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Supply Chain Management (SCM)

Postgraduate Dissertation

Blockchain applications in supply chain with emphasis on rail
freight transportation

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Patras, Greece, March 2025

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Blockchain applications in supply chain with emphasis on rail freight transportation

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To my beloved ones: Kyriaki, Dimitris and Eleni

Abstract

Supply chains have long ago passed the point of being just a repetitive and administrative set of activities bound to fulfil the needs of other departments within organizations and have often transformed themselves into a source of competitive and strategic advantage (or disadvantage). Moreover, their global reach has increased their complexity and vulnerability and as a result their effective management has proven its significance. Different technologies, systems, methods and processes are being tested in order to maximize their efficiency and minimize their costs.

One of the most promising and disruptive such technologies is blockchain, which is broadly known from its application of cryptocurrencies (bitcoin and the like). This technology offers certain distinctive advantages (both in terms of operations and in terms of the strategic objectives of a company), which thrive in multi-stakeholder and multi-transaction environments such as global supply chains and international trade in general. Although this technology has appeared in the last decade its wider adoption has not yet been accomplished.

This thesis explores the potential of this technology mainly within two very critical components of global supply chains, such as the sectors of logistics and transport. The land-based trade corridor between eastern Asia and Europe has been chosen as the background scene for this thesis due to the presence of extensive intermodal transport networks within it, which are based on railways. Ongoing or planned examples of blockchain use cases in these sectors are revealed through a literature review. In order to enable the reader, assess the dynamics of the application of blockchains into established trade routes a tailor-made theoretical framework is presented. Future research directions are also proposed.

P.S. It would be a great omission not to pay tribute to all of the people that have (directly or indirectly) played a role in this thesis with their sharing of knowledge and their inspirational guidance. To all of them and especially to my Professor Theodore Tsekeris, as well as to the organizers of this academic programme (Supply Chain Management of the Hellenic Open University) I owe a deep “thank you”.

Keywords

Blockchain; Logistics; Supply Chain; International trade; Intermodal, Railways.

Εφαρμογές (της τεχνολογίας) blockchain στην εφοδιαστική αλυσίδα με έμφαση στις σιδηροδρομικές εμπορευματικές μεταφορές

Ανδρέας Ηλιόπουλος

Περίληψη

Οι αλυσίδες εφοδιασμού έχουν προ πολλού ξεπεράσει το σημείο που αποτελούσαν απλώς ένα επαναλαμβανόμενο και διοικητικό σύνολο δραστηριοτήτων προορισμένες να ικανοποιούν τις ανάγκες άλλων τμημάτων των οργανισμών και έχουν συχνά μετατραπεί σε πηγή ανταγωνιστικού και στρατηγικού πλεονεκτήματος (ή μειονεκτήματος). Επιπλέον, η παγκόσμια εμβέλειά τους έχει αυξήσει την πολυπλοκότητα και την ευπάθειά τους, με αποτέλεσμα η αποτελεσματική διαχείρισή τους να έχει αποδειχτεί καθοριστικής σημασίας. Δοκιμάζονται διάφορες τεχνολογίες, συστήματα, μέθοδοι και διαδικασίες προκειμένου να μεγιστοποιηθεί η αποδοτικότητά τους και να ελαχιστοποιηθεί το κόστος τους.

Μία από τις πιο υποσχόμενες και ανατρεπτικές τέτοιες τεχνολογίες είναι η τεχνολογία blockchain, η οποία είναι ευρέως γνωστή από την εφαρμογή της στα κρυπτονομίσματα (bitcoin και παρεμφερή). Η τεχνολογία αυτή προσφέρει ορισμένα διακριτά πλεονεκτήματα (τόσο όσον αφορά τις λειτουργίες όσο και τους στρατηγικούς στόχους μιας εταιρείας), τα οποία ευδοκιμούν σε περιβάλλοντα με πολλούς εμπλεκόμενους φορείς και πολλές συναλλαγές, όπως οι παγκόσμιες αλυσίδες εφοδιασμού και το διεθνές εμπόριο γενικότερα. Αν και η τεχνολογία αυτή εμφανίστηκε την τελευταία δεκαετία, η ευρύτερη υιοθέτησή της δεν έχει ακόμη επιτευχθεί.

Η παρούσα εργασία διερευνά τις δυνατότητες αυτής της τεχνολογίας κυρίως σε δύο πολύ κρίσιμα «γρανάζια» των παγκόσμιων αλυσίδων εφοδιασμού, όπως είναι οι τομείς της εφοδιαστικής και των μεταφορών. Ο χερσαίος εμπορικός διάδρομος μεταξύ της ανατολικής Ασίας και της Ευρώπης επιλέχθηκε ως σκηνικό υπόβαθρο για την παρούσα εργασία λόγω της παρουσίας εκτεταμένων δικτύων συνδυασμένων μεταφορών σε αυτόν, τα οποία βασίζονται σε σιδηροδρόμους. Μέσα από τη βιβλιογραφική ανασκόπηση αποκαλύπτονται τρέχοντα ή υπό ανάπτυξη παραδείγματα περιπτώσεων χρήσης της τεχνολογίας blockchain σε αυτούς τους τομείς. Για να μπορέσει ο αναγνώστης, να αξιολογήσει τη δυναμική των εφαρμογών

blockchain σε καθιερωμένες εμπορικές διαδρομές, παρουσιάζεται ένα προσαρμοσμένο θεωρητικό πλαίσιο. Προτείνονται επίσης μελλοντικές ερευνητικές κατευθύνσεις.

Υ.Γ. Θα ήταν μεγάλη παράλειψη να μην αποδώσω φόρο τιμής σε όλους τους ανθρώπους που έπαιξαν (άμεσα ή έμμεσα) ρόλο στην εκπόνηση αυτής της εργασίας με την ανταλλαγή γνώσεων και την εμπνευσμένη καθοδήγησή τους. Σε όλους αυτούς και ιδίως στον καθηγητή μου κ. Θεόδωρο Τσέκερη, καθώς και στους διοργανωτές αυτού του ακαδημαϊκού προγράμματος (Διοίκηση Εφοδιαστικής Αλυσίδας του Ελληνικού Ανοικτού Πανεπιστημίου) οφείλω ένα βαθύ «ευχαριστώ».

Λέξεις – Κλειδιά

Blockchain; Logistics; Supply Chain; International trade; Intermodal, Railways.

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List of Abbreviations & Acronyms

3PL	3 rd (Third) Party Logistics
AI	Artificial Intelligence
ASCM	Association of Supply Chain Management
BRI	Belt and Road Initiative
BC	Blockchain
CIM	Uniform Rules concerning the Contract of International Carriage of Goods by Rail
DLT	Disributed Ledger Technology
EDI	Electronic Data Interchange
ESG	Environmental, Social and Governance
EHS	Environment, Health and Safety
EU	European Union
FIATA	International Federation of Freight Forwarders Association
ICC	International Chamber of Commerce
IoT	Internet of Things
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OSJD	Organisation for Cooperation between Railways
RFQ	Request for Quotation
SC	Supply Chain(s)
SCM	Supply Chain Management
SGMS	Agreement on International Freight Traffic by Rail
SWOT	Strengths, Weaknesses, Opportunities and Threats
TEU	Twenty-foot Equivalent Unit
UNCTAD	United Nations Conference on Trade And Development

1. Intro & Methodology

Modern global supply chains are characterized by increased complexity and vulnerability to external shocks (e.g. pandemics, trade wars). Existing geopolitical tensions add to the unpredictable environment where supply chains should perform. A comprehensive survey among supply chain professionals conducted by KPMG¹ in 2023 reveals a consensus among participants that if SC wish to overcome the issues arising from this new reality they need to move towards a new paradigm from the existing “lean” approach and develop a different set of features in the coming challenging years. This general conclusion seems to coincide with recent findings identified by scholars as to which will be the most pressing issues in the years to come around SCM. Concisely emerging trends for SC are sustainability all along (Shrivastava, 2023), constant adaptation to regulation (Bal, 2021), resilience (Holgado et al, 2023), transparency, visibility and trust-building, extensive digitization (Grzybowska, 2021 and almost all policy making position papers).

