Specifications for smart contracts and blockchain technologies in a door-to-door intermodal environment	**Output of deliverable**
The aim of this task is to develop **a conceptual framework and potential architecture** for intermodal transport using blockchain technologies and smart contracts.	All the Chapters
The project partners will realise a **SWOT analysis** on the use of those technologies in an intermodal context and will survey the market of already existing solutions and/or implementations with the support of the SG. This analysis will serve to understand if the implementations for these technologies should be eased by focusing on new digitalization's technologies such as the smart container in this intermodal transport framework. In addition, a catalogue of existing platforms (e.g. for documents electronically exchanged) will be also created.	Chapter 5 Section 5.2.4
Starting from the **main characteristics of the business model and legal framework analysed on T2.1** and the technological components that could be involved to support the business model, Smart Contacts conceptual framework and potential architecture for implementation tailored to the sector's own characteristics will be proposed. To do this, two possible implementations will be assessed: a first one based on e-CMR and a second one based on blockchain	Chapter 6 All sections
This task will serve as a **specification for the smart contract integration aiming to have an informative layer** that will build a decentralized network in which freight trains with factors in common are collected and which can adapt to their characteristics. In this layer, companies dedicated to freight transport could be involved in the network and the network would inform them of the costs and the path of their goods from the shipment of the cargo until it reaches the desired destination.	Chapter 6 Section 6.1.1
A **contractual layer** in which a generalized set of terms and clauses will be specified and implemented, as an example on the web-tool, by integrating on some well-known APIs for blockchain and e-CMR, the characteristics of the proposed solution development. This aims to assess the potential of these tools on easing the contractual relations amongst parties.	Chapter 6 Section 6.1.2
This task will provide the conceptual framework and potential architecture´s specifications of **two possible smart contracts implementations (e-CMR and Blockchain**) in both layers, the informative one and the contractual one to be incorporated in the module developed in WP3 and be piloted in WP4.	Chapter 6 Section 6.1.3 Section 6.3

5 Smart Contracts in a Door-to-Door Intermodal Environment

5.1 Smart Contracts in Door-to-Door Intermodal Transport

The term "intermodal transport" is used to describe the use of two or more different modes of transport in a single end-to-end trip to move goods from their point of origin to their destination. Intermodal transport involves the use of multiple modes of transportation—such as rail, road, and sea—to move goods from origin to destination without handling the goods themselves when changing modes. This method is crucial in modern logistics, offering flexibility and efficiency in moving goods across long distances. In the context of rail freight, intermodal transport is particularly significant because it leverages the strengths of rail—such as lower environmental impact, cost-effectiveness, and the ability to carry large volumes of goods over long distances. This approach allows the benefits of each mode of transport to be exploited, with rail transport being identified as one of the most efficient and sustainable modes.

Multimodal transport, as a comprehensive transport system, provides an effective organizational method that optimizes transport structures, enhances efficiency, and minimizes overall logistics costs. Multimodal transport documents are an essential component of multimodal transport operations, encompassing the entire process from consignment initiation to the completion of goods delivery. At present, there is no standardised multimodal transport document, which results in additional time and costs for segment carriers involved in various transport modes when carrying out document exchange operations.

However, achieving data sharing for multimodal transport requires the involvement of multiple parties, including shippers, consignees, roads, railways, waterways, ports, and more. Business collaboration involves the exchange of sensitive information, including core competitive strategies and contractual terms, which can lead to a lack of mutual trust and difficulties in sharing information. As a result, the implementation of a one-bill coverage system is challenging. The emergence of blockchain technology provides a novel approach to address these issues. Firstly, blockchain technology can establish an alliance blockchain for multimodal transport, breaking down information barriers among various entities and resolving the challenge of information sharing in the one-bill coverage system. Secondly, blockchain networks feature decentralized governance and mutual supervision, which can enhance the level of trust among entities involved in multimodal transport. Thirdly, by deploying smart contracts, contractual terms can be automatically executed, which can streamline the process of sharing information.

5.1.1 Introduction to Intermodal Transport and its significance in Rail Freight Transport

Freight transport plays a crucial role in the global economy, and the efficiency of this process is vital for both international and domestic commerce. Consequently, intermodal freight transport has emerged as a core strategy for optimising the supply chain and reducing costs. Rail freight is an essential component of intermodal transport, providing a sustainable alternative to road transport, which is often associated with higher carbon emissions and congestion. The integration of rail into intermodal transport networks allows for a seamless transition between different modes, optimizing each mode's strengths (BC4M, 2022). For example, goods may be shipped by sea to a port, transferred onto a train for the inland journey, and finally delivered by truck to their destination. This combination reduces transit times and costs, enhances the reliability of deliveries, and supports global trade by providing a robust infrastructure for the movement of goods.

The paper (Agamez-Arias and Moyano-Fuentes, 2017) represents a significant contribution to the field of intermodal transport in freight distribution, offering a systematic evaluation of the current state of research in this area. It builds upon existing literature reviews by employing a rigorous methodology to assess the body of knowledge in this field. The analysis has enabled the identification of three principal lines of research. The initial research line, which concerns the fundamental principles of intermodal transport, encompasses studies that address the definition of intermodal transport, and the outcomes achieved through the utilisation of this transportation system. The second research line, which concerns improvements to the way that intermodal transport systems work, encompasses elements and variables that impact intermodal transport systems' logistics efficiency. These include the quality of service, information and communication systems, and freight planning and linkages among system operators, with the objective of providing an adequate service. The third line of research, intermodal transport system modelling, identifies the main variables used to optimise these transport systems, the different focuses and approaches used in modelling, and the advantages and disadvantages of each focus. One of the main findings is related to the need to harmonize the contracts.

In the context of logistics, Door-to-Door (D2D) transportation refers to a mode of conveyance in which the "doors" represent warehouses, factories, or other specified points of origin and destination. The responsibility for indicating these addresses lies with the shippers. D2D transportation is typically conducted within the operational scope and coverage of the carrier or freight forwarder (RailSlider, 2023). This approach to logistics is characterized by its seamless integration of different transport modes into a single, cohesive operation that ensures goods are delivered efficiently and reliably from one door to another. The term "intermodal" emphasizes the combination of these different transportation modes, each of which is used for a specific segment of the journey based on its strengths and suitability.

Freight shipments in the door-to-door format are utilised for both domestic transportation within the country and international logistics operations. The establishment of an extensive network of services between major terminals, locations around the world, or specific regions by a carrier serves to enhance its competitive position by providing convenient services to a greater number of drop shippers interested in D2D delivery.

D2D intermodal transport represents an enhancement to logistics efficiency, offering a reliable and flexible solution that can be tailored to the specific needs of the shipper. The ability to seamlessly integrate multiple modes of transportation allows for optimisation of routes and schedules, reducing transit times and improving delivery reliability. Furthermore, the use of containerisation simplifies the logistics process, facilitating the handling and tracking of shipments throughout the supply chain.

In the course of transporting goods to a multitude of global destinations, freight forwarders and carriers are bound by a set of obligations outlined in the International Commercial Terms (Incoterms). These three-letter terms are embraced by governments, regulatory bodies, and commercial organisations with the objective of standardising and simplifying the identification of processes and participants in trade transactions, thereby enhancing international trade as a whole.

5.1.2 Smart Contracts and their general functionality

The use of smart contracts provides a potential solution for the documentation and financial exchange processes inherent to intermodal transport networks. By eliminating the need for traditional intermediaries, this tool offers a means of establishing reliable contracts while enhancing transparency. It is anticipated that this approach will offer benefits in terms of enhanced traceability and increased efficiency. The automation of transactions through the use of smart contracts reduces the incidence of manual errors and facilitates the expeditious processing of transactions. This enhanced efficiency benefits the entirety of the logistics process, rendering it more streamlined and cost-effective (Altuntaş et al., 2020).

A smart contract is a self-executing digital contract stored on a blockchain that is automatically enforced when predefined conditions are met, ensuring the terms of the agreement are upheld. Smart contracts are typically employed to automate the execution of an agreement, thereby ensuring immediate certainty of outcome for all participants, without the need for intermediary involvement or delays (IBM, 2024). They can also be used to automate a workflow, initiating the next action when predetermined conditions are met. These contracts are encoded on a blockchain—a decentralized, distributed ledger that ensures transparency, immutability, and security. The use of blockchain technology in smart contracts allows for the automation of agreements between parties, where the contract's terms are directly written into code. When the contract's conditions are satisfied, the code automatically enforces the terms, such as transferring funds or releasing goods, thus ensuring that all parties fulfil their obligations without the need for manual oversight.

The utilisation of smart contracts facilitates expeditious, efficacious and precise transactions. Upon the fulfilment of a stipulated condition, the contract is executed without delay (Sinha and Roy, 2021). As smart contracts are digital and automated, the necessity for manual document processing and reconciliation is obviated, thereby reducing the potential for errors that may arise from such manual procedures. The functionality of smart contracts extends beyond simple automation. They enable "trustless" interactions, meaning that participants do not need to trust each other or any central authority; instead, they trust the technology. This is crucial in scenarios involving multiple stakeholders, such as in supply chains, where smart contracts can streamline operations by reducing the need for intermediaries, minimizing errors, and lowering transaction costs.

Furthermore, they facilitate the establishment of trust and transparency. The absence of a third party and the use of encrypted records of transactions shared across participants eliminate the possibility of information being altered for personal benefit.

The security afforded by smart contracts is another advantage of blockchain technology. The encryption of transaction records on the blockchain makes them resistant to hacking. Furthermore, the interconnected nature of the blockchain, with each record linked to preceding and subsequent records on a distributed ledger, makes it difficult for hackers to alter a single record without affecting the entire chain.

Smart contracts streamline and automate various processes within the intermodal transport chain. This includes payment processing, document management, and the tracking of goods. For instance, smart contracts can automatically trigger payments upon the successful delivery of goods, as verified by IoT sensors. This automation reduces the need for manual intervention, which in turn reduces delays, minimizes the risk of human error, and lowers operational costs. By integrating smart contracts into the intermodal transport framework, companies can achieve greater operational efficiency and speed, which are crucial for maintaining competitiveness in the global market.

Transparency is a key challenge in intermodal transport, where goods pass through multiple hands and are subject to various regulatory requirements. Smart contracts address this issue by providing a single, immutable source of truth that all stakeholders can access in real-time. This transparency ensures that all parties have accurate and up-to-date information, reducing the risk of miscommunication and enabling better coordination. For example, stakeholders can monitor the status of shipments, verify compliance with regulatory requirements, and receive notifications of any issues that arise during transit, such as delays or damage to goods.

Trust is a fundamental aspect of any contractual relationship, especially in the logistics sector, where multiple parties need to collaborate closely to ensure the successful delivery of goods. Smart contracts enhance trust by embedding the terms of the contract directly into the blockchain, which automatically enforces the agreement. This eliminates the need for intermediaries, such as banks or legal entities, to verify or enforce contracts, thus reducing the potential for disputes. The decentralized and transparent nature of blockchain technology ensures that all transactions are visible to all participants and that the contract cannot be tampered with, further building trust among stakeholders.

Compliance with regulatory requirements is a major concern in intermodal transport, particularly when goods across international borders. Smart contracts can be programmed to automatically enforce compliance with relevant regulations by including the necessary legal clauses within the contract code. This capability not only ensures that all regulatory requirements are met but also reduces the administrative burden on companies. Additionally, smart contracts enhance risk management by providing real-time visibility into the status of shipments and enabling stakeholders to respond quickly to any issues that arise, such as delays, theft, or damage (UNECE, 2020).

In closing, it can be stated that smart contracts facilitate savings. The elimination of intermediaries in the transaction process, and the associated delays and fees, is a further advantage of this technology.

Reference (UNECE, 2019) is focused on the smart contract, electronic notary and decentralised process coordination features of blockchain, rather than cryptocurrencies. Similarly, although blockchain has a wide range of applications in sectors such as digital intellectual property rights, digital voting, digital record keeping and so on, the focus will remain on its use within supply chains.

5.1.3 Current challenges in Contractual Frameworks for Intermodal Transport

The existing legal frameworks are not aligned with the evolving landscape of transport patterns, technological advancements and market dynamics. In contrast, the present legal framework comprises a number of international conventions, regional and sub-regional agreements, national legislation and standard term contracts, all of which are designed to regulate single-mode transport, such as by road or by rail. Consequently, both the applicable liability rules and the degree and extent of a carrier's liability vary considerably from case to case and are unpredictable. Despite several attempts at drafting a set of rules to govern liability arising from multimodal transport over the years, none of these has resulted in international uniformity.

The current legal framework is fragmented and complex, which creates uncertainty and, in turn, transaction costs. These costs arise from legal and evidentiary enquiries, costly litigation and rising insurance costs. For developing countries and for small and medium-sized transport users, in particular, this is a significant concern.

This context illustrates the necessity for a harmonised contractual framework.

Despite the numerous recent developments in the tracking of goods, railways and their customers still encounter significant difficulties in monitoring the movement of specific freight consignments. This has led to concerns being raised about the reliability of rail freight services. Blockchain technology is currently being trialled in numerous locations worldwide, with the potential to enhance the quality of service provided to customers while reducing costs (Sue Morant, 2018). To illustrate, over a nine-month period, Russian Railways successfully transported in excess of 5,000 freight consignments ordered via Freight Transport, an electronic trading platform underpinned by Emercoin, a blockchain technology launched jointly by RZD and Intellex in April 2017. Similarly, the State Railway of Thailand is investing in blockchain with Internet of Things (IoT) technology to manage signalling, passenger information systems, ticketing and goods delivery.

The intermodal transport of goods is hindered by significant challenges within its contractual frameworks due to the movement of goods using multiple modes of transportation, including trucks, trains, and ships. These challenges primarily stem from inconsistencies, a lack of standardisation, and legal barriers across different jurisdictions.

The lack of uniformity in contracts across various transport modes gives rise to confusion and inefficiency. Each mode, whether road, rail, or maritime, often has its own set of contractual terms, which creates difficulties when goods are transferred from one mode to another. This inconsistency not only complicates the coordination among transport providers but also increases the risk of disputes due to differing interpretations of contract terms.

A notable deficiency exists in the standardisation of contractual terms, which are not consistently applicable across diverse modes of transportation. This absence of uniformity necessitates the customisation of each contract to suit particular circumstances, frequently resulting in legal intricacies. Furthermore, the heterogeneity of contracts impedes the deployment of technologies such as blockchain-based smart contracts, which rely on standardised inputs to operate effectively.

The existence of different legal frameworks in various countries and regions represents a significant obstacle to the implementation of seamless intermodal transport. The presence of disparate regulations pertaining to matters such as liability, insurance, and dispute resolution within different jurisdictions introduces a considerable degree of complexity, rendering the drafting of contracts that are both comprehensive and compliant with all relevant laws a challenging endeavour. This issue is particularly prevalent in the context of international transport, where the convergence of multiple legal systems can give rise to conflicts of law and jurisdiction.

5.1.4 Benefits of a Harmonized Contractual Framework

The harmonization of contractual frameworks in intermodal transport offers numerous benefits, which can significantly enhance the efficiency and reliability of global supply chains.

The implementation of a harmonised framework has the potential to reduce the frequency and severity of disputes by providing clear, standardised terms that can be easily understood and followed by all parties. The establishment of a uniform set of guidelines may contribute to a reduction in conflicts over contract interpretations, which could result in more efficient operations and a decrease in legal confrontations. The UNESCAP study (UNESCAP, 2018) on the harmonisation of documents for international transport suggests that such standardisation could mitigate disputes and streamline legal proceedings.