A very promising solution to most of the issues presented above comes from a relatively new technology: the blockchain. Although mostly made known to the world through its first use case of cryptocurrencies, the core features that this technology offers show a great potential not only to solve known and upcoming issues in to the domains of supply chain and logistics but also to transform fundamentally the way everyday business is done. And this potential is exactly the subject of the current thesis, which is conducted as part of the Masters in Supply Chain Management program, which is offered by the Hellenic Open University.

The current thesis aims to analyse and confirm the potential of this technology by examining blockchain-based pilot or commercial projects in areas or subareas of the above fields. The focus shall be primarily given to applications of the blockchain in intermodal transport and particularly where railway is conducting the majority of the transit. For this the East – West route (Asia to Europe) shall be used as a reference. A mix of literature review and field data is used during the analysis and the presentation of the results. Therefore, this thesis is structured as follows:

¹ <https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2023/09/kpmg-future-of-supply-chain-report.pdf>

Chapter 2 looks into the current state of international freight markets and the mega-trends that influence them with a focus on figures concerning the volume of trade on the selected routes. Chapter 3 presents the peculiarities of rail freight since this medium plays a crucial role in land-based transport for the abovementioned routes. Chapter 4 then explains briefly the challenges and issues of the SC / logistics sector in these corridors and in particular when more than one means of transport are concerned (intermodal). In chapter 5 the promising new technology of blockchain is presented. Its basic concepts and expected benefits for the supply chains are explained with the help of a critical literature review as well as its interfaces with other emerging or promising technologies bound to change the supply chains. Primarily the main focus remains whether it can address the issues identified in chapter 4. In the following chapter 6 some real-life blockchain-based projects from other industries are presented in order to confirm (or not) whether this technology has the potential to deliver tangible results to the Eurasia railway freight markets. Finally in chapter 7 an assessment framework is presented, which shall serve as a means to evaluate the expected benefits that the adoption of this technology can bring to the SC under discussion.

In terms of methodology the following elements and limitations should be mentioned: The thesis is a hybrid of secondary literature review and qualitative analysis conducted with the help of data gathered through various sources. There is a deliberate bias towards most recent research (especially in the subject of blockchain integration in SC) as the intention is to capture and use the most recent research developments in the field. The quality and validity of some statistical data has not been verified in an independent way; especially for the data that do not come from well-known and/or established bodies. This choice has been made due to the difficulty of data collection in the geography / sector (not following the same norms as in the west) and in order to keep the richness of sources. The focus here is more shifted towards “capturing the trend” rather than presenting a “single point of truth”. Therefore, a basic assumption is that whichever data have been selected from the research papers of other researchers have been already validated by their original authors.

Despite all methodological limitations the basic conclusion remains that blockchain is indeed a transformative and disruptive technology for the SC and has a lot of benefits to offer under the condition that it is properly implemented.

2. International freight market: From east to the west

2.1. Global trade

Let's begin with a rather absurd self-reflection: is trade among nations important? And what about nations that are not simply adjacent one to another but rather thousands of kilometres away (as is the case with the two modern trade power horses China world's factory and Europe or even more USA the two biggest trading partners in the West)?

International trade has its roots in antiquity. It is the process of exchanging goods or/and services between at least two different countries, which have a comparative advantage over the production of the exchanged goods². It is a central concept within the science of economics and it has been proven throughout centuries that international trade makes societies better off benefiting even those countries with an absolute production advantage.

The numbers speak for themselves. According to statistics published by the UNCTAD³ the total value of the international trade for 2023 has been estimated to approach a whopping 31 trillion US dollars in value, absorbing and adjusted to all trend shifts following both the covid19 pandemic and the slowing global demand for goods that has been recently observed. The share of services in this figure is around 24% leaving the rest to material goods that need to be physically exchanged. China, USA and EU remain the 3 most important trading "pillars" of the world, something which is consistent with their status as the 3 biggest economies in the world. What is also interesting to observe is the flows of goods to be traded.

² <https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/Trade>

³ United Nations Conference on Trade and Development (https://unctad.org/system/files/official-document/ditctab2024d1_en.pdf)

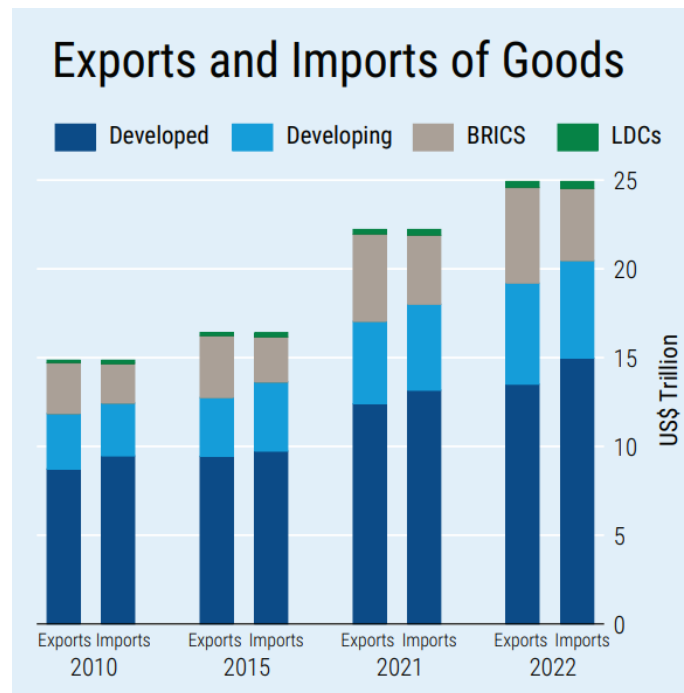


Figure 2.1-1: Value of global trade between basic trading partners (source:UN)

From the Figure 2.1-1 above we can observe that the importance of the BRICS countries (Brazil, Russia, India, China, Saudi Arabia) in the world trade follows an increasing trend shaping the corresponding trade flows. In a “free translation” this means that the share of the specific countries in world trade increases and will therefore provide an increasing demand for transportation services for their goods. This trend is also reflected in the projections for world trade (Figure 2.1-2), which point to a moderate growth of around 3% for the coming years picking up from issues faced during the last 2-3 years (supply chain issues, economic slowdown, etc).

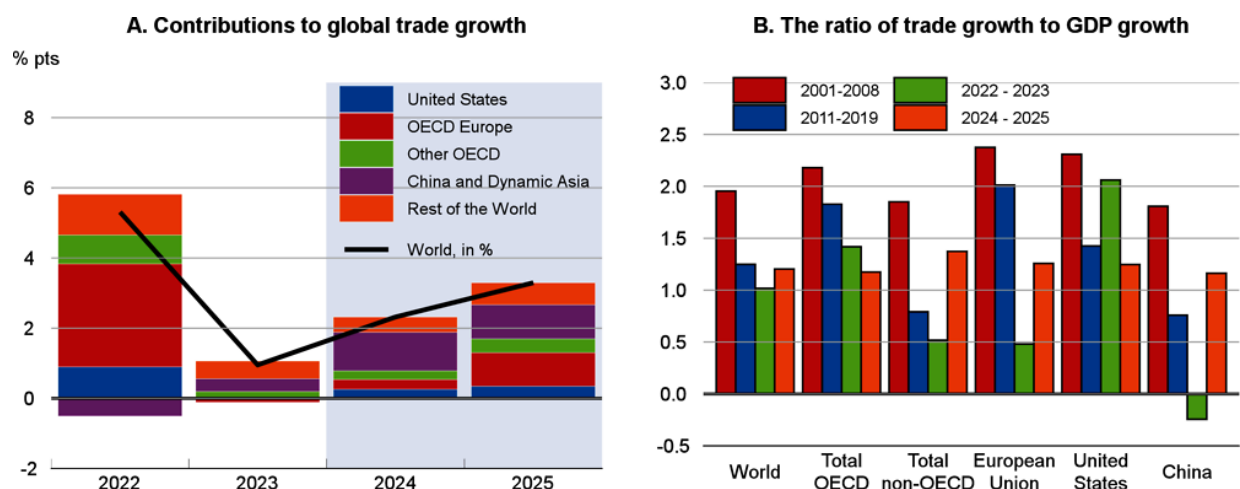


Figure 2.1-2: Projections of global trade growth (Source: OECD Global Economic Outlook 2024)

2.2. How is global trade facilitated (Supply chains and Logistics)

International trade is driven by globally organized supply chains. From the examination of the figures presented earlier it is clear that there is a solid demand for the transportation of goods (and services) between several geographies in order for the supply chains to perform their function. Some pairs of these geographies (origin and destination) can be classified as “major” due to the sheer volume or importance of the goods traded without downplaying the significance of the “secondary” ones.