The standardisation of contractual terms facilitates more efficient coordination between different modes of transport, resulting in smoother transitions between transportation modes and reduced delays. This, in turn, improves the overall speed and reliability of the supply chain. Furthermore, standardised contracts can facilitate the implementation of digital technologies, such as electronic bills of lading and blockchain-based smart contracts, which enhance operational efficiency by reducing paperwork and the potential for human error.

A unified contractual structure facilitates enhanced collaboration among stakeholders by establishing a shared legal language that all parties can consent to. This uniformity cultivates trust and cooperation, as all parties are assured that their rights and responsibilities are consistently recognised and enforced. Furthermore, enhanced collaboration can result in more strategic partnerships and enduring relationships between carriers, shippers, and logistics providers, thereby reinforcing the global transportation network.

5.1.5 Existing Digital Platforms for Transport

This section includes research to identify existing solutions for the intelligent management of transport documents, in particular consignment notes (CMR, CIM). A number of platforms have emerged, offering varying levels of service. It is interesting to highlight that some platforms designate the eCMR simply as a document generation process, while others have introduced an integrated service that allows for tracking the progress of a transport step by step, monitoring it, making comments—including the ability to take photos—and securing both the steps and the documents in a repository.

Below is an overview of the existing platforms.

5.1.5.1 DOXIS

Doxis (SER Group, 2024) is an enterprise content management (ECM) platform designed to automate and streamline document management. It uses Artificial Intelligence (AI) to classify, extract, and centralise business documents, enabling efficient automation of processes such as invoice handling, contract management, and compliance. Doxis integrates with various systems (e.g., Microsoft, SAP) and supports industries like finance, insurance, logistics, and manufacturing. It facilitates secure storage, real-time collaboration, and information access across organisations.

Table 2 DOXIS brief information

Category	Values
General info	Doxis counts several features including document management, team collaboration, intelligent archiving, workflow automation, built-in intelligence, business connectors, invoice automation, compliance & governance tool, workspaces
Technology used	AI, Cloud-based solutions
Type of consignment notes supported	CMR or CIM
Website	https://www.sergroup.com/en/

5.1.5.2 CMR Management

The CMR Document Management Online Software (CMR Management, 2024) is a free PDF editor that allows users to create, modify, and manage CMR (Consignment Note) documents used in logistics. It simplifies the process by storing customer and delivery data, offering multi-language support, and reducing the time needed to complete forms. Accessible from any device, it enables users to produce personalized CMRs quickly and for free. The “software”, which remains a basic eCMR generator, was last updated in 2017.

Table 3 CMR Document Management Online Software brief information

Category	Values
General info	The application stores customer data, delivery addresses, and supports shipment reporting by customer or period. It offers the possibility to generate new CMRs by duplicating existing ones, search through CMRs using keywords, and export CMR documents to PDF for emailing or printing in various formats. It supports multiple EU languages and offers real-time shipment reports.
Technology used	Pdf
Type of consignment notes supported	e-CMR
Website	https://cmr.transportator.info/

5.1.5.3 Pionira

Pionira (Pionira, 2024) is a software solution for digital documents focused on transport and logistics and an accredited provider of e-CMR. Their solutions integrate with major systems like ERP (Enterprise Resource Planning), TMS (Transport Management Systems), WMS (Warehouse Management Systems), and on-board computers. They also offer a digital IDF for the waste industry and time slot booking to streamline operations. Their Yard Management Service provides real-time tracking of trailers to improve site efficiency.

Table 4 Pionira brief information

Category	Values
General info	Pionira uses a digital platform called eWastra, which integrates various e-services including e-CMR. The e-CMR service integrates with existing systems such as ERP, TMS, WMS, and on-board computers. This ensures seamless data flow and document management.
Technology used	Web platform, possibly cloud as it allows for secure, global access and real-time updates
Type of consignment notes supported	e-CMR, e-IDF, e-MOVE, e-SOILS and others.
Website	https://www.pionira.be/en/

5.1.5.4 TransFollow

TransFollow (TransFollow, 2024) is a digitalisation solutions provider focused on transforming transport planning and operations. It aims to integrate supply chains more effectively through a unified digital platform that enhances operational control and efficiency without necessitating changes to users' existing technical environment. The platform is designed to facilitate seamless digital interactions and streamline transport processes, making it ideal for businesses that currently lack a TMS, FMS (Fleet Management System), or WMS. The site features an API to connect with supply chain partners (Transfollow Connect), a portal to manage transports (Transfollow Portal), an application for drivers' use (Transfollow Drive), and a backoffice to connect with subcontractors (TransFollow Messenger).

Easily sort and prioritize your transports, focusing specifically on those that require your immediate attention for further exception handling.

Table 5 TransFollow brief information

Category	Values
General info	Web-based interface for managing transport orders, which centralises data, allows documents dispatching, offers real-time visibility into operations, and helps sharing information with partners, customers, and drivers. The platform can integrate with existing workflows and can digitalise operations even if users do not have a TMS, FMS, or WMS.
Technology used	Web platform
Type of consignment notes supported	e-CMR, Proof of Delivery, possibly CIM as users can create and manage custom document templates for various transport needs
Website	https://www.transfollow.org/

5.1.5.5 Dashdoc

Dashdoc (Dashdoc, 2024) is a digital platform that simplifies the management of transport operations through e-CMR. It allows users to create transport orders and assign them to drivers. Drivers validate the transport documents electronically, including signatures at loading and unloading points. The platform ensures compliance with legal requirements in 32 countries and allows for real-time sharing of documents like weight slips and photos with partners and clients. It supports offline functionality, ensuring it works even in remote areas. The e-CMR includes enhanced evidence such as photos, timestamps, and GPS positions made to improve productivity and reduce disputes.

Table 6 Dashdoc brief information

Category	Values
General info	Dashdoc digitalises transport management with e-CMR, allowing easy creation, dispatch, and validation of transport documents. It ensures legal compliance, enhances productivity with real-time document sharing, and offers offline capabilities.
Technology used	Web Portal, possibly cloud
Type of consignment notes supported	CMR, possibly CIM
Website	https://www.dashdoc.com

5.1.5.6 ShipHub

ShipHub (ShipHub, 2024) is an online platform designed to streamline international freight by allowing users to compare quotes for sea, rail, and air freight from various verified freight forwarders. The platform focuses on cost-efficiency, enabling businesses to receive multiple transport offers through a single form, thus saving time and reducing costs for their shipments. ShipHub offers users transparency in pricing and managing shipments from a desktop or smartphone. It supports various transportation methods (air, ocean, rail), helping businesses make informed decisions based on real-time freight rates.

Table 7 ShipHub brief information

Category	Values
General info	The platform integrates various tools to make the process more transparent, including options for viewing and managing shipments, and receiving quotes across different shipping methods.
Technology used	Cloud-based platform
Type of consignment notes supported	e-CIM, e-CMR
Website	https://www.shiphub.co/

5.1.6 Other Smart Contracts solutions

There are also several solutions on the market that offer comprehensive solutions that include not only smart contracts, but also document management and integrated solutions for intermodal transport. The best known are:

5.1.6.1 CargoWise

CargoWise (Rajamanickam, 2024) is a fully integrated global software solution that enables customers to conduct highly complex logistics transactions and manage their operations in a single database for multiple users, roles, countries, languages and currencies. CargoWise executes complex logistics transactions and manage freight operations from a single, easy to use platform, powered by advanced technology, automation and analytics.

5.1.6.2 Widoit

Widoit (Widoit, 2024) is an online Document Management System (DMS) specialized in suppliers of transport, maintenance and services. It provides document control service for transport suppliers, document control service for external suppliers from a different branch of services, and E-CMR / WAYBILL - Legal alternative to printed paper in road freight transport.

5.1.6.3 WanaTruck

WanaTruck (WanaTruck, 2024) is a technological solution for the digitalization of freight transport, open and modular. It has several modules: Wana-Cargo manages loads and assigns trips automatically, Wana-Connect controls all loads with the Drivers App and sends all data of each load to drivers and manages trips efficiently, Wana-Doc facilitates digitized documentation on carrier, vehicles, license plates, drivers and allows access to load centres, Wana-Cold Chain integrates with the truck's cold device, controlling in real time the cold temperature range, Wana-Blockchain offers all parties involved in the transport chain an extra layer of security and trust between the parties by guaranteeing the immutability of the data received, Wana-eDocuments allows to have the transport documentation in electronic format, Wana-API allows to easily integrate the ERP, Wana-Trace allows to know at any time the status of loads and track them from any device, Wana-eCMR allows to have the transport documentation in electronic format, Wana-Delivery Note allows to add the e-delivery note to the transport documentation, and Wana-Data measures service indicators and generates reports.

5.1.6.4 WebTrans

WebTrans (WebTrans, 2024) is a multimodal, unique operations platform for transport logistics that seeks to make the work of its customers simpler and safer. They offer several tools such are freight exchange, e-CMR or TMS. TranSmart is a real-time visibility tool that is aimed at helping companies to optimise their supply chain management, providing a global and detailed view of what is happening in the logistics chain and allows the exchange of data between the parties that are involved.

The e-CMR tool helps in the process of digitalising the freight documents, allowing carriers to always be up to date on any changes and unexpected issues, which enables more logistical efficiency. Finally, TMS software helps to manage logistics operations and optimize shipments, by reducing complexity, connecting all the actors in the logistics process and unifying these processes in a single tool.

5.1.6.5 Global Candace

Global Candance is a comprehensive platform that, once integrated with the business's ERP system, displays vessel locations on a map in real-time. By simply clicking on a selected vessel, users can access its updated ETD (Estimated time of departure) and ETA (Estimated time of arrival) information, product or reference details, internal purchase number, shipping company, container, supplier, customer, and destination warehouse.

5.2 Blockchain Technology Fundamentals

On the other hand, blockchain technology is based on a set of fundamental principles that make it particularly well-suited for the creation of secure and transparent contractual frameworks. A blockchain is a highly secure, shared data chain that helps business networks exchange assets, store information, and record transactions (Columbia Engineering, 2021). These digital ledgers use consensus and permanent record keeping to make these processes more efficient, trustworthy, and secure for all parties involved. At its core, blockchain is simply a type of database. However, the key difference between blockchain and traditional databases is the way the data is structured. Unlike traditional databases, which store data in centralized, relational tables, blockchain is an open, peer-to-peer (P2P) network that favours communal functionality over a centralized, controlling entity.

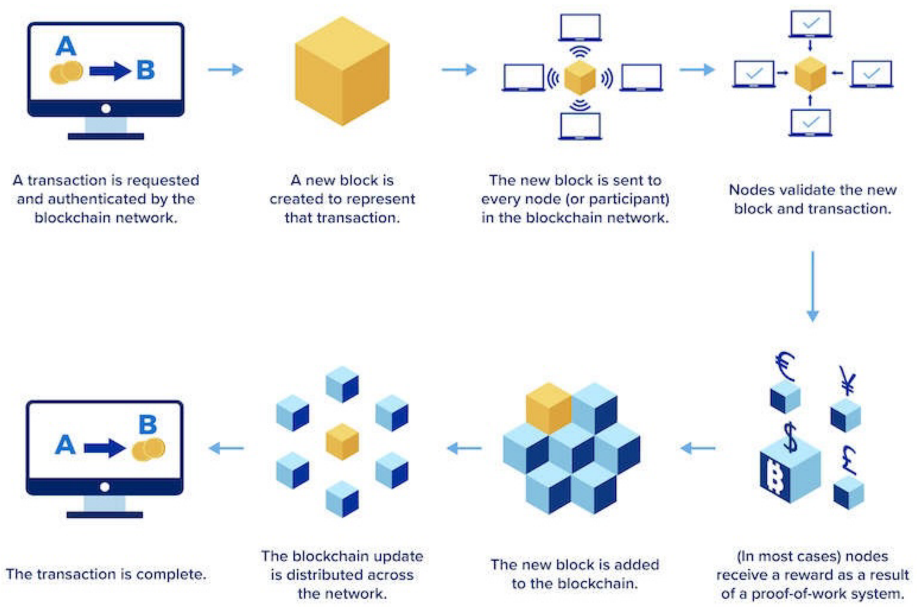


Figure 1 The Blockchain process (Columbia Engineering, 2021)

5.2.1 Fundamental concepts of Blockchain Technology for creating transparent and secure Contractual Frameworks

Blockchain technology is based on a set of fundamental principles that make it particularly well-suited for the creation of secure and transparent contractual frameworks. The blockchain technology is decentralised at its core, whereby data is not held by a single entity but distributed across a network of nodes. This decentralisation is of great consequence, as it prevents any single point of failure and ensures that all participants in the network have access to the same data. This is of particular value in contexts where trust and fairness are of paramount importance (Siddik et al., 2021). The decentralised nature of blockchain is further enhanced by its immutability; once data is recorded on a blockchain, it cannot be altered or deleted. This immutability is achieved through cryptographic hashing, which links each block of data to the previous one, forming an unbreakable chain. Such a feature is vital for contractual frameworks as it guarantees the permanence and reliability of contracts and transactions (Hassan et al., 2019).

Furthermore, blockchain networks depend on consensus mechanisms, such as Proof of Work (PoW) or Proof of Stake (PoS), to validate and concur on the status of the blockchain. These mechanisms guarantee that the majority of network participants concur on the legitimacy of transactions before they are incorporated into the blockchain, thereby preventing fraudulent activities and ensuring that all participants possess a consistent and accurate perception of the data (Gupta et al., 2020).

The principles of decentralisation, immutability, and consensus are fundamental to ensuring transparency, security, and trust within blockchain-based contractual frameworks. The transparency afforded by blockchain arises from its decentralised structure, which allows all participants to access the entire ledger. This transparency is particularly beneficial in contexts such as international trade, where blockchain can provide a transparent record of the entire supply chain, ensuring that all parties have access to the same information (UNECE, 2019).

In terms of security, blockchain's immutable nature is of critical importance. Once recorded, data cannot be altered, thereby ensuring the integrity of contracts and transactions. This, in conjunction with advanced cryptographic techniques, guarantees that data remains secure from tampering and unauthorised access. Furthermore, the decentralised structure enhances security by eliminating central points of vulnerability, which is particularly valuable in sectors where data security is of the utmost importance, such as finance and energy (Mohanta et al., 2019).

The consensus mechanisms inherent to blockchain technology facilitate the fostering of trust, which is a fundamental aspect of any contractual framework. These mechanisms guarantee that all transactions are validated and agreed upon by the network before being recorded, thereby providing confidence in the accuracy and reliability of the data. This process reduces the need for intermediaries, as participants can independently verify the authenticity of the data, reinforcing trust across the network (Siddik et al., 2021).

The practical applications of blockchain technology across various sectors demonstrate its capacity to enhance transparency, security, and trust. In the context of supply chain management, for instance, IBM's Food Trust blockchain platform facilitates the tracing of food products from the point of origin, namely the farm, to the point of consumption, namely the table. This application exemplifies the transparency and trust that blockchain technology can facilitate, as all parties, including suppliers, retailers, and consumers, have access to verified information about the origin and handling of products. The immutable nature of the blockchain ensures that this information remains accurate and tamper-proof, thereby reducing the risk of fraud and enhancing consumer trust (Gupta et al., 2020).