But apart from the importance of any given trade route or perfection of any supply chain two elements need to be absolutely in place and coordinate with each other in order to realize any transport of goods: the transportation medium and its supporting services; all collectively known as logistics. Apart from transportation logistics also include services such as warehousing, freight forwarding, delivery, packaging, legal and customs clearing and financial transacting (Lummus et al, 2001). According to the specialized firm Statista⁴ the value of the global combined logistics market is bound to rise up to a value of 13.7bn USD in 2027. This is the market where the specialized freight transportation companies compete and operate. The basic means of freight transport are by sea (shipping), air (cargo airplanes), rail (rail freight) and road (trucks). Typically, a combination of means of transport need to be used for any given cargo to reach its final destination realizing what is known as intermodal trade. It has to be mentioned that another popular way of measuring the volume of trade is by TEU (twenty-foot equivalent unit), which is particularly applicable in goods being in standardized containers

2.3. Intermodal vs Multimodal trade⁵

As mentioned, intermodal trade is the combination of different modes of transport (at least 2) in order to deliver a cargo to its final destination. This way of conducting trade of goods has been greatly enhanced by the prevalence of the standardized containers which enables the goods to stay at all times inside the container regardless of the means that carries them. The most common combinations of modes include ships & trains or

⁴ <https://www.statista.com/topics/5691/logistics-industry-worldwide/#topicOverview>

⁵ <https://www.investopedia.com/terms/i/intermodal-freight.asp>

trains & road trucks. A term that is equally present in everyday practice is multimodal trade. This way of transferring goods is slightly different from the intermodal train but uses the same basic principle of using multiple modes of transport. In multimodal trade the whole transport process is covered by a single contract and the responsibility lies with a single carrier all along; in contrast intermodal trade can implicate several contracts and carriers. Within the context of this thesis this differentiation will not be used and the term intermodal trade shall focus on the utilization of different means of transport regardless of the contractual status of them.

2.4. EU as a trading partner

For the economic bloc of the EU the four major trading partners are USA, UK, China and Switzerland according to a bulletin⁶ published by Eurostat, the European statistics service. However, if we combine other Asian countries (see Figure 2.4-1), we can observe that this geographic region comes second in terms of value in traded goods thus creating a solid trade route from the east towards the west. These goods are imported to / exported from Europe by all principal means.

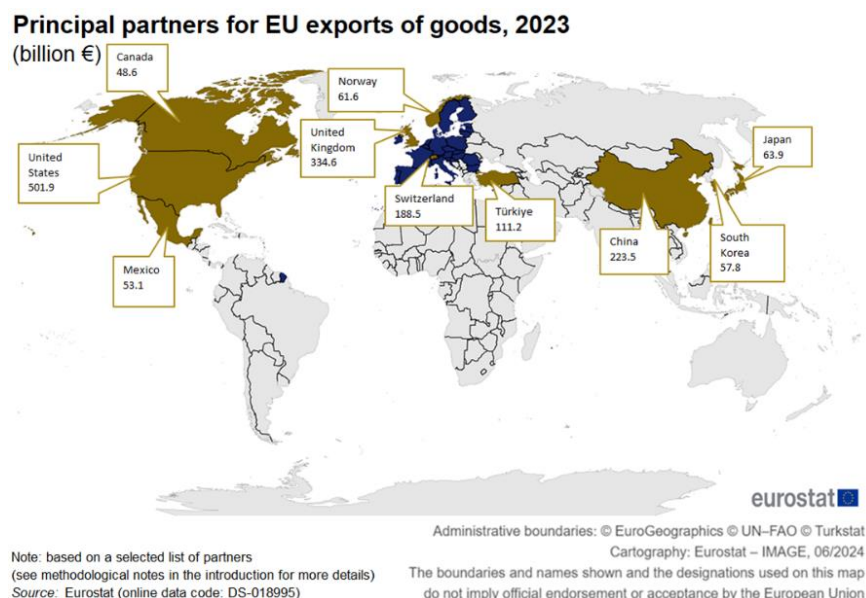


Figure 2.4-1: Principal partners of EU trade for 2023 (Source: Eurostat)

⁶ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Principal_partners_for_EU_exports_of_goods,_2023.png

The next chapter will focus on the railway as a means of transport but in order to get an understanding of the volume of the business it is worth observing the relevant contribution of each means of transport for the east-to-west route in the following Figure 2.4-2 (east: China and other countries in Asia, west: EU countries).

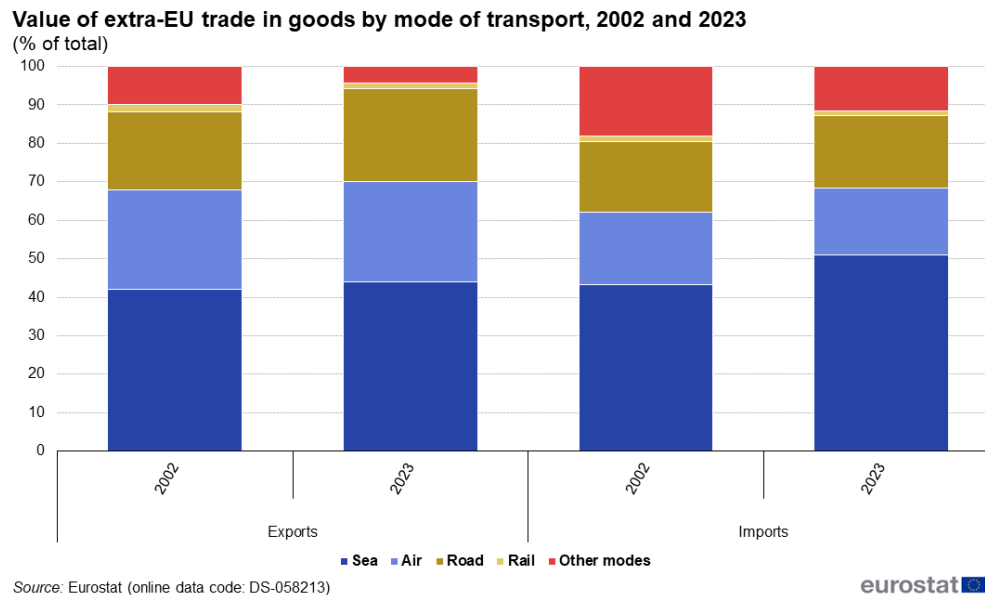


Figure 2.4-2: Comparative value of extra-EU trade by means of transport (source: Eurostat)

It is easily observable that seaborne trade accounts for almost half the incoming trade in EU something that can be easily understood due to the economies of scale that this means of transport offers. Rail freight has remained relatively unchanged during the last 20 years, which has its explanations.

2.5. The BRI initiative

The east-west trading route is not at all new. With the emergence of China as the “world’s factory” in the last couple of decades the ancient “Silk Road” has seen a revival albeit in a different context. Better known nowadays as the “Belt and Road Initiative (BRI)” or earlier as “One Belt One Road (OBOR)” it consists of a series of investments (principally funded by Chinese banks) in infrastructure projects (maritime or land) in order to reduce shipment times and costs, increase the reliability of the deliveries and enable or facilitate the connectivity of countries, people and policies in

the regions covered by this initiative (Schramm et al, 2018). This set of policies, which was announced in 2013, is backed politically by a strong vision of growth via trade and economic development, which embraces many developing or even developed countries. Some researchers claim that it also serves long-term diplomatic objectives of China (Jakobowski et al, 2018). The invested funds in the various projects within this initiative has already surpassed 1 trillion USD⁷ with a target of up to 8 trillion (Genovese, 2023) up to 2049 (the total investment target has not been possible to be confirmed by multiple sources or through official documents). The direct result of this initiative is that new routes have been developed (or are under development or/and under modernisation) and the significance of 3PL companies has increased reshaping the way that trade flows from east to west (Wang et al, 2024).

The BRI mainly focuses on the so called “middle corridor” which is seen as an alternative to the established northern route (via the Russian Federation) and has been gaining in importance for geopolitical reasons as well. More details on the dynamics of each route are presented in paragraph 3.2.



Figure 2.5-1: Major trade corridors from the east to the west (source: World Bank)

The Figure 2.5-1 above shows the main East – West trade corridors, which exist nowadays.

⁷ <https://www.weforum.org/agenda/2023/11/china-belt-road-initiative-trade-bri-silk-road/>

2.6. Future trends impacting international trade and supply chains

International trade has been deeply impacted by a certain number of factors during each historical era that define the goods in demand, its way of being conducted and all the policies, systems, equipment and processes which are devised in order to conduct it. These are the same factors that shape the supply chains in each era as well. According to various industry sources⁸ (KPMG, UN, EU) as well as academic researchers (Shrivastava, 2023, Horn, 2004 and Panova et al, 2017) the major trends that are already impacting the future of global supply chains and consequently international trade are the following:

- Extensive digitalization at all levels: under the influence of disruptive new technologies (i.e. artificial intelligence, robotics, blockchain, IoT, etc) quite similar to what is known as “industry 4.0”
- Resiliency: the big shocks after the covid19 period have revealed the vulnerabilities of supply chains so they need to become more resilient
- Sustainability: whichever evolution has to lead to more sustainable SC models which are more environmentally friendly
- Intermodalism: freight policy makers encourage the optimum use of the transport system as a whole and this is not possible without promoting intermodal transport
- Compliance: new regulations always impact trade and SCs (e.g. climate protection, decarbonization, accounting transparency, trade agreements etc)
- Transparency: new business norms like ESG are less tolerant towards hideous or unethical practices
- Strategic sourcing: this trend has already begun classifying some resources or suppliers as strategic thus requiring an adaptation of business models and supply chains. Some call this trend as “de-risking”
- Cost control: rising costs and inflationary pressures require new ways in order to keep costs under control

⁸ <https://kpmg.com/us/en/articles/2024/supply-chain-trends-2024.html>

- Geopolitics: free trade rules may not continue to be the basic assumption of global trade and protective measures or restrictions may impact established supply chain structures

3. Railway Transport

3.1. Rail freight (with a focus on Eurasia)

The global railway freight market is estimated to be worth between 220 – 250 billion USD on an annual basis according to the specialized consultancy Rail Market Research⁹. The share of rail freight for goods transported to the EU area has stayed rather stable over the last 2 decades and is relatively small at around 1.5% of the total value of goods entering the bloc as seen in Figure 2.4-2. There is a number of specific factors that explains this negligible size, with the three most important ones being the a) efficiency, maturity and cost effectiveness of maritime transport, b) the absence of a global regulating body for railway freight and c) the imbalance of railway infrastructure among economic regions. However, there is a consensus among different data sources that this trend is bound to be reversed and its share shall rise.

Figure 3.1-1 shows the comparison of rail freight to its main competitors (maritime and air). Rail freight is somewhere in the middle in the sense that it shows the following features:

- Rail freight is quicker than maritime (but more expensive per unit of freight)
- Rail freight is cheaper than air (but slower per unit of freight)

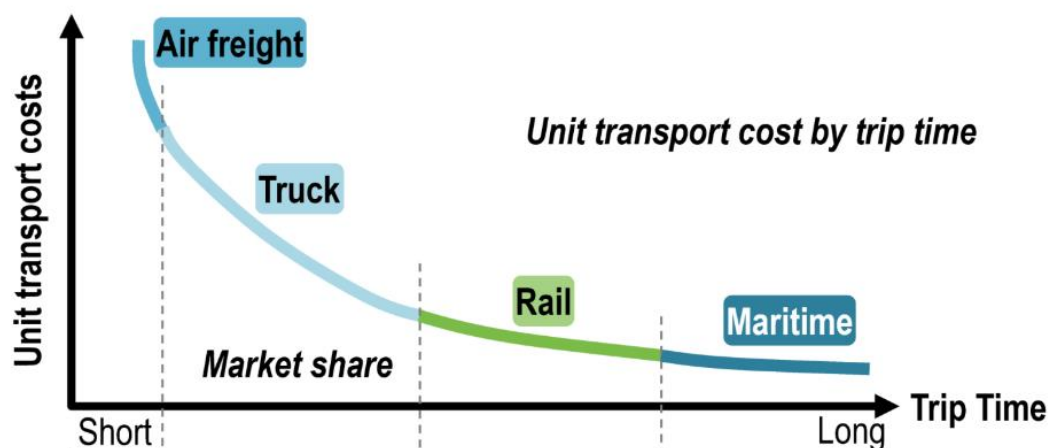


Figure 3.1-1: Comparison of main modes of freight transport (Source: Cargo from China)

⁹ <https://railmarketresearch.com/product/global-rail-freight-market-2021-2026/>

Data showing the real trade volume by rail in the China – Europe route are rather contradicting and not homogenous for two main reasons: a) there is not a single data consolidating authority and figures mostly come from logistics operators or customs offices and b) in many cases a single train also serves intermediary countries and particularly Central Asia thus making it difficult to correctly report the tonnage exclusively destined for European destinations. However, the reported volume from the UTLC Eurasian Rail Alliance Index (ERAI)¹⁰, an alliance of national railways of Kazakhstan, Russia, and Belarus, show that rail freight is on the rise (674.000 TEUs for 2023 and 362.000 TEUs for the first half of 2024) despite temporary fluctuations. In 2016 for instance the reported freight volume had been 145.000 TEUs (International Union of Railways, 2020), which shows the progress made in less than a decade. For 2024 the final figures shall be even better despite an overall observed decline in the EU China trade.

The following Table 3.1-1 shows data collected by Chinese customs gateways (cargo figures concern both international and intra-regional tonnage):

Port	Number of trains	TEUs for 2024
Alashankou (Alataw)	8023	330.829
Horgos (Khorgos)	1943	205.014
Manzhouli	1451	155.172
Erenhot	1433	157.492
Suifenhe	85	9.354
Tongjiang ¹¹	93	1.062,5

Table 3.1-1: Operating Information by Chinese Port Stations (September 2024) westbound traffic

From a simple analysis of the current market dynamics, it is quite evident that any disruptions in the established maritime “belt” favor the transition of some cargo to the more stable and less volatile Eurasia rail routes (e.g. the ongoing disruptions in the Red Sea area).

Although most of the available data is focused in China this does not distort the general conclusion. Most of the international rail freight is done via existing lines that cross the countries of Central Asia, where the necessary facilities exist to support freight trains.

¹⁰ <https://index1520.com/en/news/perevozki-iz-kitaya-byut-rekordy-a-pikovyy-sezon-zakazov-eshche-vpered/>

¹¹ <https://www.crexpress.cn/en/#/single-news>

Similarly, the goods of other Asian countries (e.g. Korea, Malaysia) that wish to be transferred by train are routed via mainland China to the big terminal ports of departure.

3.2. Eurasia rail corridors

In Figure 3.2-1: Railway routes (or corridors) from China to Europe (Source: China Rail Express Plan)¹² below the main rail routes for freight transport connecting Europe with Asia are demonstrated. It is worth exploring some more details of each one and listing some available options that 3PL companies actually use nowadays. It should be clarified that the term route refers to a single point-to-point connection (from a city of origin to a city of destination), which often implies a trip “aller-retour”. Due to the nature of the railway network the same infrastructure can be used for multiple different routes (for instance 95% of the route can be identical with a differentiation towards the end of it in order to serve a different city of destination). Therefore, several routes that use by majority the same backbone infrastructure can be grouped into a corridor. There are 3 main rail corridors between Asia and Europe:

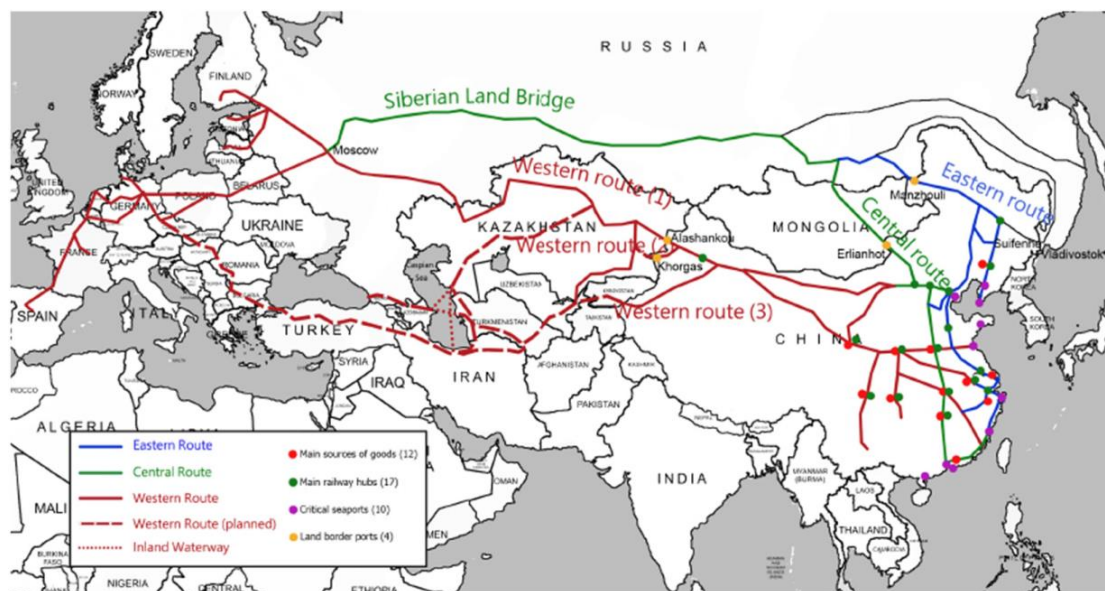


Figure 3.2-1: Railway routes (or corridors) from China to Europe (Source: China Rail Express Plan¹²)

Northern route or Eurasian Land Bridge: this 11.179 km route connects major Chinese cities (like Chongqing, Xinjiang, Shanghai) to Duisburg or Hambourg in Germany. It has

¹² Ye, J. Regional Orientated Global Logistics Networks Redesign with Respect to the Belt and Road Initiative (BRI). Ph.D. Thesis, Universität Bremen, Bremen, Germany, 2020

3 main branches upon exiting China: the western through Kazakhstan (Alashankou/Dostik), the central through Mongolia (Erenhot/Zamyn-Uud) and the eastern through Manchouria (Manzhouli/Zabajkalsk). It then crosses Russia, Belarus and Poland with some major stops in these countries. It is mainly operated by a joint-venture company of these countries and its usage is for IT goods (given that major IT producers like Foxconn exist in that part of China). The journey takes 14 to 16 days. Its advantage is that it relies a lot on the Russian railway infrastructure (specifically the Trans-Siberian Railway), which is considered of a good condition and technologically mature. A newer leg (NELB - New Eurasian Land Bridge) is also part of this corridor by allowing trains from China to enter Kazakhstan in Altynkol/Khorgos. This leg has been one of the main BRI objectives but has lost its momentum¹³ after the outbreak of the Russia – Ukraine war.

Middle corridor: Alternatively known as TITR (Trans-Caspian International Trade Route) this route goes via Kazakhstan, Azerbaijan, Georgia and Turkey. Its main advantage is that it is considerably shorter than its northern counterpart. It is also avoiding Russian or Ukrainian soil. Parts of it are under modernization programs (within the context of the BRI) including a small water passage by boat in the Caspian Sea, as its attractiveness has grown since the war in Ukraine. It still suffers though from low harmonization between the different countries that it consists of in terms of tariffs and border processes, partly due to it being multimodal.

Southern corridor: it is an ambitious idea to create a railway backbone that goes south of the Caspian Sea and crosses Kazakhstan, Uzbekistan, Kyrgyzstan, Turkmenistan, Iran with possible links to Armenia, Iran and Turkey by upgrading or connecting already existent regional lines. Its main advantage is that it cuts even more the transit distances compared to the Middle corridor and gives an outlet to many regional markets of South Asia but its disadvantage is that it is still immature and lots of infrastructure projects have to be made. Additionally, these countries are in negotiations for the implementation of other international railway links (such as the International North South Corridor) making the final form of their rail networks difficult to predict.

It is worth focusing on two important details, which explain the historical evolution of these routes.

¹³ <https://thediplomat.com/2022/03/what-will-russias-invasion-of-ukraine-mean-for-chinas-belt-and-road/>

Trans-Siberian railway: a pre-existing and established line connecting Manzhouli and the eastern Russian ports with different European destinations (via Moscow) with multiple logistics checkpoints across the route. It has been a reliable line with reliable service, modern infrastructure and good connections. It forms the basis of many corridors passing through Russia

China Railway Express: this is a joint venture of operators (Deutsche Bahn, RZD and China Railway Corporation) offering a combination of services (of all corridors) that aims to provide flexibility regarding origins and destinations and with a focus on diminishing customs delays. Often used for higher value cargo. Various origin-destination routes are offered from this joint venture with more trips under consideration (an example of current routes is presented in table 2).

It has to be clarified that the exact geographical limits of these corridors may differ in practice (or from report to report) and their boundaries are not strictly defined. However, it can also be concluded that as long as the infrastructure evolves multiple new routes can be used by the various rail freight actors creating new origin-destination pairs.

In the Table 3.2-1 below some main rail trips as well as their characteristics from this corridor are summarized (sources; Various forwarders)

Origin	Destination	Length (km)	Trip duration (days)	Passes through...	Main countries served
Chongqing	Duisburg	Almost 11.000	14-15	Kazakhstan (Alashankou), Rusia, Belarus, Poland	Russia, Germany, Poland, Netherlands, Chech Republic
Chengdu	Lodz	9.965	11-12	Kazakhstan (Alashankou), Rusia, Belarus, Poland, Germany	Germany, Poland, Netherlands,
Zhengzhou	Hambourg	10.461	13	Kazakhstan (Alashankou), Rusia, Belarus, Poland	

Wuhan	Hambourg or/and Duisburg	10.880	18.2	Kazakhstan (Alashankou), Rusia, Belarus, Poland	Russia, Germany, Poland, France, Netherlands, Chech Republic
Suzhou	Warsaw	11.190	14	Kazakhstan, Rusia, Belarus	Russia, Poland, Germany
Yiwu	Madrid	13.052	18	Kazakhstan, Rusia, Belarus, Poland, Germany, France	Russia, Germany, Poland, France, Spain, UK
Shilong	Hambourg	12.283	17		Russia, Poland, Germany
Xi'an	Malaszewicze			Kazakhstan (Alashankou or Horgos), Rusia, Belarus, Poland,	

Table 3.2-1: Major railway freight transport pairs (origin - destination) from East to the West
(Source: China Railway Express)

3.3. Types of freights

Railway freight from China to Europe is best suited to a specific profile of customer needs given its positioning compared to its 2 big “competitors” (maritime and air); it tends to be preferred for the transport of goods with some time sensitivity (e.g. perishable food, fashion clothes), bulk cargo or/and higher value or higher profit margin goods such as electronics or automotive spare parts (OSJD activity report, Railwaypro¹⁴). Overall, various types of goods have been seen in times such as: bulk commodities, chemicals and hazardous materials, special cargo, construction materials and finished consumer goods (source: International Forwarding Association, Uber Freight). Nowadays the Eurasian railway routes are used to transfer electronics, textiles, machinery and spare parts. The selection of this mode of transport obviously depends on the trading partners but some other elements also play their role (Jakobowski et al,

¹⁴ <https://www.railwaypro.com/wp/increased-freight-train-traffic-from-xinjiang-to-europe/>

2018): the geographical location of the goods, their value and vulnerability and the overall impact on the environment.