Similarly, in the field of trade finance, blockchain-based smart contracts are transforming the manner in which transactions are conducted. These smart contracts automatically execute actions when predefined conditions are met, thereby eliminating the necessity for intermediaries and reducing the potential for disputes. To illustrate, in Letter of Credit transactions, blockchain technology guarantees that payments are released only when all contractual conditions are satisfied, thus simplifying complex transactions and enhancing trust between international trading partners (UNECE, 2019).

In the energy sector, blockchain is being employed in trading platforms that facilitate direct consumer-to-consumer energy transactions via smart contracts, obviating the necessity for a central utility company. The technology guarantees the transparency, security, and immutability of transactions, thereby fostering trust among participants and supporting innovative business models that prioritize decentralization and peer-to-peer interactions (Hassan et al., 2019).

Furthermore, the potential of blockchain technology has been investigated in the rail sector with a view to enhancing transparency and operational efficiency. A study by (Tardivo and Sánchez, 2023) demonstrated how blockchain adoption in the rail industry could streamline processes and ensure secure, transparent records of operations and transactions. The study highlighted the technology's capacity to address existing inefficiencies in the sector by providing a reliable, tamper-proof ledger that all stakeholders can trust.

The broader implications of blockchain technology for the creation of transparent and secure contractual frameworks extend across various industries. In international trade, for example, blockchain can significantly reduce the complexity and costs associated with cross-border transactions by providing a single, immutable record of all transactions. This reduction in complexity also means less reliance on intermediaries, faster processing times, and better compliance with international regulations (Siddik et al., 2021).

Moreover, blockchain's capacity to automate and enforce contracts through smart contracts has the potential to transform the legal landscape. These smart contracts can autonomously execute, enforce, and verify the terms of a contract, obviating the necessity for human intervention. This not only enhances operational efficiency but also mitigates the likelihood of disputes, as the terms of the contract are enforced by code rather than interpreted by individuals (Mohanta et al., 2019).

In the context of data privacy and security, blockchain technology offers substantial advantages. The technology's foundation in cryptographic techniques guarantees the secure storage and sharing of data only with authorized parties, making it especially valuable in sectors such as healthcare and finance, where the protection of sensitive information is of paramount importance (Hassan et al., 2019).

In conclusion, blockchain technology, with its core principles of decentralisation, immutability, and consensus, provides a robust foundation for the creation of transparent and secure contractual systems. As evidenced by its implementation in diverse sectors, including supply chain management, trade finance, energy trading, and the rail industry, blockchain technology has the potential to transform the manner in which contracts are created and enforced. As the technology continues to evolve, its applications in the establishment of secure and transparent contractual frameworks are likely to expand, offering even greater benefits across a wide range of industries.

5.2.2 Blockchain Technology in Freight Transportation: Maritime, Air, Road and Rail

Blockchain technology, originally introduced as the backbone of cryptocurrency transactions, has evolved beyond its roots to find applications in various industries, including logistics and transportation. Freight transportation, which spans maritime, air, rail and road networks, has traditionally been plagued by inefficiencies, lack of transparency, and security risks. Blockchain offers a decentralised, transparent, and tamper-proof ledger system that has the potential to revolutionise these sectors by addressing these challenges.

Blockchain technology holds enormous potential for transforming freight transportation across the maritime, air, and road sectors by addressing inefficiencies, improving transparency, and enhancing security. In maritime shipping, blockchain platforms like TradeLens (Scott, 2018) are already reducing administrative costs and improving visibility in global supply chains. In air freight, blockchain-backed smart contracts and tracking solutions are enhancing both speed and security, while in road freight, blockchain is helping to tackle fragmentation and fraud. However, regulatory hurdles, technological limitations, and a lack of standardisation must be addressed before blockchain can achieve widespread adoption across the industry. As the technology matures, its integration into freight transportation promises to deliver substantial long-term benefits, reshaping how goods are moved globally.

This analysis explores how blockchain is reshaping freight transportation across maritime, air, and road modes, with a particular focus on its potential benefits, current implementations, and challenges that must be overcome. The application of blockchain to the railway freight transport is described in more detail in the following section.

5.2.2.1 Maritime Freight Transport

The maritime industry, responsible for moving approximately 80% of global trade, faces numerous challenges including long documentation processes, customs delays, and a lack of transparency in supply chains. These inefficiencies contribute to higher operational costs and make the system vulnerable to fraud, such as falsified shipping manifests or counterfeit goods.

Blockchain technology offers a solution by digitising and securing the flow of information. In traditional shipping, documentation such as bills of lading and shipping manifests are manually processed and stored in centralised databases, which can be prone to manipulation. By decentralising this information on a blockchain, stakeholders—including shippers, carriers, customs officials, and insurers—can access a single, immutable record of every transaction and movement within the supply chain.

IBM and Maersk's TradeLens (Scott, 2018), a blockchain-enabled shipping platform, is a prime example of how blockchain is being used to streamline the global supply chain by improving transparency and reducing administrative costs.

Blockchain, coupled with IoT devices, can also enable real-time tracking of cargo. In maritime shipping, where delays or misplacements of containers are common, the ability to trace shipments from the point of origin to the final destination offers significant operational benefits. With blockchain, data from IoT sensors tracking a ship's location, temperature of containers, and even cargo conditions are logged on an immutable ledger, accessible by all parties. This can help prevent fraud and improve response times to unexpected disruptions, such as rerouting in the case of weather anomalies.

The paper (Farah et al., 2024) investigates the impact of Maritime Blockchain on Supply Chain Management, offering a practical roadmap for the integration of blockchain technology into the Maritime Industry, presenting a comprehensive framework that maritime stakeholders can adopt to unlock the advantages of blockchain in their operations.

5.2.2.2 Air Freight Transport

Air freight is a key component of the logistics sector, known for the speed of its services, but it often faces challenges such as security concerns and complex documentation processes. These concerns arise due to the multiple touchpoints between airports, airlines, and freight forwarders, where documentation can be lost or tampered with. Blockchain technology can address these issues by providing a single, secure platform where all relevant documents are stored and accessed by approved parties.

For instance, blockchain can be used to streamline the process of clearing goods through customs. In traditional systems, documentation errors and inefficiencies often lead to delays and increased costs. By using a blockchain-based platform, customs officials can quickly verify the authenticity of shipping documents, reducing processing times.

The paper (Poleshkina, 2021) examines and summarizes the world practice of using blockchain technology to manage information and financial flows in air cargo.

Projects like SkyCell (SkyCell, 2024), which provide blockchain-backed air freight containers, are already implementing smart contracts to track shipments and ensure compliance with temperature and handling requirements.

Smart contracts, which execute automatically when pre-defined conditions are met, are another blockchain innovation transforming air freight (Freightwaves, 2024). These contracts can be used to automate payments and dispute resolutions between freight carriers and shippers. For example, if a shipment arrives late, a smart contract could automatically trigger a penalty or compensation without the need for human intervention. This reduces the time spent on manual contract management and ensures that all parties are held accountable. Through blockchain, the air freight industry can reduce the number of disputes and improve trust between stakeholders, enhancing efficiency across the board.

5.2.2.3 Road Freight Transport

The road freight industry is often fragmented, with numerous small players such as independent truck operators and local carriers contributing to the logistics chain. This fragmentation leads to communication breakdowns, data silos, and inefficiencies. Fraud, particularly around falsified delivery records or duplicated invoices, remains a prevalent issue in this sector.

The paper (Callefi et al., 2024) identifies a blockchain-enabled capabilities framework that enables an understanding of blockchain's role in road freight transportation operations.

Blockchain can act as a unifying layer by enabling data sharing across all stakeholders. For example, blockchain can ensure that delivery records are stored in an immutable ledger, visible to all relevant parties, thereby preventing disputes over delivery times or conditions. The French start-up "Chronotruck" is one such example of blockchain use in road freight, where it connects carriers and shippers on a transparent platform (Chronotruck, 2024).

In the traditional road freight system, a significant amount of time is spent on paperwork, such as invoices, proof of delivery, and contracts. By digitising these documents on a blockchain, administrative burdens are drastically reduced. Since the data is immutable and time-stamped, the chances of human error or intentional manipulation are minimised, streamlining the entire process. For smaller operators who might not have access to expensive logistics management systems, blockchain provides an affordable, scalable alternative.

5.2.2.4 Blockchain Technology and Smart Contracts in Rail Freight Transport

The rail freight transport sector is undergoing a digital transformation driven by the need for greater efficiency, transparency, and security in supply chain operations. At the forefront of this transformation are blockchain technology and smart contracts, which offer innovative solutions to the long-standing challenges in the industry. This chapter explores the specific applications of blockchain technology to rail freight transport, the benefits of using smart contracts, and real-world examples of their current utilisation.

Blockchain technology has the potential to transform rail freight transport by addressing critical issues related to data management, transparency, and trust among stakeholders. In the context of rail freight, blockchain can be utilised to develop a unified platform for tracking and managing shipments across different stages of transportation. This guarantees that all parties involved, including railway operators, logistics providers, and customers, have access to accurate, real-time information about the status of goods.

One particularly notable application of blockchain technology in the context of rail freight is the tracking and recording of cargo movements. Each instance of loading, moving, or unloading a shipment can be recorded on the blockchain. This results in the generation of a tamper-proof record that can be accessed by authorised stakeholders, thereby reducing the risk of discrepancies and delays. Furthermore, blockchain technology facilitates the integration of IoT devices, which can provide real-time updates on the condition of the cargo, including temperature and humidity levels. This is especially beneficial for the transportation of sensitive goods, where maintaining specific conditions is of paramount importance.

Furthermore, blockchain technology can facilitate greater transparency in rail freight operations by providing a unified source of truth for all transactions and data exchanges. This is particularly crucial in a sector where numerous parties, frequently with competing interests, must collaborate to guarantee the seamless transportation of goods. By documenting all transactions on a decentralised ledger, blockchain minimises the likelihood of disputes and guarantees that all parties are operating with the same information. This is exemplified in the UNECE's "White Paper on Blockchain in Trade Facilitation" (UNECE, 2020) which illustrates how blockchain can streamline intricate logistics processes by automating data sharing and reducing the necessity for intermediaries.

Smart contracts are a critical component of blockchain technology, offering a way to automate and enforce agreements between parties without the need for manual intervention. In the rail freight transport sector, smart contracts can provide several benefits, including automated execution of contracts, real-time tracking, and enhanced security.

The application of blockchain and smart contracts in rail freight transport is not merely theoretical; numerous pilot projects and implementations are already in progress. These initiatives are illustrating the practical advantages of these technologies and facilitating the wider adoption of such technologies within the industry.

One noteworthy example is the European Union's Horizon 2020 project, designated "B4CM (Blockchains for Condition Monitoring)" (BC4M, 2022). The project's objective is to utilise blockchain technology for the management and monitoring of rail infrastructure and rolling stock. The implementation of a blockchain-based testbed is intended to demonstrate the advantages of blockchain in attributing data costs across organisational boundaries and ensuring the accessibility of accurate and verifiable data for all stakeholders. Additionally, the project investigates the potential of smart contracts in automating data sharing and cost attribution processes, thereby reducing the likelihood of disputes and ensuring the fair compensation of all parties for their contributions.

Furthermore, reference (Tardivo and Sánchez, 2023) examined the potential benefits of blockchain technology in the railway industry. A review of the literature on blockchain applications in the sector was conducted, followed by an examination of its early applications in railways. Subsequently, areas in which this technology may offer benefits to freight, and passenger transport were identified. The areas of cross-border operations, logistics, data distribution, MaaS (Mobility as a Service), traffic management, signalling, and maintenance systems are of particular interest in terms of their overlap between academia and industry. Additionally, the paper suggested further examination of LCC (Life Cycle Cost) management, GHG (Greenhouse gases) production, MaaS functionalities, and sovereign digital identity as possible avenues for leveraging blockchain technology in this sector. Future research should adopt a cross-sectorial perspective to evaluate the feasibility of establishing an EU-wide blockchain platform.

5.2.3 How Blockchain can enhance processes in the Rail Freight Industry

Blockchain technology offers substantial potential for a radical transformation of the rail freight sector, through the mitigation of prevailing inefficiencies, the enhancement of operational transparency and the reinforcement of security across an array of operational procedures.

One of the principal advantages of blockchain technology in the context of rail freight is its capacity to facilitate enhanced asset tracking and visibility. Traditional systems frequently encounter challenges associated with fragmented data, which can lead to delays and inefficiencies. Blockchain's decentralised ledger enables real-time monitoring of railcars and cargo, guaranteeing that all stakeholders have access to accurate and up-to-date information. This can significantly minimise the probability of delays, misplacement of cargo, and operational congestion.

To illustrate, blockchain can be integrated with IoT devices to facilitate the monitoring of railcars in real time (Tardivo and Sánchez, 2023). The data collected from these sensors, encompassing variables such as temperature, humidity, and shock levels, can be stored on the blockchain, thus establishing a definitive, inviolable record. This ensures the safety of sensitive cargo and allows quick action if any problems, such as temperature fluctuations, are detected. The transparency afforded by blockchain helps to foster trust among the various stakeholders in the rail freight process, from shippers to customers.

Furthermore, blockchain offers a means of streamlining documentation processes, an area of critical importance within the context of rail freight, which is frequently characterised by inefficiencies (Astarita et al., 2019). Currently, there is a considerable reliance on paper-based documentation within the rail freight industry, which is prone to errors, delays, and instances of fraud. The utilisation of blockchain technology can facilitate the digitisation of such documents, which include bills of lading, customs declarations, and insurance certificates, into a secure and shared digital ledger, which is accessible to all relevant parties in an encrypted format.

This digitisation process not only reduces administrative overhead but also enhances the speed and reliability of document verification and approval. As an example, smart contracts, which are automated agreements that execute when certain conditions are met, can be utilised to enforce compliance and contractual obligations in real time; as a result, there is less likelihood of disputes and a reduced need for intermediaries, which streamlines the entire process and reduces costs.

The field of security represents another crucial domain where blockchain technology can exert a significant influence. The rail freight industry frequently handles high-value cargo, rendering it susceptible to theft and fraud. Blockchain's immutable ledger guarantees that once data is entered, it cannot be modified or erased without the consensus of the network, making it exceedingly difficult to alter. This strengthens the security of transactions and mitigates the risk of fraudulent activities (Feng Tian, 2017).

In the event of a dispute or loss of cargo, the blockchain provides an immutable record of the entire chain of custody, which can be used to resolve issues expeditiously and equitably. Furthermore, the distributed nature of blockchain mitigates the risk of cyber-attacks that could compromise sensitive data, as there is no single point of failure.

The capacity of blockchain to provide a unified, transparent source of truth has the potential to markedly enhance trust and collaboration among the diverse stakeholders in the rail freight industry. The industry is typically characterised by the involvement of multiple parties, including rail operators, freight forwarders, shippers, and customs authorities, each with its own set of interests and priorities. This absence of trust and transparency can give rise to disputes, inefficiencies, and delays.

The use of blockchain technology enables all stakeholders to access the same verified data, thereby reducing the probability of disagreements and fostering a collaborative environment (Wang et al., 2019). For instance, disputes concerning delivery times, payment terms, or cargo conditions can be promptly resolved by referencing the immutable records stored on the blockchain. This heightened transparency not only enhances operational efficiency but also fosters long-term trust and cooperation among partners.

The potential of blockchain technology in the rail freight industry is exemplified by its application in the rail sector, as evidenced by recent studies. The utilisation of blockchain can enhance the efficiency of cross-border rail operations by providing a transparent and secure platform for the tracking of cargo and the management of documentation. This not only improves operational efficiency but also ensures compliance with international regulations, thereby reducing delays and costs associated with cross-border trade.