3.4. Containers

The majority of goods are packaged into intermodal containers, which sometimes are characterized as one of the most revolutionary inventions of world trade due to the convenience they have brought to world trade. A great feature they have is that although they have been invented to serve the shipping industry traincars have been adapted to accommodate them as well (Figure 3.4-1); therefore, they can be transferred by several means (ship, truck, train, air) without need to load/unload their content. The majority of the containers are classified to what is known as a “dry container” which normally comes in two dimensions: 20-foot and 40-foot. The 40-foot are the preferred container type. Most of the times they may be equipped with GPS and alarm devices (for tracking and safety reasons). For special or hazardous cargos specialized containers or railcars have to be used, which are more expensive. There are different modes of owning and filling a container in rail cargos and this can give a lot of flexibility to carriers. Currently in the market the following schemes can be found:

- Owning a container
- Leasing a Container

In terms of container utilisation 2 schemes are mainly in the market:

- FLC¹⁵ or Full-Container-Load: When a client books a full container regardless if it is full or not
- LCL or Less-Than -Container-Load: When several loads (clients) share a container

¹⁵ <https://www.ups.com/us/en/supplychain/resources/glossary-term/full-container-load.page>



Figure 3.4-1: Intermodal containers loaded on railcars (Source: China Railway Express website)

3.5. Railcars

While containers are the cornerstone of accommodating and organizing the different types of goods, railcars are the ones that enable their safe and reliable transport. The majority of railcars used today are the so called “intermodal railcars” which are like a platform on wheels able to hold, fasten and transfer an intermodal container. Railcars are organised in the so-called “block-trains”, which is the model prevailing in the China – Europe routes. Apart from intermodal railcars other types exist in order to transport other types of cargo. Examples include open top for bulk raw material, boxcars for palletized goods, specialized railcars for cars, logs, objects of peculiar shape, tank railcars for liquids, refrigerated for perishable goods etc. A constant challenge for operators is to assure the availability of the correct type of railcar that is best suited to each cargo.

3.6. Incoterms

The term Incoterms (International Commerce Terms) relates to a set of rules governing international trade (basically the seller and the buyer). They clearly state which tasks, costs and risks, shall be shared between the buyer and the seller as well as the way the

goods shall be delivered. Since they are issued by the International Chamber of Commerce they are globally applicable at least within the countries that are members of the ICC. The current version of these 11 rules is called Incoterms 2020. Due to their wide practical and legal adoption they form the basis for transport contracts in all means of transport. Some Incoterms are specifically designed for shipping. For all the other modes as well as for intermodal transport including rail these incoterms exist:

EXW (Ex Works), FCA (Free Carrier), CPT (Carriage Paid To), CIP (Carriage and Insurance Paid to), DAP (Delivered at place), DDP (Delivered Duty Paid), DPU (Delivered Place Unloaded). The most popular are the EXW, DAP and CIP.

3.7. Tariffs

The cost of rail freight from Asia to Europe is influenced by several factors but some are specifically related to railway cost. Obviously, the general driving force is the well-known supply and demand balance at each given moment but these elements do also play their role in the final pricing:

- cost for intermediary road transport
- cost of accessing the nearest port (more suitable for consignors deep in the mainland)
- lift costs to load the railcars (not always).
- Level of tariffs of competitive modes (especially maritime)
- Extra cost of capital (aggregated by delays)
- Container leasing cost / container availability

As shown in Figure 3.1-1 rail freight tends to be cheaper for longer land distances as opposed to shorter routes, where road transport becomes cheaper. It still remains cheaper than air freight and quicker than maritime transport.

The tendency of the prices for containerized rail freight from China keeps going upwards as the following figure confirms (in Figure 3.7-1 a multi-source average price per ton-km is presented, for journeys of 500 and 1000 miles respectively).

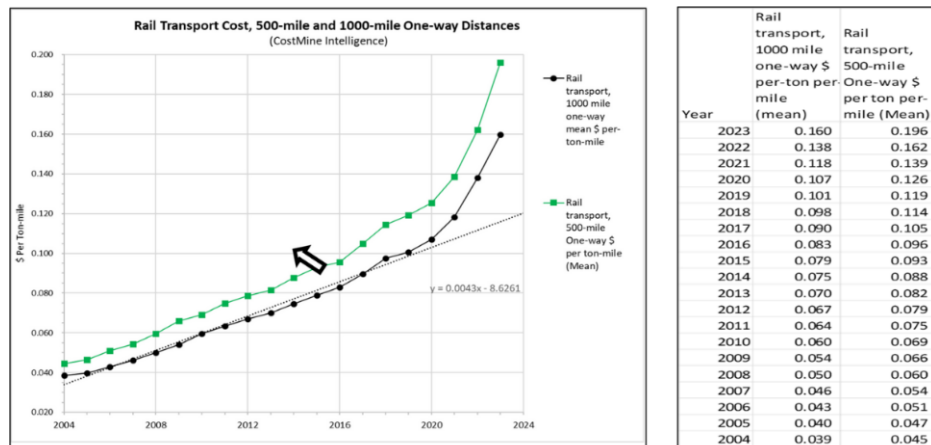


Figure 3.7-1: Rail transport costs 500-mile and 1000-mile one-way distances. (Source: <https://hawleylogistics.co.uk/increase-in-cost-rail-china-europe/>)

In a different way to confirm the same tendency it can be observed that the cost of containers has been systematically growing; therefore, the final price to transport a unit (container) by rail will grow. The following Figure 3.7-2 shows the evolution of container costs for maritime usage but it can be safely assumed that the container cost for rail freight use is very close. The following Figure 3.7-3 shows a real quote for a “mock RFQ” asked for the needs of this thesis.

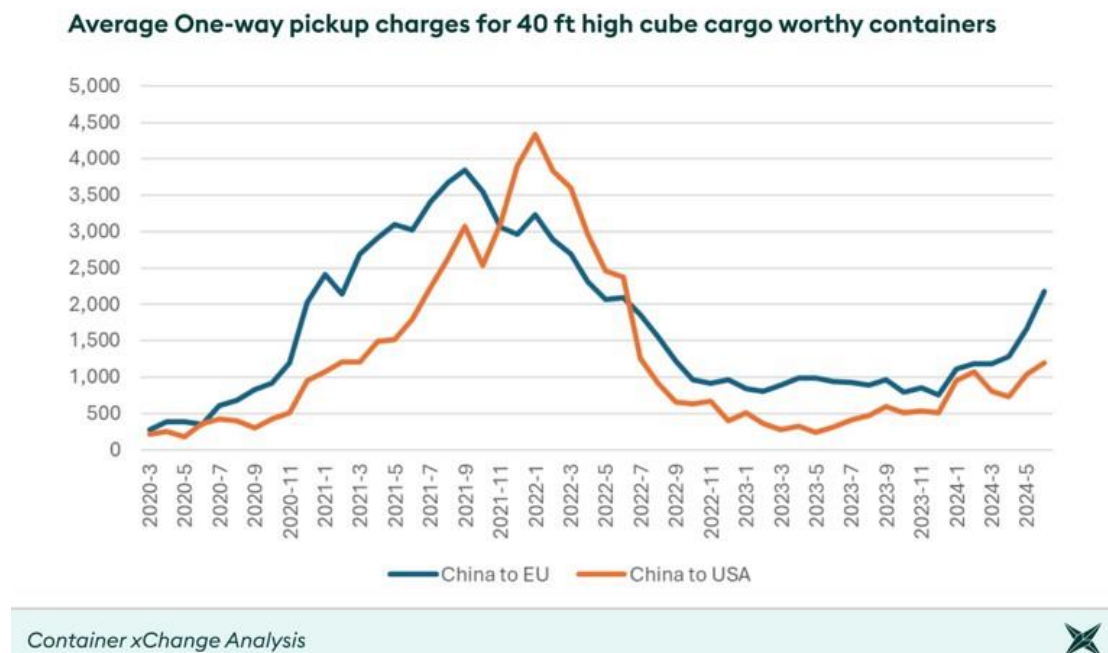


Figure 3.7-2: Container leasing costs (Source: <https://www.hellenicshippingnews.com/container-prices-double-leasing-rates-triple-in-china/>)

The objective has been to understand the current level of prices and the special terms (if any) that a typical quote contains. Some negotiation regarding unitary prices is possible following standard commercial practices. It is interesting to observe that some costs are not known in advance.