Furthermore, blockchain technology can be employed to construct a more resilient rail freight network by enhancing the precision and dependability of data throughout the entirety of the supply chain. This can result in more effective route planning, superior asset utilisation and a diminished environmental impact, as logistics companies are able to optimise their operations based on real-time, reliable data.

Blockchain technology has the potential to significantly enhance processes in the rail freight industry. This is due to its ability to improve asset tracking, streamline documentation, enhance security, and foster collaboration among stakeholders. As the industry continues to evolve, the adoption of blockchain could lead to more efficient, transparent, and secure operations. This would pave the way for a more resilient and innovative rail freight sector.

5.3 SWOT analysis

UIRR organised a webinar using collective intelligence (in this case, design thinking) to understand the strengths, weaknesses, opportunities, and threats that could arise from using blockchain technology in managing contracts for intermodal freight transport. We enlisted the consulting firm D-Fine, whose department specialises in blockchain technology, to assist in coordinating and supporting our research efforts.

UIRR's role involved coordinating the platform's design, implementing its governance, and managing stakeholders and their requirements. Additionally, UIRR was responsible for developing standards, providing neutral administration, and offering operational support, particularly for handling disputes.

A self-assessment of blockchain knowledge, including smart contracts and self-sovereign identity, was conducted to ensure everyone was on the same page. Drawing on their experience, D-Fine presented a crash course to consortium members to further their understanding of blockchain technology, smart contracts, how they work, and how they have been used in industries somewhat different from logistics. This enabled the consortium to define key focus areas, requirements, use cases, actors involved in the transport chain, as well as challenges and pain points. This process facilitated the creation of new business models.

Thanks to the initial groundwork, we were able to engage a large number of stakeholders to define use cases potentially applicable to the intermodal transport sector. The consortium identified four different use cases, which were then discussed in a joint workshop.

The process unfolded as follows: D-Fine gathered initial ideas for use case proposals and conceptually began to develop the SWOT analysis from a technical perspective. This was followed by a brainstorming session using a collaborative mirror board, where the consortium split into discussion groups to exchange ideas on each use case. Later, the results of these discussions were presented when the consortium reconvened. This allowed the assembly to gather requirements for the various use cases, incorporating the perspectives of different actors in intermodal transport.

The four use cases are as follows:

5.3.1 Intermodal Booking Platform

Intermodal operators would share their services and pricing through a digital platform, making it easier to book transport services when different parts of the route are managed by various operators.

The creation of this platform involves developing a quick booking tool for intermodal transport, where operators share their routes and pricing to create seamless connections. Blockchain would enable secure and reliable interactions between operators without the need for formal contractual agreements. Smart contracts would automate bookings and agreements between operators, reducing the need for prior negotiations.

Currently, shippers cannot book intermodal services that involve operators without pre-existing agreements. A digital service provider would offer a platform for collaborative offers. At present, intermodal operators only collaborate after detailed individual negotiations. This platform would use internationally accepted standards, allowing negotiations directly on the platform with various actors.

The challenge lies in potential operational difficulties during transshipment, and the lack of contractual agreements, especially in the event of handling delays or missed connections, could pose problems.

Operators are hesitant to share their pricing with competitors. However, platforms using blockchain technology can offer confidentiality regarding pricing schemes.

The platform could help the sector become more resilient to delays and establish clear procedures for refunds and responsibility sharing.

Strengths:

The use of this platform would bring several benefits, including saving time for customers and streamlining document management. It would simplify the process of booking transport services and automate agreements between operators, reducing the need for lengthy pre-negotiations. This could help companies make better use of their resources and potentially lower transport costs for shippers by increasing transparency and encouraging competition among providers.

Operators could also reach new customers and markets. The platform would offer a central hub where transport providers are listed, making it easier to access a market overview and attract new clients.

In addition, it would enhance transparency and security, especially in the contractual process, which would contribute positively to the development of the rail and intermodal transport markets. Increased competition and improved service efficiency would result, with long-term contracts ensuring reliable service.

Weakness:

The platform relies on new technology that may not be widely adopted or fully understood by the key stakeholders involved. Early adoption could also be costly, with the risk of investing in the platform without knowing if it will succeed or provide real business value. Additionally, workers would need to be trained to use the new technology effectively.

At first, the platform would likely have a small customer base, competing with traditional booking platforms that are already well-established. There is also uncertainty around the business model, such as what percentage of earnings would need to be paid to the platform and how it would be funded.

Another weakness is that the platform might require stakeholders to share sensitive pricing information, which could lead to reduced profit margins on bookings made through it. Moreover, the risk of potential security breaches is a concern.

Opportunities:

The platform can simplify the process of setting up contracts by using a standardised framework. A transport optimiser that works across various routes and operators would minimise empty trips and find the best routes. This would also allow for last-minute bookings of available space and enable users to make ad-hoc bookings without needing to go through a formal tender process.

The platform would ensure secure exchange of documents and could lead to more sustainable practices by improving the use of resources.

It offers a chance to make combined transport options more attractive and could boost demand for intermodal transport by making it more reliable, efficient, and straightforward.

Additionally, it aligns with European Commission initiatives on transport digitalisation and data sharing, as well as the growing emphasis on decarbonising transport.

Finally, the platform could help drive the standardisation of practices in the industry.

Threats:

Negotiations can be challenging, especially if the predefined conditions are not suitable. Many parts of the transport chain, particularly road transport, have low or no digitalisation. This requires API connections with different Transport Management Systems (TMS). Ensuring that the platform works seamlessly with a wide range of existing systems can be difficult.

In some countries, multimodal rail transport has a very low market share, which can lead to limited acceptance of joint platforms among rail operators. There is also resistance to changing traditional processes and potential competition issues. A large number of participants must agree to use the system, and some stakeholders might be reluctant to shift customers from proprietary platforms to a multi-operator platform.

Additionally, there is a low level of reliability along the transportation chain due to issues not related to operators or shippers but to rail infrastructure managers, such as infrastructure work and rigid path reassignment procedures. Long-term contractual agreements will need to take this platform into account.

5.3.2 Document Sharing System

A number of problems exist, such as inconsistencies and communication issues caused by the different formats used in the transport system. There are also too many manual procedures, leading to errors that can cause delays or mistakes in document transmission. Additionally, many transport documents are still in paper format, meaning they can be lost, damaged, or forged. Finally, there is a lack of real-time visibility into the progress of transport, leading to uncertainties.

This business model aims to address these issues by providing a system that simplifies document exchanges for intermodal transport operations through the creation of a digital infrastructure where all actors in the transport chain can collaborate.

Strengths

This solution would avoid redundant administrative work because documents are generated and data is stored centrally. This allows for the flexible and easy creation of documents, and it makes it simple and cost-effective to introduce new documents.

The platform would ensure traceability of data and documents through version control and automates manual processes. It can generate documents in various standards using the data from the platform. Administrative costs would be reduced, and fewer repetitive and tedious tasks would be needed.

Weakness

Data security must be guaranteed. Handling confidential data can be challenging and requires additional measures to integrate the platform with other transport planning solutions. There also needs to be a strategy for dealing with unconfirmed or missing data.

Opportunities

Efficient transport operations would be enhanced with fewer and faster administrative processes. The platform allows for the creation of digital standard documents and its audit trail could make reconciliation processes unnecessary. It also promotes increased collaboration between intermodal companies.

There is an opportunity to integrate an accredited translation service into the platform, making data accessible to all actors in the chain. With fewer paper documents and a more digital, streamlined system, responding to new regulations would be easier.

Threats

Handling different languages could pose a challenge. There is also a dependence on a central platform operator, and participants might be unwilling to agree on common standards. Some stakeholders may lack trust and want to verify the data themselves. For the system to work effectively, everyone must agree to use it, and overall trust in the platform needs to be established.

5.3.3 Contracts for Traction Services

The intermodal sector faces issues of complexity and repetitiveness in negotiating contracts with lead Railway Undertakings (RUs), which can result in delays, misunderstandings, and unnecessary legal and administrative costs. Additionally, underutilisation of market capacity due to booking process problems is a challenge for the sector. The lack of transparency in transport execution leads to delays and disputes.

This use case aims to address these issues by creating a system that allows lead RUs to offer traction services more easily to intermodal operators. By automating contractual agreements—such as payments based on timestamps and proof of service provision—the platform would streamline procedures after initial negotiations, ensuring clear, efficient, and transparent agreements while reducing costs and legal risks. This approach would not only optimise services but also provide more precise monitoring of traction operations and improve their reliability.

Strengths

The platform would reduce administrative costs and streamline internal contractual processes across different business partners, leading to lower administrative costs in addition to improving transparency for all stakeholders involved.

Additionally, changing traction service providers would be easier, though finding a provider is not within the platform's scope. The platform would also allow for better comparability between offers, even though locating a traction service provider is outside its scope.

Weakness

Users of the platform would require digital training, which could lead to additional costs associated with implementing this new system. It may be difficult to identify all stakeholders in advance, and a wide variety of stakeholders could be involved. There could also be resistance from staff due to the changes in existing processes.

Opportunities

The platform would help establish standardised processes between RUs and intermodal operators, as well as harmonise the contractual framework for all involved parties. It will also expand the pool of potential suppliers, including those from other geographical regions.

Threats

There could be potential connectivity issues with different systems, and not all actors may be ready or open to adopting this innovation. Additionally, some lead Railway Undertakings may be reluctant to share transparency about their subcontracted RUs.

5.3.4 Subleasing of Wagons

Some problems may arise for an intermodal operator when it comes to lease or sublease a wagon. First, operators must enter into bilateral agreements and manually manage terms and conditions, which creates complexity and limits widespread practice. Tracking mileage often leads to discrepancies between actual use and recorded data. The question of regular maintenance of wagons requires complex coordination among the involved parties. Finally, invoicing and tracking extra fees might still be done manually, leading to potential errors.

The fourth use case aims to optimise the leasing and subleasing of wagons through a platform. This would provide a transparent contractual base and clarify the rights and duties of each party. It would also enhance wagon utilisation by speeding up the spot market, enable tracking of wagon usage and location, streamline maintenance management, and make maintenance records transparent and verifiable. Finally, the platform would automate payments and settlements based on wagon usage.

Strengths

The platform would reduce the need for direct communication between parties, making it easier to schedule necessary wagon maintenance and keep current wagon holders informed. This leads to optimised capacity, and if the wagon fleet is used more efficiently, the railway undertaking experiences minimal losses.

Weakness

Users of the platform would require digital training, which could bring additional costs for implementing the new system. It may be challenging to identify all stakeholders in advance, and many different parties might need to be involved. There could also be resistance from staff due to changes in established processes.

Opportunities

The platform would standardise processes between RUs and intermodal operators, ensuring a harmonised contractual framework for all parties involved. It would also expand the pool of potential suppliers, including those from other geographical regions, though it wouldn't function as a booking platform.

Threats

There could be connectivity issues with different systems, and not all participants may be ready or willing to adopt this new technology. Additionally, some lead RUs may not be open to sharing information about their subcontracted RUs.

5.3.5 Blockchain based platforms

There are platforms based on Blockchain technology that synchronise shipments. Two of the most significant examples are:

5.3.5.1 Certifydoc

Certifydoc (Certifydoc, 2024) is a tool that offers a Software as a Service solution (SaaS) for interoperability of critical data with legal notarization, blockchain tracing and intelligent document recognition.

Two open-source connectors send or receive the interoperable data using world standard universal language (JSON), ensuring operational and economic efficiency, risk mitigation and prevention, and regulatory compliance for sustainability and decarbonization programs. For the first time, interoperable data will be immediate, trusted, immutable, secure, notarized, traceable, standardized, public.

5.3.5.2 Usyncro

Usyncro (Usyncro, 2024) is an online platform that synchronize and automate processes securely with Blockchain and Artificial Intelligence. Usyncro uses a permissioned Blockchain that uses its network of computers (nodes) distributed worldwide, replicating the information that is generated in an automated way. In this way, the information is decentralized, more secure and traceable than with any other system. Any change in the nodes would affect the rest, thus leaving a record of activities and modifications on any shared information flow.

It uses AI and machine learning ensuring interaction on the platform. Its application allows decision making based on data, as well as the detection of anomalies in the incorporation of information from each record. It allows us to automate and optimize tasks through the identification and extraction of data from unstructured documents and the identification of tariff with an inaccurate description of the goods (with a 90% success rate).

5.4 Standards and Regulations necessary for the adoption of Blockchain and Smart Contracts in Intermodal Transport

Despite its advantages, blockchain technology faces significant regulatory and standardisation challenges in the freight transportation industry. Different countries and regions have varying regulations around data privacy and shipping practices, making it difficult to implement a universal blockchain system. Moreover, there is a lack of standardisation in blockchain platforms, which prevents seamless interoperability between different systems. For example, while Maersk's

TradeLens (Scott, 2018) operates in one part of the world, other shipping companies may use entirely different blockchain platforms, limiting the potential for widespread adoption.

It is important to recognise that significant technological advancements often require a period of standardisation, due to the necessity of adapting existing infrastructures and technologies for widespread implementation. In this context, the establishment of standardised protocols and regulations is crucial for the successful integration of innovative solutions such as blockchain and smart contracts within the intermodal transport sector. The value of these standards and regulations lies in their ability to facilitate interoperability, enhance security, and provide legal clarity.

It is of critical importance to implement standardised protocols in order to guarantee that the various systems and technologies employed in the intermodal transportation sector are able to operate in a seamless and integrated manner. This is of paramount importance given that the sector comprises a multitude of stakeholders, including shipping companies, rail operators, port authorities and customs agencies, who are required to share and access data across a plethora of platforms. In the absence of standardisation, each entity may utilise disparate formats, resulting in inefficiencies and communication barriers. The implementation of standardised data formats and communication protocols facilitates seamless data exchange and cross-platform integration, thereby fostering collaboration and enhancing overall efficiency within the transportation chain.

Some regulations have been published regarding data transfer in freight transport as well as different systems to merge into a harmonized framework for transport.

The Common Framework for Transport Logistics in Universal Business Language ISO/EIC 19845:2015 (ISO, 2015) sets out the specifications for the use of a universal set of XML based data as well as defining the different processes, documents and schemes for electronic commerce. This is a way of setting a baseline for the communication and messaging while using digital ways for commerce.

The implementation of this solution for the contractual layer has not been developed but it could be a good base for a future development of the web tool in which it could integrate the whole negotiation process and not only the documentation regarding the transportation.

The European commission, by adopting the EU 2020/1056 regulation (EUR-Lex, 2020), stablishes a legal framework for electronic communication of regulatory information between economic operators and competent authorities. In this regulation on electronic freight transport information, eFTI´s (electronic Freight Transport Information) database, platforms, service providers etc are defined by setting up the requirements. The development of this smart contract architecture by the use of MMT RDM is intended to be a base for the webtool to be able to work as an eFTI platform in a future development.

Although blockchain technology offers a high level of security due to its decentralised and immutable nature, the implementation of standardised security protocols is essential for the protection of sensitive data and the assurance of transaction integrity. The establishment of standards for data encryption, identity verification and access control serve to safeguard sensitive information from unauthorised access and cyber threats. The maintenance of consistent security measures provides assurance to all participants in the intermodal transport chain that their data is protected, thereby reducing the risk of potential vulnerabilities that could be exploited.

Both international standards and EU regulations address and regulate the adoption of blockchain, or more generally, Distributed Ledger Technologies (DLT), in various domains, including international trade and logistics. The most pertinent standards and regulations are discussed in the following sections.

There have been developments for even a deeper understanding of the transport like the TAF TSI (Telematics Applications for Freight Service TSI) (EU Agency for Railways, 2014), this interoperability regulation for rail freight transport developed by the European authorities has also implementations on traffic management and operational rules. This is a much deeper vision of the transport operation since it not only includes the availability but also marshalling yard operations like train preparation etc.

The web tool developed in the project is intended to be in a higher layer of the multimodal transport, but these kinds of regulations help define a greater grade of harmonization if implemented on future developments.

5.4.1 ISO/TC 307: Blockchain and Distributed Ledger Technologies

ISO/TC 307 (ISO, 2024a) is a technical committee within the International Organization for Standardization (ISO) that focuses on the standardization of Blockchain and DLT. This committee has published several relevant reports and standards aimed at ensuring interoperability, security, privacy, and robustness of DLT systems. The technical reports that have been produced by this committee provide information and data on the state of the art of the following areas:

- ISO/TR 3242:2022 - Use cases
- ISO/TR 6039:2023 - Identifiers of subjects and objects for the design of blockchain systems
- ISO/TR 6277:2024 - Data flow models for blockchain and DLT use cases
- ISO/TR 23244:2020 - and personally identifiable information protection considerations
- ISO/TR 23249:2022 - Overview of existing DLT systems for identity management
- ISO/TR 23455:2019 - Overview of and interactions between smart contracts in blockchain and DLT systems
- ISO/TR 23576:2020 - Security management of digital asset custodians
- ISO/TR 23644:2023 - Overview of trust anchors for DLT-based identity management

It should be noted, however, that they are used to share research, findings and knowledge, but do not establish formal requirements. In contrast, Technical Specifications focus on areas that are still under technical development or where a future consensus on an international standard is anticipated, although not immediately. They are generally more detailed and specific than a Technical Report and are published for immediate use and as a means of obtaining feedback. The ISO/TC 307 committee has thus far published the following Technical Specifications:

- ISO/TS 23258:2021 - Taxonomy and Ontology (ISO, 2021)
  It specifies a taxonomy and an ontology for blockchain and DLT. The taxonomy includes a taxonomy of concepts, a taxonomy of DLT systems and a taxonomy of application domains, purposes and economy activity sections for use cases. The ontology includes classes and attributes as well as relations between concepts (ISO, 2021).
- ISO/TS 23635:2022 - Guidelines for governance (ISO, 2022a)
  It addresses relevant issues such as decision-making rights, accountability and incentives, with an emphasis on the challenges of decentralized governance. Effective governance mechanisms, both inside and outside the ledger, are essential for resolving disputes, inspiring trust among stakeholders, and, therefore, ensuring the integrity of the system.

The objective of a technical specification is to eventually be transformed and republished as an international standard, which provides rules, guidelines, or characteristics for activities or their results. These are designed to achieve the optimum degree of order in a given context. In this regard, ISO/TC 307 has produced the following international standards.

- ISO 22739:2024 – Vocabulary (ISO, 2024b)
  It defines fundamental terminology for blockchain and DLT
- ISO 23257:2022 - Reference architecture (ISO, 2022b)
  Provides a reference architecture that comprises several key concepts and cross-cutting aspects. Key concepts include DLT and blockchain systems, networks and communications, DLT platforms, system interfaces, consensus mechanisms, event handling, the integrity of ledger content, subchains, sidechains, applications, solutions, smart contracts, transaction processes and various types of tokens and cryptocurrencies. Cross-cutting aspects cover security, identity, privacy, governance, management, interoperability and data flow. It also describes different architectural considerations including accounting technology, control and storage architecture, subletting and permissions, as well as architectural views from functional and user perspectives.

The work carried out by ISO/TC 307 is aimed at standardising DLT. However, this work also benefits the intermodal transport sector, as it improves the transparency, security and interoperability of data between different modes of transport and concerned parties.

5.4.2 UN/CEFACT

A narrowing of the focus to trade facilitation reveals that the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT) has developed guidelines with the objective of harmonising and standardising the use of blockchain technology in international trade and logistics. In this regard, the "Blockchain White Paper" (UNECE, 2019) represents the most pertinent publication to date, delineating the ways in which blockchain can enhance the efficiency, transparency, and reliability of supply chains by confronting pivotal challenges pertaining to the movement of goods, data, and capital.

The UN/CEFACT Blockchain White Paper examines the impact of blockchain technology and identifies potential new technical specifications that could enhance its value for trade facilitation and electronic business. While this document does not present any regulatory or standardisation proposals, the White Paper offers detailed recommendations to facilitate the adoption of blockchain and related technologies across diverse supply chain sectors, including maritime trade, road transport, agriculture and energy. It outlines the potential of blockchain to enhance data security, regulatory compliance and operational efficiency, while addressing challenges such as implementation complexities and privacy concerns. It is regarded as a key reference document for all parties interested in the technical applications and implementation of blockchain technologies.

Furthermore, as previously stated in (D1.1 ESEP4Freigth, 2024), UN/CEFACT has made significant contributions to the advancement of data exchange standards for essential documents accompanying goods in diverse modes of transportation. This has effectively addressed the fragmentation of digitalization efforts. To elaborate, UN/CEFACT has devised the Multi Modal Transport Reference Data Model (MMT RDM) (UNECE, 2018), which is founded upon the UN/CEFACT Core Component Library (CCL) (UNECE, 2024), an assemblage of data exchange necessities pertinent to international multimodal transport operations, encompassing trade, insurance, customs, and other regulatory documentation requirements. The library is designed to be extensible, allowing it to evolve in accordance with the specific requirements of a given sector. For example, a multitude of data elements pertaining to sensors have been incorporated to accommodate prospective IoT implementations, including smart containers and other IoT devices, which could significantly benefit the rail sector. This is particularly beneficial in terms of organising Business Information Entities (BIEs) and standardising their relationship with one another and with the real world. Furthermore, UN/CEFACT has introduced the concept of Data Pipelines, which establishes that data is delivered directly at its source on a single occasion, and then reused across the entire supply chain, regardless of the transport modes, stakeholders, or regulatory bodies involved. In another section where the smart contracts architecture is defined, the MMT RDM is used to establish relationships between BIEs across various exchanged documents. This is illustrated through a case example involving the transport of cargo across multiple modes of transportation.

5.4.3 IEEE

The Institute of Electrical and Electronics Engineers (IEEE) Computer Society Blockchain and Distributed Ledger Standards Committee plays a key role in the standardisation of blockchain and DLT for trade facilitation. They oversee the development of numerous standards that cover various aspects of blockchain systems and their applications across industries and have published two relevant standards. The first standard is IEEE 2418.2-2020, entitled "IEEE Standard for Data Format for Blockchain Systems" (IEEE, 2020). This standard defines data formats specific to blockchain systems, addressing their structure, classification, element format, type, and length. Moreover, the IEEE 2418.7-2021, entitled "IEEE Standard for the Use of Blockchain in Supply Chain Finance" (IEEE, 2021), sets forth guidelines for the deployment of blockchain technology in the context of supply chain finance. It defines a baseline architectural framework and functional roles. Moreover, a multitude of active standards projects are currently underway, including those pertaining to digital asset identification, blockchain interoperability, consensus frameworks, digital identity systems, and IoT applications. The committee's objective in establishing these standards is to promote interoperability, security, and reliability in blockchain-based systems, thereby facilitating their adoption and effectiveness in global trade processes. Their efforts contribute significantly to shaping the regulatory landscape and ensuring consistency and best practices in blockchain technology applications that would benefit the rail sector by facilitating trade and enhancing intermodal transport.

5.4.4 Others

The European Union takes an active role in the blockchain standards community, engaging and working closely with all relevant bodies around the world and in this section, some of the efforts made by the EU in this field are highlighted.

It is important to begin by noting that in Europe, regulations and standards are developed within a legal framework involving three organisations. The European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI) are the three organizations responsible for developing European standards. In this context, CEN and CENELEC established the Focus Group CEN-CLC/JTC 19, entitled "Blockchain and Distributed Ledger Technologies," in accordance with the recommendations set forth in the CEN-CENELEC White Paper. It adopts existing and developing international standards and collaborates with the aforementioned ISO/TC 307. Additionally, it addresses specific European legislative and policy requirements to support the EU Digital Single Market's development. The aforementioned White Paper is an open-source document that collects a set of recommendations for the successful adoption in Europe of emerging technical standards on DLT and blockchain (CEN/CENELEC, 2018).

Moreover, the European Parliament and the Council of the European Union published Regulation (EU) 2022/858 on Distributed Ledger Technology Market Infrastructures (European Commission, 2022) which establishes a pilot regime for regulating crypto-assets that qualify as financial instruments within the EU. The objective of this regulation is to enhance market efficiency and digital innovation. This regulation facilitates the trading of DLT financial instruments, thereby supporting the development of the EU Digital Single Market. It outlines the requirements for DLT market infrastructures, including permissions, exemptions, and operational guidelines, while maintaining investor protection and market integrity. In addition to the previously mentioned standards and initiatives that are mostly related to enhancing the adoption of DLT itself, the regulation is crucial for intermodal transport and the rail sector as it promotes seamless digital transactions, thereby reducing administrative burdens and enhancing transparency across the supply chain.

At a public level, the European Commission and the European Blockchain Partnership created the European Blockchain Services Infrastructure (EBSI) (European Commission, 2024a) to promote the use of Blockchain in public services allowing for new forms of verification, traceability and transparency for citizens. Although up to date this infrastructure has only been used for supporting the creation of cross-border services such as Education and Social Security, this is a major step in the adoption of Blockchain technology for document traceability, which is key to the reliability of intermodal transport operations.

At last, the European Commission has devised a rolling plan for ICT (information and communication technology) standardisation. This plan has been formulated as a result of the Commission's engagement in dialogue with a diverse array of interested stakeholders. The plan is subject to annual review and comprises a comprehensive inventory of potential areas where ICT standardisation could prove instrumental in advancing EU objectives. It also delineates the specific requirements and actions necessary to achieve that level of ICT standardisation. In greater detail, the plan includes a specific rolling plan for Blockchain and Distributed Digital Ledger Technologies (European Commission, 2024b), which reports on the objectives, progress and potential shifts in perspective with regard to policy and legislation. Furthermore, the plan enumerates the requested actions and activities carried out by all the organisations contributing to the standardisation of blockchain and DLT (ISO, IEEE, ETSI, CEN&CENELEC, UNECE, etc.). This rolling plan is an invaluable resource for keeping up to date with the standardisation and regulatory developments in this field.

As previously stated, some of the standardisation and regulatory efforts mentioned above do not directly influence the uptake of blockchain and smart contracts in intermodal transport at this time. However, they represent crucial and indispensable steps towards that objective.

5.4.5 Compliance requirements and challenges

All standards and standardisation actions must comply with a number of requirements and face a variety of challenges. It is therefore of the utmost importance to address these issues at the earliest possible stage in order to increase the impact and benefit of the efforts made. This section examines the pivotal challenges associated with regulatory adherence, data privacy, the legal recognition of smart contracts, standardisation efforts, interoperability issues and cross-border regulatory compliance.

Ensuring the privacy and security of data within blockchain systems necessitates adherence to the prevailing regulations that govern data protection laws on a global scale. The public nature of blockchain can render sensitive information susceptible to exploitation, a risk that is particularly acute in the freight sector, where companies share valuable data that they are keen to safeguard from dissemination in a network accessible to other companies. Key challenges include reconciling the transparency of blockchain with the imperative to protect personal data, as well as ensuring compliance with data subject rights, data minimisation principles, and secure data processing protocols.

Blockchain's decentralized nature presents challenges for data privacy, as personal information may be stored across multiple nodes. Legal frameworks like the General Data Protection Regulation (GDPR) must be considered to ensure compliance with data protection laws while using blockchain in rail freight transport.

Furthermore, the legal status of smart contracts is frequently misconstrued. It is imperative to recognise that smart contracts do not possess legal value. A distinct concept is that of the "smart legal contract," which refers to legal contracts in digital format. These and other similar misconceptions have significantly impeded the development of standards for smart contracts and the automation of contracts from a legal perspective. It should be noted, however, that in certain jurisdictions, smart contracts may already be regarded as legally valid, whereas in others they may require the involvement of additional legal contracts to validate them (Capocasale and Perboli, 2022). Consequently, although it remains an active area of research, it can be asserted that smart contracts have the potential to automate certain aspects of legal contracts. This transition is gradual and will continue to be so since integrating them effectively into legal frameworks involves a complex interplay between computer science and legal considerations.

The standardisation of contractual terms in smart contracts is a crucial step towards achieving clarity, enforceability and interoperability across different blockchain platforms. The challenges are diverse and include the need to accommodate several legal systems and specific industry requirements while maintaining flexibility for innovation. Furthermore, the data used by smart contracts to verify and execute themselves must be of the highest confidence; therefore, relying on oracles, as is commonly done, could be a potential source of manipulation. However, eliminating oracles is rarely possible, and thus the objective should be to use oracle services that rely on multiple data feeds (Capocasale and Perboli, 2022).

The term "interoperability" is used to describe the process of facilitating communication and data exchange between different platforms and existing IT systems that are used in the context of intermodal transportation. It is therefore evident that the implementation of standardised protocols and APIs (Application Programming Interfaces) is of paramount importance in order to overcome the challenges associated with the reconciliation of disparate consensus mechanisms, data formats and governance models that exist within the context of blockchain networks.

By addressing these compliance requirements and challenges, stakeholders in the intermodal transportation and trade sector can facilitate the adoption and integration of blockchain and smart contracts, thereby paving the way for enhanced efficiency, transparency and regulatory compliance in global supply chains.

6 Architecture definition

In this project, the use of blockchain and smart contracts will be demonstrated through a case study involving cargo transported via multiple modes of transport. Smart contracts will perform specific actions based on requests or real-world events as the cargo moves downstream in the supply chain. These contracts will also need to interact with the blockchain core to access detailed information about transport modes, required documents and their data elements, applicable regulations and standards, oracles, and more. Therefore, defining the architecture of the smart contract is crucial to ensure accurate programming later on.

In simple terms, this type of smart contract will first need to receive information from the above sources and declare the required initial variables. Depending on the final purpose of the smart contract, certain verification and control actions will take place and finally, after compliance verification and code finalisation, the smart contract can be finalised and the corresponding hash and block created and integrated into the chain. At this point, it should be noted that although smart contracts are usually associated with a blockchain network, if they are considered as a self-executing program that automates the required actions, they could also help facilitate the implementation of e-CMR. For this reason, the following simplified architecture presents e-CMR (Figure 2).