Figure 3.7-3: Mock RFQ for the transportation of 1 container 40" from China to Europe

3.8. Advantages of rail freight

The following is a list of advantages which have been observed by users of rail freight services or scholars studying them. However, it should be noted that some elements on this list may not be fully applicable to the rail routes from Asia to Europe (or at least not to all of them):

- **Cost effectiveness:** rail freight is cheaper when compared with road or air transport as it provides a more economical way of moving goods especially in longer distances. Given that it is faster than shipping it presents an interesting price / delivery time ratio. A bonus point is the lower volatility on tariffs historically.
- **Environmentally friendly:** compared to other modes of transport and particularly air or road it presents a lower percentage of greenhouse emissions per ton kilometre
- **Speed:** Although freight trains are subject to multiple elements that limit their speed (priority over passenger services, network limitations, weight etc) still the

journey from Asia to Europe is significantly faster than the traditional way by sea (in average it takes 2 weeks from far east to the far west)

- Scalability: it is rather easy to add up wagons in order to accommodate larger shipments. In some routes stacking up containers is also possible although this is largely limited by the infrastructure features
- Flexibility: in the same sense it is rather easier to change the configuration of wagons “en route” to the destination
- Reliability: all things being equal the railway is normally less affected by road or weather conditions thus offering greater reliability of service
- Accessibility: it is more accessible to smaller businesses either physically (railways cross many rural areas) and economically
- Safety: relatively speaking railways present fewer accidents than road trucks
- Intermodality: with increased connections with major ports rail trucks can be ideally used to unload large cargo ships quickly or vice versa (to transfer cargo quickly in order to fill a ship)

3.9. Disadvantages

Not everything is rosy though in the railway cargo. Some disadvantages of rail cargo are the following:

- Total Cost: the cost of rail freight is more expensive than the unitary cost of maritime transport. That could make a difference for shipments of great volume.
- Availability of infrastructure: the existence of crucial infrastructure (e.g. spare wagons, depots or parking yards, electrification of routes, cranes for loading / unloading etc) can affect many decisions of a freight forwarder on if and how to use a specific route
- Interoperability of infrastructure: especially in transits where many countries have to be crossed it is important to have railway systems that can operate on the same rules, which is not the case always (e.g. the gauge difference between railways in Russia and Kazakhstan)
- Legal regimes: especially for rail routes that cross borders it is certain that they have to operate under different national laws; thus the work done by

international organizations in standardizing operations, processes, equipment, etc is of great importance

- Physical and operational constraints: physical constraints such as bridge tolerances, tunnel heights, morphology of the terrain etc as well as operational limitations (e.g. line traffic, speed limits, maintenance works on tracks etc) can certainly impact the capacity and overall efficiency of a rail cargo
- Border crossings: apart from the technical requirements of interoperability border crossings add a layer of administration and customs dimension to each transit. Since many different jurisdictions exist it is easy to imagine the complexity of a rail trip
- Limited coverage: railways cannot cover all the areas but usually a part of it. In these cases, intermodal capabilities (and particularly the existence of road trucks) play a crucial role in order to increase the usefulness of the train
- Transit times: typically, cargo trains have a lower priority over passenger trains on mainlines which creates longer journeys. This may not be desirable for certain types of goods (e.g. perishables)
- Security: as a big proportion of railway lines is laid through the countryside or less populated areas the issue of security is always a challenge for railway operators

3.10. Main actors in rail freight

There can be numerous stakeholders in the rail freight sector and each one of them can impact positively or negatively the performance of the operations. A brief description of the main actors follows with a focus on their potential impact in rail freight operations

- Consignors and Consignees: these are practically the people or the enterprises for which the whole SC operates. The consignors is the party sending the original goods and the consignee is the receiving end. They could be called as the clients for all the other actors.
- Railway OEM producers: these are the companies that manufacture and provide the necessary infrastructure elements such as rolling stock, railcars, railway

lines, all signalling and control equipment etc. This market is rather oligopolist with a few global giants and some smaller more specialized manufacturers. It is obvious that the OEM producers provide the necessary technologies to the sector and the features of each specific equipment thus impacting directly the capabilities of the operations

- Rail operators: alternatively known as carriers these are normally the companies that possibly provide and operate the various railway equipment and provide the operating personnel (e.g. drivers, marshals, etc). These companies can be often state-owned but their main focus is to manage all operating issues in order to provide a pre-defined or agreed service level to their clients namely freight forwarders or cargo owners. This service level is usually measured as number of services per time unit
- Infrastructure owners and maintainers: in some cases, the operator, the maintainer and the owner of the rail infrastructure is not in the same entity as the operator although corporate linkages may exist. Although there are counter arguments as to the efficiency of this fragmented model it is not to be argued that the infrastructure owners and maintainers can highly impact operations as the availability and capacity of the infrastructure is the basis of any service level agreement. This conclusion applies both on the fixed infrastructure (e.g. line sections) as well as on the movable (e.g. railcars).
- Shippers: Shippers are the entities that prepare the cargo (packaging, labelling, documentation) which makes them almost the starting point for the existence of the whole logistics chain. The quality of their work has direct impact till delivery of the cargo since any mistakes done at this stage (especially with documentation) may have cause lots of delays and issues at a later stage.
- Forwarders, logistic providers and 3PL: these terms and their functions may co-exist in a single company or they may reside in 3 different entities. Freight forwarders usually work on behalf of shippers in order to organize the transport of goods acting as an intermediary with the rail companies. They usually also contract with the final clients at both ends. Some freight forwarders provide their service all along the route till the final delivery of the shipment (meaning not staying within the national borders). They do things such as route planning,

consolidation of shipments or contract management. A logistic provider is a broader term of company that provides a wider spectrum of services including those of shipment or/and freight forwarding such as warehousing, tracking, inspection, “first / last mile pickup / delivery etc. In some cases they could manage the whole supply chain of larger companies. 3PL is a type of logistics provider focusing on the logistics part of the supply chain. They can act as fully integrated yet outsourced partners to larger corporations managing the totality of their logistics need. The actions of all these 3 types of companies can decisively impact the performance of the supply chain within which they operate.

- **Regulatory, Certification bodies & International Standardization organizations:** these international or governmental bodies develop common rules across different aspects of the railway industry and therefore their work can have profound impact upon a multitude of actors. Apart from technical standards equally important are operational and code of conduct standards or international trade agreements that give the directions on how to handle certain operational aspects of railway cargo. Particularly important for the Europe-Asia trade are the COTIF and its CIM consignment note part (Intergovernmental Organization for International Carriage by Rail – OTIF) and the SMGS consignment note issued by the OSJD, which are used in different countries of this area. Since 2006 the International Rail Transport Committee (CIT) has produced a combination of these two consignment notes (CIM/SMGS) in order to increase the “legal interoperability” between all trade partners and minimize the need to use two different consignment notes on the same route. The objective is to have this document accepted in the greatest possible extent of a rail network. The importance of using the same transport document all along the route is highlighted by the fact that an approximate saving of 40€ per document (Galushko D., 2016) goes to the consignor and a total saving of 10-12 hours in total for the whole journey is realized (each time when there is no need to do a reconsignment).
- **Customs & Customs Brokers:** Customs are another crucial point in all modes of freight and not exclusively rail. They are state-owned services and their main role is to inspect that the national and international rules of importing and

exporting goods are respected. They have the ability to bring a cargo to a complete halt if it is not compliant to the regulation, so they are always a major source of risk for delays or unpredicted fees. According to the World Customs Organization¹⁶ there is a lot of ongoing harmonization work between customs in order to facilitate world trade and towards more sustainable supply chains. Customs brokers can be either independent entities or part of a larger freight forwarder, logistics provider or 3PL company whose main duty is to make provide customs clearance to the imported or exported freight.

- **Terminal operators (ports):** Terminal ports are an important part of the logistics chain in railway freight and they can be either combined with other modes (e.g. ships, road trucks) or not. They act as intermodal interfaces, collection or distribution points or even temporary storage facilities. Obviously, the location, the equipment and the facilities of each one play a decisive role in the total efficiency of the supply chain and especially in the avoidance of unpredicted fees or delays.
- **Insurers:** Insurance is an integral part of every supply chain and its logistics operators and there are different levels of insurance. The particularity of rail freight that crosses several national borders is whether there exists an insurance that covers the whole route (including potential intermodal interfaces) or whether there are insurance covering segments of this route. Incidents such as derailment, collision, fire, theft, delays which are probable in the complex railway environment (given the number of stakeholders) need to be thought of. Also depending on the type of cargo, incoterms (see paragraph 3.6) and the specific consignment notes the insurance coverages may differ significantly. In any case it is important to have a detailed approach towards the subject of insurance as serious legal implications can arise from inadequate coverage.
- **Unions:** Unions are everywhere and can certainly impact the performance of any supply chain either in a positive or a negative way. Their massive course of action can have a huge impact on supply chains (e.g. the union actions in the ports of the west coast in the USA in late 2023) although it is not very common.