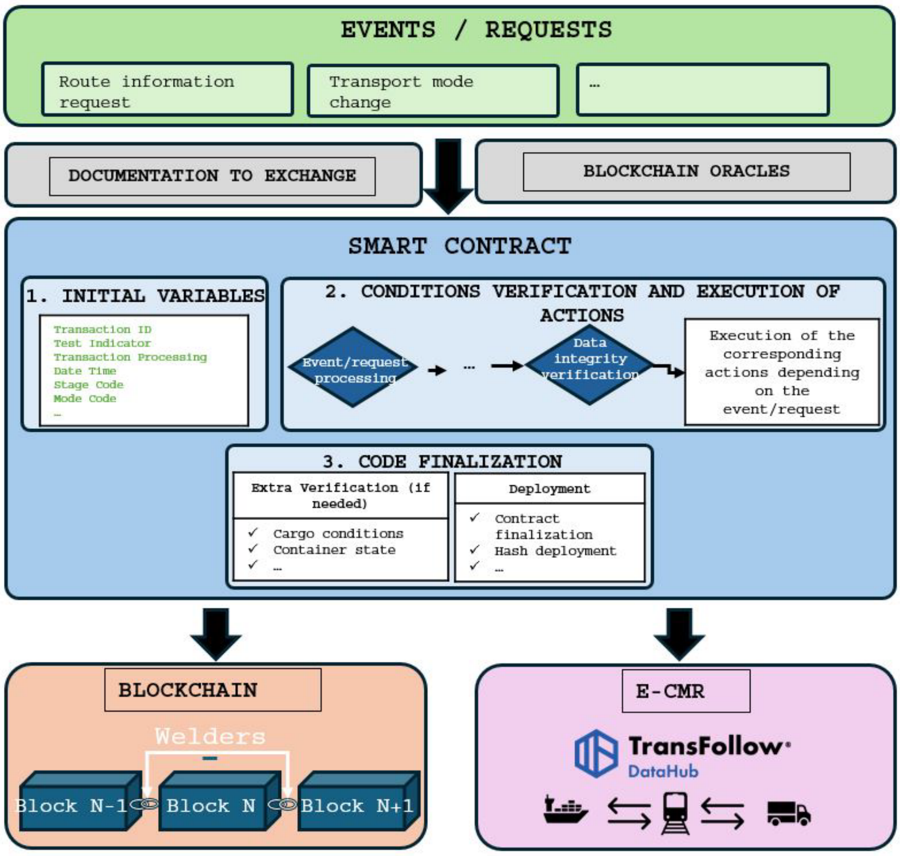


Figure 2 Smart Contract proposed architecture

To develop the specifications for smart contracts, a distinction is made between the so-called informative layer and the contractual layer.

6.1 Development of Smart Contracts Specifications

Given the evolution of transport, both in terms of volume and globalisation, many actors from many different origins need to interact with each other to complete a freight transport. This includes many border crossings and journeys through different countries with different governments and cultures with different requirements.

As noted in 5.1.5, various digital platforms are in use today. The problem with the lack of standardisation or a harmonised common framework is that many different solutions are offered on the market, forcing customers or other stakeholders to choose a particular solution which may not be useful if their network is very widespread and has many different providers with many different platforms.

This problem can be seen as the problem of railway signalling systems in Europe. If a train were to travel through many different countries, it would have to be equipped with each country's national signalling system.

This is why ERTMS was designed and ETCS was specified so that, with a common signalling system, the same train could travel throughout the EU with only one signalling system on board, bringing the concept of interoperability to a common ground of signalling requirements and functions across the interoperable lines.

For the transport of goods across modes, smart contracts require a common data model to harmonise the variables present in all relevant documents that need to be exchanged.

To enhance this kind of relation amongst actors, a more secure and paperless way is designed to improve multimodal transportation contract engagement. For this reason, another objective is to develop two sets of specifications for the implementation of smart contracts: one set for an informative layer and a second one for a contractual layer

As stated in (D1.1 ESEP4Freigth, 2024), the key areas to improve the performance of rail and its share of the transport market are rail automation and digitalization, which include the introduction of advanced innovations. To improve in this digitalization of the railway market the specifications for a smart contract and e-CMR solutions architecture have been defined. To define this architecture, extensive research was carried out between work package 1 for the upcoming innovations and work package 2 as a state of the art for the desired definition.

During this research it was found that there are some international bodies that already have some recommendation towards the harmonization of these kinds of solutions. This was taken on account to develop the framework for the specification of the smart contract architecture. The Multimodal transportation data reference model was used to have the less interfaces possible and adopting a common reference for the system´s variables.

The results for these recommendations and the definition of the new solution specifications will have a proof-of-concept design in future work packages to show how this solution could work and be merged into the web-tool. For this project, establishing a common ground is the main objective to have a common ground for smart contracts and e-CMRs.

The UN/CEFACT white papers have been used as a basis for the development of this tailored solution for multimodal transport. For the architecture and functionalities, the white paper on blockchain trade facilitation was the main source of inspiration.

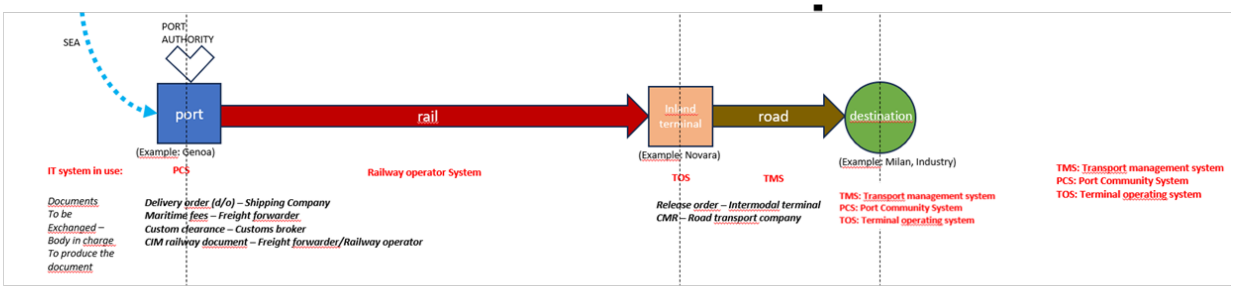
For the data dealt with in the contracts, a common reference framework is essential for this purpose, and the MMT RDM developed by UN/CEFACT effectively meets this need, as mentioned in the previous sections. It integrates the different transport modes (e.g. road, rail, sea, air) into a single reference model, ensuring that all parties involved in the transport chain can seamlessly share and interpret data. In doing so, it aligns variables across different transport documents, such as shipping manifests, bills of lading and delivery orders. The MMT RDM data elements are divided into 7 groups that address certain common terms:

- Exchanged Document Context
- Exchanged Document
- Exchanged Declaration
- Logistics Transport Movement
- Logistics Transport Equipment
- Transport Service
- Supply Chain Consignment

To illustrate the use of this data model, a case example has been created to show how documents involved in freight transport across different modes of transport adapt to this data model. This case example is shown in the figure below and consists of a shipment whose final destination is Milan. This information has been gathered from a real multi-modal transport case example handled by the consortium partner Grubber.

In this example we can observe a typical multimodal transport where the cargo arrives at the port by sea, is loaded onto a freight train and travels the last mile by road,

At each step of the supply chain in this example (Figure 3), the necessary documents to be exchanged and the information contained in these documents are indicated in order to find the variables within the MMT RDM to be included in each electronic document to be "exchanged".



Delivery order

Variables
Delivery Order
Container ID
Container Type
Container Seal
ETA
Codice Viaggio Terminal
Spttabile
Consegnare a
Polizza
Peso netto
Provenienza
Destinazione finale
Freight Description
Validitá Buono
Transporter

Maritime Fees

Variables
Sigla N./Targa
Freight Weight
Nave
ETA
A2-Data
PF cin-data
Date

CIM

Variables
Consignor
Consignee
Delivery Point
Commercial Specification
Destination station and country/Railway
Description of goods
Signs and remarks
Packaging
Goods
Nº of packages
Consignor's declarations
Cosignor's reference
Contract nº
Document attached by the consignor
Acceptance point
Wagon nº
Mass after transshipment
Exception consignment
Mass as given by the consignor
Mass determined by the railway
Declaration of value
Examination
Customs endorsements
NHM/GNG code
Route Code
Currency
Charged mass
Km/Zone
Container/conventional wagon
Contractual Carrier
Simplified transit procedure for rail
Code for the principal
Acknowlegment of receipt
Place and date completed

Release order/Bill of landing

Variables
Shipper
Consignee
Notify Party
Combined Transport
Port of Loading
Port of Discharge
Type of Movement
Destination
Booking No
Bill of Landing No
Forwarding Agent and References
Point and Country of Origin
Container No
Description of godos
Type of movement
Gross Weight
Date landen on board
Charges
Signature of the Carrier

CMR

Variables
Sender
Consignee
Destination
Origin
Container Nº
Marks and numbers
Nº of packages
Method of packing
Nature of goods
Statistic nº
Gross weight
Volume
Sender's instructions
Special agrement
Instruction as to payment carriage
Cash on delivery
Carrier
Succesive carriers
Carrier's reservations and observations
To be paid by
Goods received
Signature and stamp of sender
Signature and stamp of carrier

Figure 3 Real case example

In Figure 4 we can see an example of the MMT RDM, where we can see the variables that can be handled in a multimodal transport environment. In Appendix 1 MMT RDM variables assignment matching issued documents there is an equivalence between the model and the information seen in the previous figure, which is contained in the documents exchanged during the transport of goods.

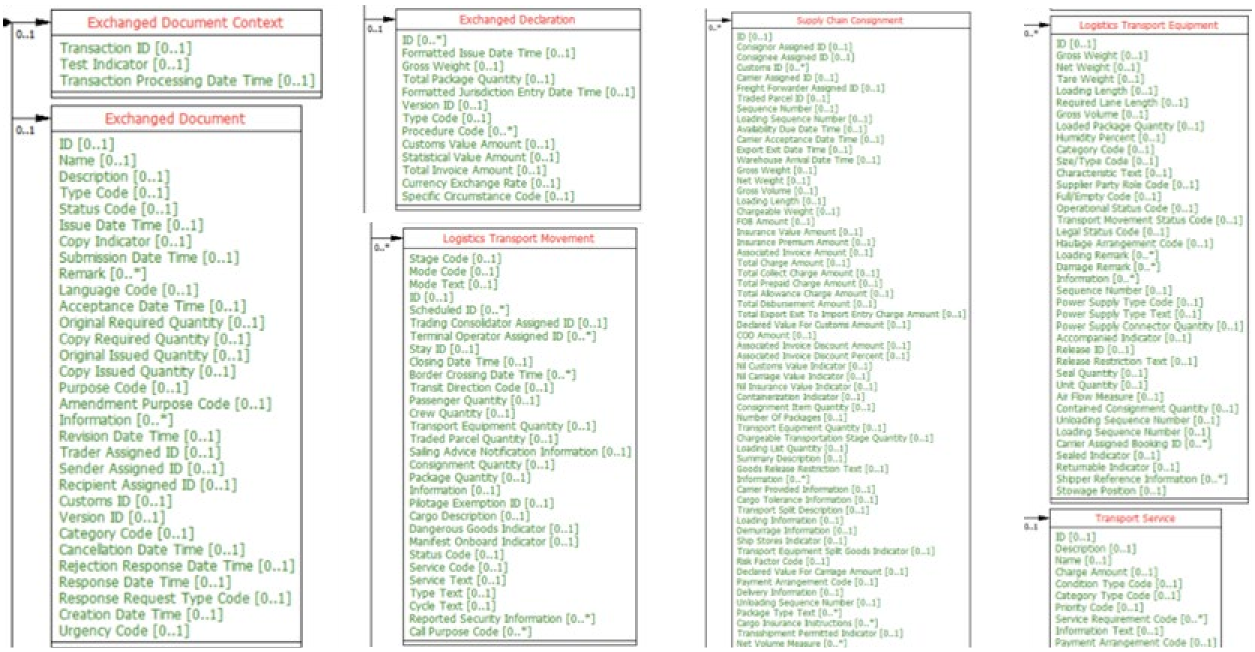


Figure 4 MMT RDM Data elements

At this point in the development of the specifications for smart contracts, a distinction is made between the so-called information layer and the contractual layer.

6.1.1 Informative Layer

The informative layer of smart contracts focuses on ensuring that all relevant data is exchanged transparently and efficiently between stakeholders involved in intermodal transport. This includes details such as shipment status, location updates, delivery schedules and regulatory compliance. The architecture of each layer is essentially the same, and it is the content of the requests, events, verifications and actions that really change the outcome of the smart contract.

Considering that the informative layer usually manages less sensitive data, fewer security measures than in the contractual layer could be implemented to reduce processing time and facilitate the execution of a larger number of transactions at the same time.

For the project, the informative layer will have a fixed itinerary extracted from a real case (Figure 5).

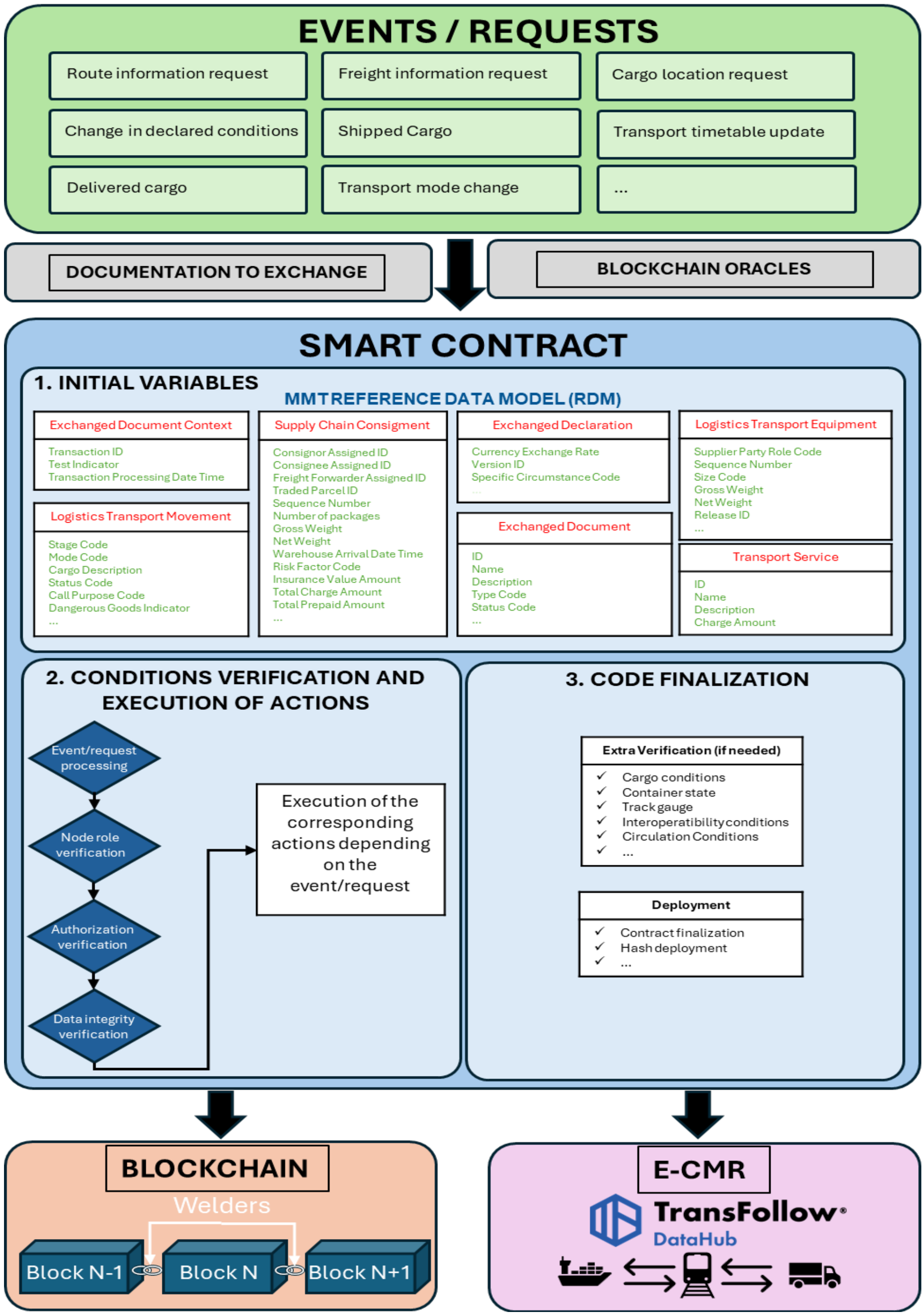


Figure 5 Informative Layer architecture

6.1.2 Contractual Layer

The contract layer deals with the automated execution and enforcement of agreements between parties using smart contracts. These contracts codify terms and conditions, such as payment triggers, delivery milestones and penalties for delays, into self-executing code on the blockchain. In this way, smart contracts can automate processes such as milestone verification and payment release, reducing administrative overhead and optimising the use of time. This automation is particularly beneficial in complex intermodal transport chains, where coordination between multiple stakeholders is required (Figure 6).

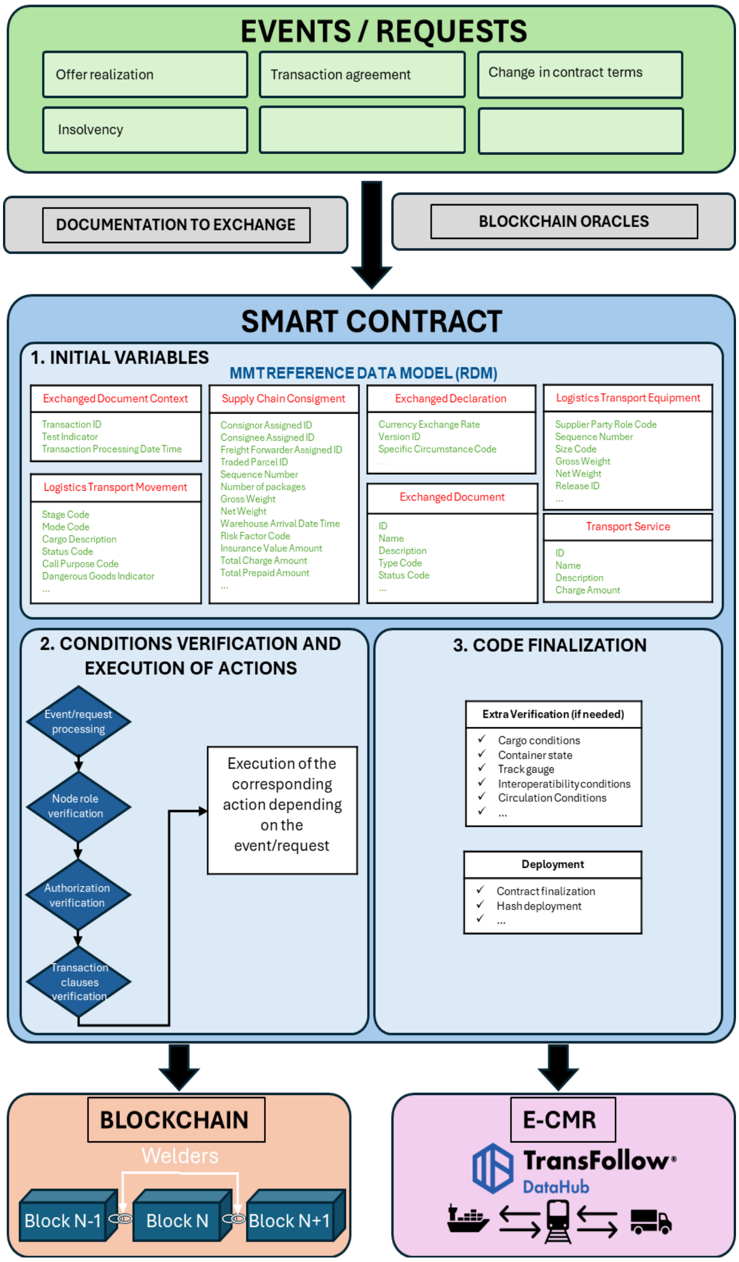


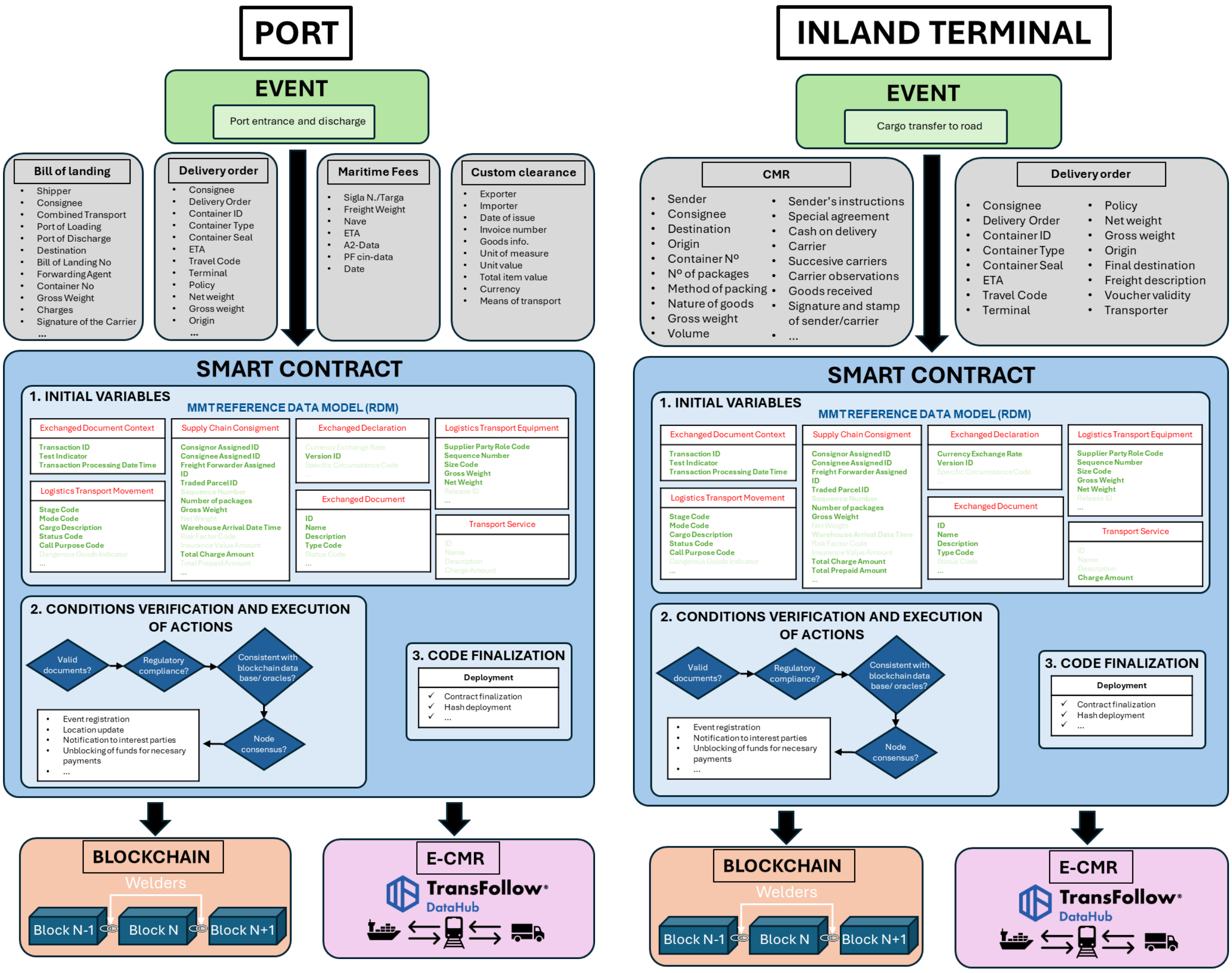
Figure 6 Contractual Layer architecture

6.1.3 Architecture specification of Different Events

For the sake of tailoring to multimodal transport and the documents that need to be issued at each step, the following figures show the different situations that can trigger an event in the smart contract and the information that will be added to it.

For each of the events shown in the proof of concept, a particularised view of how the architecture is defined is shown in the figures below.

We can see in Figure 7 the event that triggers the block writing and the documents generated in the information layer, as well as the variables handled in these specific steps.



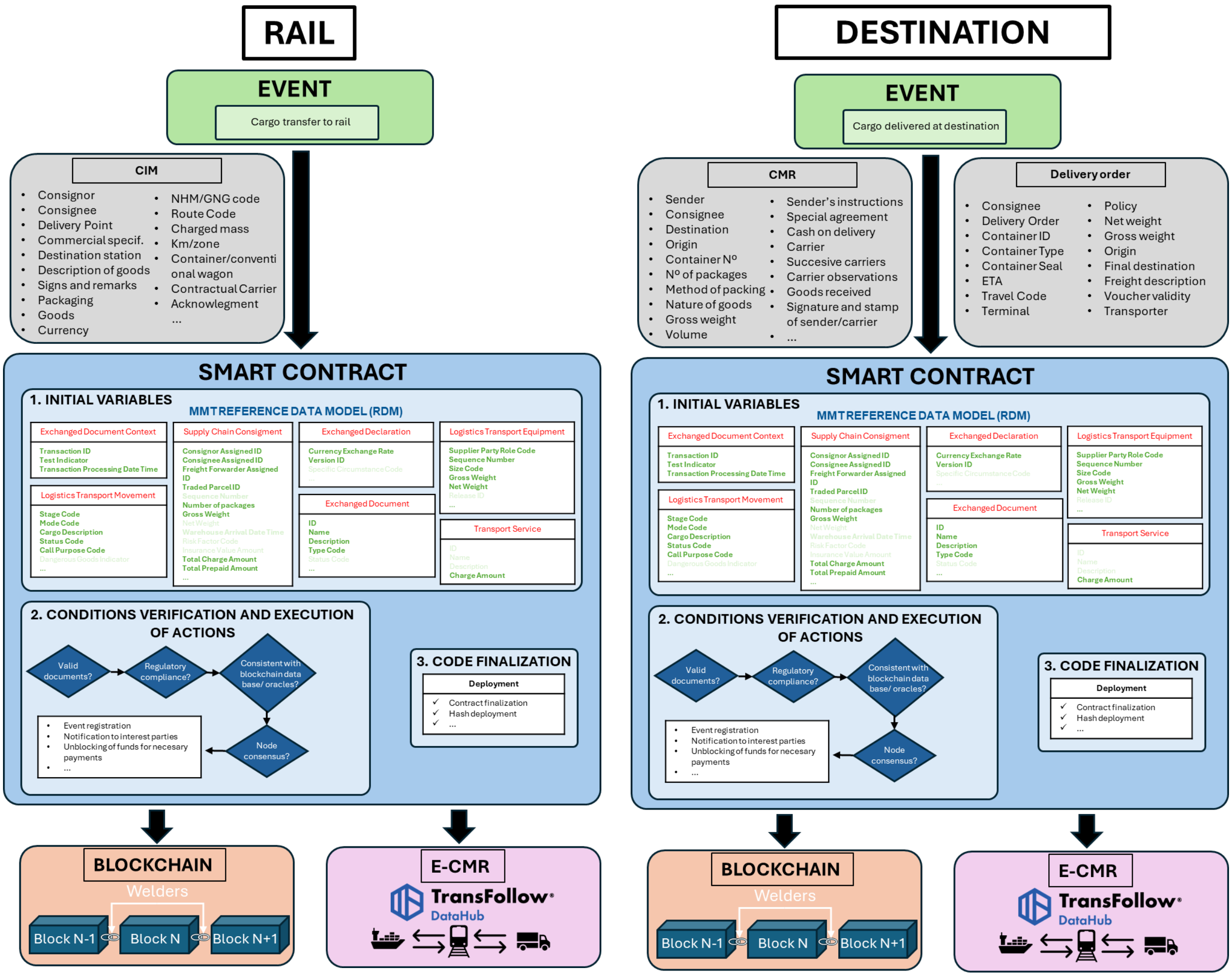


Figure 7 Different Events architecture example

6.2 e-CMR specific development

As seen in 5.1.5, the use of e-CMR solutions is already on the market and there are many different options for private development.

The aim of the project is to harmonise and improve the digital documentation associated with multimodal transport. Some of the aforementioned solutions are simply digital solutions for the Convention on the Contract for the International Carriage of Goods by Road (CMR) to suppress the paper handling and generation to save more time in transport, which is the main variable to look for in transport.

The objective of the e-CMR solution, as shown in the previous figures, is to have the information and documentation generated accessible from the web platform servers, which would serve as a common interface with any user to get access to any document needed when transporting goods.

This would eliminate the creation of an entire network, and the CO2 emissions associated with the creation of a block in each node of the blockchain network. In addition to this consequence, the loss of security associated with blockchain would make it easier to hack the system or access the platform.

As has been explained and demonstrated in the various sections on blockchain technology, this type of network increases security not only through the encryption of data, but also through the fact that the same event is registered in each node of the network, so that each node must be hacked in order to steal/add information to the system.

The nodes are not transparent to the encryption of the data, which means that although the information is written to your system, the process of accessing that information is limited to the network manager.

As mentioned in chapter 6.1.1, in order to meet the requirements of the project in terms of the objectives of the web platform, the informative layer of the smart contract should have an encryption that is visible to the platform owner, which makes it visible to the rest of the users.

This implies a certain level of regulation and trust between stakeholders. If this development is made by a private actor, it is likely that no other actor except their usual customers would feel comfortable using such a solution. This would give the network owner access to sensitive information on commercial and contractual agreements.

For this reason, the ownership of the web platform and the blockchain network that would result from the smart contract module should be handled by public authorities or a clear neutral organisation that guarantees confidential data between competitors.

This could also provide a certain level of transparency for the goods being transported, which could help authorities with some of the usual processes, such as border cargo control during customs inspections.

From the consortium's point of view, this ownership should be taken by the European Union authorities by integrating it into one of their neutral chamber of commerce organisations or by creating a dedicated working group to ensure the privacy of the solution.

6.3 Technical Framework and Architecture

This chapter includes the technical framework and architecture aspects to be considered.

6.3.1 Choice of Blockchain Platform

The choice of the appropriate blockchain platform is critical to the successful implementation of smart contracts in intermodal transport. The choice depends on factors such as security, scalability and the ability to support complex transactions.

- **Hyperledger Fabric** (Hyperledger, 2024a): Hyperledger Fabric is a permissioned blockchain framework designed for enterprise use. It features a modular architecture that enables customisation of components such as consensus algorithms and smart contracts. Fabric's separation of transaction processing into distinct phases ensures high performance and scalability, making it ideal for business applications that require security, privacy and control. As demonstrated in projects such as B4CM, Hyperledger Fabric offers flexible user roles and advanced privacy features, making it suitable for managing access to sensitive railway data. It enables the creation of private channels and the use of dynamic APIs, which are essential for secure data exchange.

- **Hyperledger Iroha** (Hyperledger, 2024b): Hyperledger Iroha is a simple, easy-to-integrate blockchain platform designed for building secure and reliable decentralised applications. It is particularly focused on providing a straightforward development experience with a user-friendly interface, making it accessible to developers, especially in mobile and web applications. Iroha is known for its emphasis on simplicity and minimalism in design.
- **Hyperledger Sawtooth** (Hyperledger, 2024c): Hyperledger Sawtooth is a modular blockchain platform that supports both permissioned and permissionless networks. It is known for its unique consensus algorithm, Proof of Elapsed Time (PoET), which is designed to be energy efficient and secure. Sawtooth's architecture allows for the separation of core blockchain functions from the application layer, providing flexibility and ease of development.
- **Ethereum** (Ethereum, 2024): Ethereum is a decentralised, open-source blockchain platform known for its smart contract functionality. Unlike bitcoin, which is primarily a cryptocurrency, Ethereum allows developers to create decentralised applications (dApps) using its native programming language, Solidity (Solidity, 2024). Ethereum's public blockchain and extensive developer community make it a popular choice for a wide range of applications, from financial services to gaming and beyond Ethereum. While Ethereum is popular for its smart contract capabilities, platforms such as Hyperledger are often preferred for industrial applications due to their permissioned nature and better privacy controls. However, Ethereum's widespread adoption and robust developer community can offer advantages in terms of ecosystem support and interoperability.
- **Polygon** (Polygon, 2024): Polygon is a powerful scaling solution designed to improve the performance and usability of Ethereum. By creating a network of sidechains that operate alongside the Ethereum mainnet, Polygon makes transactions faster and cheaper. This means that users can enjoy faster transaction times and significantly lower fees compared to the Ethereum mainnet alone. What makes Polygon particularly attractive to developers is its seamless compatibility with Ethereum. Projects built on Ethereum can be easily migrated to Polygon thanks to support for the Ethereum Virtual Machine (EVM). This compatibility allows developers to use familiar tools and frameworks without having to rewrite their existing code. Polygon offers various scaling solutions, including Proof of Stake sidechains and rollups, which provide flexibility depending on the specific needs of different applications. The platform also includes a set of developer tools and resources that make it easier to build and deploy high-performance, cost-effective distributed applications (dApps). In essence, Polygon is like an upgrade to Ethereum, making it more efficient and accessible while retaining the benefits of the Ethereum ecosystem. This helps

drive the growth of decentralised technologies and applications, ensuring a smoother and more affordable experience for users and developers alike.

In the B4CM project (BC4M, 2022), in its deliverable 1.1, there is a very good comparison between some of these different blockchain platforms, where the different platforms are compared across different features. This is very helpful in comparing and selecting the most appropriate platform for developing these types of solutions.

The aim of this project is to demonstrate the possibility of using this type of solution by creating a proof of concept within the development of a web platform. For this reason, since there are not many features that would be needed for this purpose, it is chosen to develop this proof of concept based on Solidity.

Solidity, a high-level programming language designed for the Ethereum blockchain, is specifically tailored to handle the complexities of smart contract development. It offers a rich set of features, including inheritance, libraries, and custom data types, allowing developers to build robust and scalable contracts.

In Solidity, you can define complex logic that governs how the contract works - who can interact with it, how data is managed, and what conditions trigger specific actions. For example, a contract could be responsible for automatically transferring ownership of a digital asset when certain conditions are met. The clarity and precision of Solidity's syntax makes it possible to encode these rules directly into the contract, ensuring that once deployed, it works exactly as intended.

For the specific solution, Polygon's Testnet was chosen due to the unique requirements of the project. As the platform aimed to provide a seamless and scalable user experience, it was crucial to ensure that the underlying blockchain infrastructure could handle a high volume of transactions without incurring prohibitive costs. While Ethereum is powerful, it is often associated with high transaction fees and slow transaction times, particularly during periods of network congestion. This led the development team to explore alternative solutions that could offer similar capabilities, but with greater efficiency.

Polygon, a Layer 2 scaling solution for Ethereum, quickly stood out. Its cost effectiveness was complemented by Polygon's faster transaction processing speeds, ensuring the platform could deliver real-time interactions and a smooth user experience.

In addition, Polygon's Testnet offered full compatibility with Ethereum's tools and infrastructure, allowing the team to use familiar development frameworks such as Solidity. This seamless integration meant that the smart contracts could be developed, tested and refined on Polygon's Testnet with minimal customisation, before being easily migrated to wherever they were needed.

For the future development of the proposed solution into a functional document handling and smart contract platform, a dedicated new network with many nodes is to be developed, which will probably change the chosen platform for the proof of concept, as a much more robust and complicated blockchain network should be created.

6.3.2 Data Structure and Storage

Efficient data management is crucial for the smooth operation of blockchain-based systems. The data structure must support the high volume of transactions and ensure quick retrieval and processing of information.

- **Data storage**: Blockchain platforms such as Hyperledger Fabric and Sawtooth enable secure storage of encrypted data. Implementations can include decentralised storage of transaction data, shipment details and compliance records, ensuring data integrity and security. Data storage solutions should also consider scalability, ensuring that the system can handle increasing amounts of data without compromising performance.

- **Data format**: Adopting standardised data models, such as the UN/CEFACT MMT RDM, ensures compatibility and ease of data integration across different systems and stakeholders. These standards help maintain a consistent data structure, which is critical for the interoperability of blockchain solutions in intermodal transport.

As the aim of the project is to develop a proof of concept in the web platform, most of the variables used for this purpose are fixed.

This makes data storage much easier as most of the interaction between the user and the platform for this module is fixed and the variables are pre-set to a fixed value extracted from the real case facilitated by the consortium partner.

Another feature for this module will be the selection of clauses from the Harmonised Contractual Framework, which is a bank of pre-defined clauses from which the user chooses which to implement in the smart contract.

6.3.3 Integration

Integrating blockchain technology with existing systems and processes is essential for its adoption in the intermodal transport sector. This involves connecting the IT systems of different stakeholders to the blockchain network, ensuring seamless data flow and interoperability.

- **APIs:** The development of robust APIs that facilitate communication between blockchain platforms and existing transport management systems is critical. Dynamic APIs, as seen in SMARTRAIL, enable real-time data exchange and improve system responsiveness. These APIs should be designed to handle different data formats and protocols used by different stakeholders.

- **IoT integration:** Projects such as B4CM demonstrate the importance of IoT integration, where sensors and monitoring devices collect and analyse data in real time. This data is then hashed and stored on the blockchain, providing a secure and transparent record of the condition and status of goods. IoT integration can significantly improve the accuracy and timeliness of data, leading to better decision-making and more efficient operations.

For this project, as mentioned above, the integration of the technology will be demonstrated through a proof of concept within the web platform.

This proof of concept will integrate the work developed in work package 2 into the functionalities of the platform. For this purpose, the analysis performed in deliverable 2.2 of the project will also be part of the proof of concept as a common arrangement among the selectable clauses that will be offered to the user for implementation in his smart contracts.

In addition to this, other functionalities such as the valuable transparency offered by the information layer on location, time spent, and other variables can be seen by following the different events shown in the proof of concept.

In order to fully implement the contract layer in a further development, it is important to emphasise the importance of negotiation in this type of transport business. Even if the information can be set in the web platform to optimise the route or to find the most suitable mode of transport, there is a need to negotiate the different terms of the contract before setting the contract.

For this purpose, blockchain networks offer the possibility of triggering certain events or even a hash within the network when the same conditions are met in two different nodes. In order to use the web platform as a complete system for what is intended, apart from the need to have real-time data, the smart contract module could trigger these clauses when both the provider and the client insert the same conditions for the different clauses of the contract, which means that the negotiation phase has been completed and there is an agreement on the numbers included in said clauses.

7 Technology Readiness Level

Blockchain is a well-proven and widely used technology with a TRL 9. It was first implemented in 2008 with the advent of Bitcoin, which began functioning as the inaugural Bitcoin protocol network at the start of 2009.

Despite its initial application as a security protocol to guarantee economic transactions, the advent of this novel payment system has prompted a shift in focus for blockchain technology. Rather than solely relying on its security and transparency features for economic transactions, the potential for blockchain to address a wider range of objectives has emerged.

The smart contract defined here begins at TRL 2, as we aim to leverage the blockchain's security features to guarantee security and privacy in the event of a goods transport. However, there is currently no established solution for a unified contractual framework.

As previously discussed, there are already digital platforms utilising this technology for transport, which have reached TRL 9 as they are currently in use in the market. However, there is a lack of a common framework and the need to adopt privately developed solutions.

These privately developed solutions are effective for large actors who have their own platforms for connecting with clients and providers. However, as previously mentioned, each company has a unique solution.

The objective is to advance these definitions and specifications to a TRL4 through the development of a proof of concept within the web platform. This will be validated by expert assessment with the input of the Stakeholders Group and integrated into the web platform as a lab test.

8 Conclusions

Multimodal transport, as a comprehensive transport system, is an effective organisational method that optimises transport structures, increases efficiency and minimises overall logistics costs. Multimodal transport documents are an essential part of multimodal transport operations, covering the entire process from the initiation of the shipment to the completion of the delivery of the cargo.

During the implementation of the project it was found that there are a number of problems that the industry or stakeholders involved in multimodal transport are trying to solve. Depending on the type of stakeholder, the problems are different and the solutions vary from one problem to another. Currently, there is no standard multimodal transport document, which results in additional time and costs for segment carriers involved in different modes to exchange documents. However, achieving data exchange for multimodal transport requires the involvement of multiple parties, including shippers, consignees, roads, railways, waterways, ports and more. Business collaboration involves the exchange of sensitive information, including key competitive strategies and contract terms, which can lead to a lack of mutual trust and difficulties in sharing information.

For this reason, this deliverable aimed to develop a conceptual framework and a potential architecture for multimodal transport using blockchain technologies and smart contracts.

After analysing the main characteristics, requirements, challenges and existing tools for smart contracts and blockchain implementations, a conceptual framework for both e-CMR and blockchains was proposed.

The proposed architecture includes an informative layer, which focuses on ensuring that all relevant data is exchanged transparently and efficiently between stakeholders involved in intermodal transport, including details such as shipment status, location updates, delivery schedules and regulatory compliance. A second layer, called the contractual layer, has also been specified, which deals with the automated execution and enforcement of agreements between parties using smart contracts. These contracts codify terms and conditions, such as payment triggers, delivery milestones and penalties for delays, into self-executing code on the blockchain. In this way, smart contracts can automate processes such as milestone verification and payment release, reducing administrative overhead and optimising the use of time. An analysis of the possible platforms to be used was also carried out, and the data structure was defined.

The results of this deliverable will then serve to provide the conceptual framework and potential architectural specifications of two possible smart contract implementations (e-CMR and Blockchain), both at the information and contractual layers, which will be the inputs for the module developed in WP3 and piloted in WP4.

The main limitation of this solution would be the implementation of the negotiation in the platform. The platform is conceived as a single window for customers to arrange this transport, which will have mandatory negotiation of the terms for the clauses. Although these clauses will have a common framework, the final details of the contracts will always be an agreement between the parties as an open market economy, which is difficult to implement for a single window where all competitors would have equal access.

As mentioned throughout the deliverable, blockchain offers opportunities to overcome these types of problems. This makes the proposed solution a very good one for multimodal transport.

If this solution is to be implemented in the future, a common platform with a harmonized contractual framework and a governance structure that is overseen by the public authorities would provide sufficient confidence to transport actors, allowing them to utilize this single window platform for their contractual arrangements. A robust blockchain network should be established for this purpose, with every node (clients and providers) connected. Additionally, the information layer of this network will provide visibility within the platform to track cargo at each transportation step.

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Appendix 1 MMT RDM variables assignment matching issued documents

Document	Data elements	MMT RDM equivalence
Delivery order	Delivery Order	Sequence Number
	Container ID	Carrier Assigned Booking ID
	Container Type	Size/Type Code
	Container Seal	Seal Quantity
	ETA	Formatted Issue Date Time
	Codice Viaggio Terminal	Terminal Consolidator Assigned ID
	Spttabile	Departure Date Time
	Consegnare a	Consignee Assigned ID
	Polizza	Cargo Insurance Instructions
	Peso netto	Net Weight
	Provenienza	Origin
	Destinazione finale	Final Destination
	Freight Description	Cargo Description
	Validitá Buono	Formatted Issue Date Time
	Transporter	Carrier Assigned ID
Maritime Fees	Sigla N./Targa	Power Supply Type Code
	Freight Weight	Gross Weight
	Nave	Shipper Assigned ID
	ETA	Formatted Issue Date Time
	A2-Data	Data information
	PF cin-data	Data information
	Date	Formatted Issue Date Time
CIM	Consignor	Consignor Assigned ID
	Consignee	Consignee Assigned ID
	Delivery Point	Delivery Information
	Commercial Specification	Description
	Destination station and country/Railway	Formatted Jurisdiction Entry Date Time
	Description of goods	Cargo Description
	Signs and remarks	Remark
	Packaging	Package Type Text
	Goods	Summary Description
	Nº of packages	Total Package Quantity
	Consignor's declarations	Cargo Description
	Cosignor's reference	Shipper Reference Information
	Contract nº	Carrier Assigned Booking ID
	Document attached by the consignor	Shipper Reference Information
	Acceptance point	Trading Consolidator Assigned ID
	Wagon nº	Transport Equipment Quantity
	Mass after transshipment	Gross Weight

	Exception consignment	Specific Circumstance Code
	Mass as given by the consignor	Gross Weight
	Mass determined by the railway	Gross Weight
	Declaration of value	Declared Value for Customs Amount
	Examination	Information
	Customs endorsements	Customs ID
	NHM/GNG code	Category Code
	Route Code	Procedure Code
	Currency	Currency Code
	Charged mass	Gross Weight
	Km/Zone	Zone
	Container/conventional wagon	Containerization Indicator
	Contractual Carrier	Carrier
	Simplified transit procedure for rail	Customs Procedure Code
	Code for the principal	Principal Code
	Acknowledgment of receipt	Remark
	Place and date completed	Formatted Issue Date Time
Bill of landing	Shipper	Sender Assigned ID
	Consignee	Recipient Assigned ID
	Notify Party	Consignee Assigned ID
	Combined Transport	Transport Movement Status Code
	Port of Loading	Trading Consolidator Assigned ID
	Port of Discharge	Trading Consolidator Assigned ID
	Type of Movement	Movement Type
	Destination	Final Destination
	Booking No	Carrier Assigned Booking ID
	Bill of Landing No	Carrier Assigned Booking ID
	Forwarding Agent and References	Freight Forwarder Assigned ID
	Point and Country of Origin	Origin
	Container No	Carrier Assigned Booking ID
	Description of godos	Cargo Description
	Type of movement	Movement Type
	Gross Weight	Gross Weight
	Date landen on board	Formatted Issue Date Time
	Charges	Charge Amount
	Signature of the Carrier	Carrier Signature
CMR	Sender	Sender Assigned ID
	Consignee	Consignee Assigned ID
	Destination	Final Destination
	Origin	Origin
	Container Nº	Carrier Assigned Booking ID
	Marks and numbers	Markings
	Nº of packages	Total Package Quantity
	Method of packing	Packing Method

	Nature of goods	Goods Nature
	Statistic nº	Statistical Number
	Gross weight	Gross Weight
	Volume	Gross Volume
	Sender's instructions	Sender Instructions
	Special agrement	Service Requirement Code
	Instruction as to payment carriage	Payment Arrangement Code
	Cash on delivery	COD Amount
	Carrier	Carrier Assigned ID
	Succesive carriers	Trading Consolidator Assigned ID
	Carrier's reservations and observations	Remark
	To be paid by	Payment Arrangement Code
	Goods received	Information
	Signature and stamp of sender	Sender Signature
	Signature and stamp of carrier	Carrier Signature
Custom clearance	Exporter	Trader Assigned ID
	Importer	Trader Assigned ID
	Date of issue	Formatted Issue Date Time
	Invoice number	Trader Assigned ID
	Goods info.	Information
	Unit of measure	Unit Quantity
	Unit value	Charge Amount
	Total item value	Associated Invoice Amount
	Currency	Currency Code
	Means of transport	Mode Text