¹⁶ <http://www.wcoomd.org/>

4. Supply chain / Logistics challenges for intermodal transport

4.1. Flows

There are 3 basic flows in each supply chain (some authors count them up to 5) regardless of the number of suppliers that participate in it:

- Goods flow: this includes the movement of raw materials, (semi-) finished goods or returns from customers.
- Money flow: this includes all the financial transactions that accompany all the other flows within a SC and mainly the goods flow
- Information flow: this includes the exchange of all necessary information that complement or facilitate the activities produced in the other 2 flows. The information can be paper based or in digital form.

According to ASCM logistics is the engineered or transactional flow of goods, money and information between the network of suppliers of the SC in order to ensure the delivery of “the right goods to the right place in the right time”¹⁷. The continuous and uninterrupted interaction of these flows is therefore what makes logistics so important and their efficiency (in other words the seamless integration of these flows) impacts decisively the whole SC.

It is very rare that a novelty or improvement that appears in one flow does not have an impact upon the others due to their strong correlation. This perspective shall be kept in mind whenever evaluating new methods that appear in either flow.

¹⁷<https://www.ascm.org/topics/logistics/#:~:text=The%20supply%20chain%20is%20the,and%20money%20within%20that%20network.>

4.2. Basic documentation¹⁸

International trade is facilitated by numerous documents in different stages of the logistics flow, which contain a great volume of information. Each bit of information has a role to play in the complex processes that are associated with global transport. With the focus on freight transportation through railway the most basic of these documents are the following:

- Bills of lading (or rail B/L): it is the document that is issued by the transportation company to a shipper. It briefly describes the goods to be transported (type and quantity), the date of reception, their condition and their destination. It should accompany the cargo at all times as it legally defines the responsibilities of the transporter, proves the transfer of goods from the one party to the other and acts as a title of cargo ownership. For multimodal transport the FIATA Bills of Lading is to be used.
- Rail Waybill (CIM/SMGS¹⁹): it is a detailed multi-page form of the transport process deriving from international treaties such as the AIGT / SMGS (Agreement on International Goods Transport by Rail)²⁰, the CIM Uniform Rules or the COTIF (Convention on the Contract for International Carriage of Goods by Rail)²¹ and acts as transport contract. It details the stations of the route, the borders it shall cross, cargo and container information, etc
- Commercial invoice: this is the basis for customs declaration and tax calculation and refers to the value of the shipment
- Customs document: this is a document that lists the goods to be exported (or imported)
- DGD (Dangerous Goods Declaration): it is used specifically when dangerous goods are transported and has more to do as part of a safety risk mitigation process

¹⁸ <https://www.digitalizetrade.org/ktdde>

¹⁹ <https://www.cit-rail.org/en/freight-traffic/cim-smgs/#any>

²⁰ https://www.utlc.com/en/press-center/detail/aigt_eng/

²¹ https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XI-C-8&chapter=11&clang=_en

- Packing List (or packing slip or shipping list): it is a detailed inventory of all items to be transported with information upon buyer, seller, date of departure and physical characteristics of the goods
- Letter of Credit: used as a guarantee of payment from the buyer side towards the seller
- Certificate of Origin: it is a mandatory document that declares the origin of a product and will be used during the customs clearance process in the importing country. The EUR.1 is used for instance in the EU bloc
- Insurance certificate: is a document providing details regarding on how the shipment is insured and what damages are covered
- POD (Proof of Delivery): A form issued by the carrier that serves as a proof of delivery to their final destination.

As it is highlighted elsewhere the volume of documentation is quite extensive and is often responsible for delays in the logistics flow. Duplication of information or information overlap cannot be avoided. Therefore, there is a growing number of initiatives and actions²² to pass to an electronic documentation era which can significantly speed-up specific processes in the flow (e.g. pre-declaration of goods could enable the customs office of the importing country to give their authorization without the need for the train to make a long stop upon crossing the borders).

4.3. A typical logistics example

It is worth illustrating a typical workflow for a package that wants to leave its place of production (somewhere in mainland China) and needs to be delivered in Denmark (either the ordering unit is the final client or a wholesaler). There are 2 main reasons to illustrate the logistics flow for this “mega-transaction”

- a. To identify the major players / interfaces / steps of the supply chain and
- b. b. to better understand later in this chapter the biggest challenges faced

²²<https://index1520.com/en/news/andrey-slepnev-caes-i-kitay-uprostyat-perevozku-gruzov-po-zheleznym-dorogam-za-schet-vnedreniya-elek/>

The major players that are to be found in an international shipment are shown in the following Figure 4.3-1 whereas a typical route for containerized cargo can be seen in Figure 4.3-2



Figure 4.3-1: Main players in international shipments (Source: World Bank)

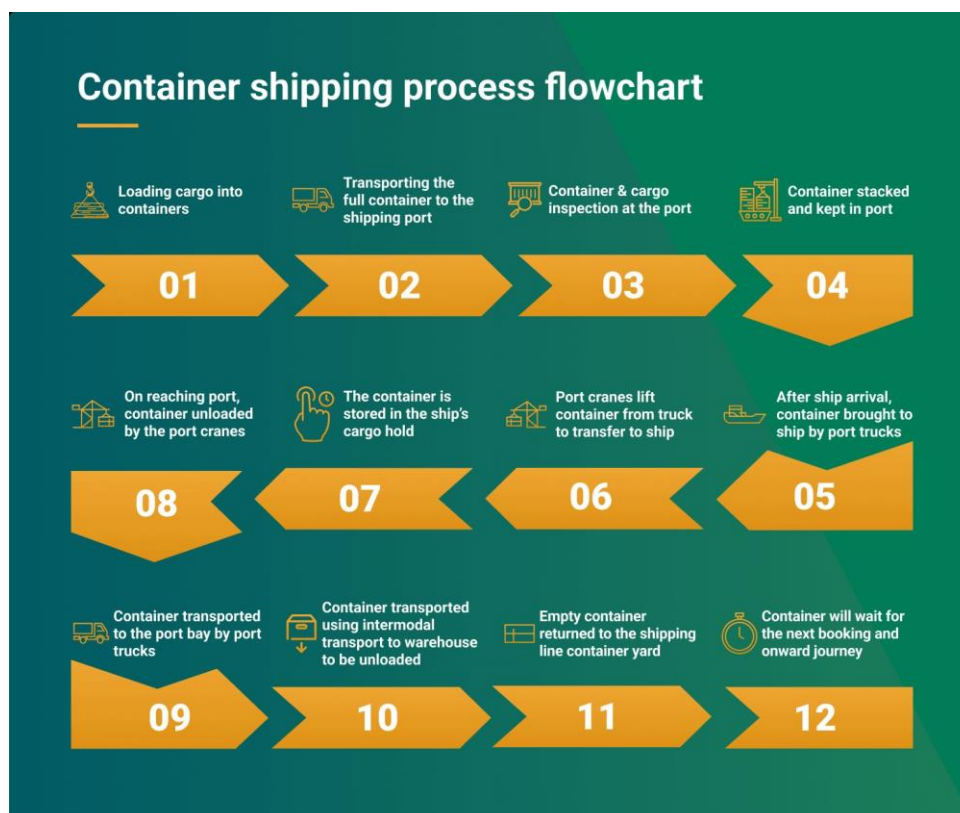


Figure 4.3-2: The journey of a container (Source: <https://www.container-xchange.com/blog/container-flow/>)

1. The receiving end of an order and at the same time the starting point for a shipment is the shipper. The factory or the wholesaler that has to send out the package or the load towards its final destination. This company should contact a freight forwarder in order to arrange how the shipment should leave its premises.
2. The freight forwarder is responsible for several back-office operations²³. Firstly, they have to arrange that the shipment is picked up by the origin and delivered either to an intermediary depot or a shipment port. If it is not properly packaged, they may complete this step before anything else (usually in pallets). Then, depending on the nature of the goods, they have to arrange for the cargo to get either in a container (fully booked for the shipment or shared with other cargos) or directly in a transport means (vessel if by sea, plane if by air, railcar if by rail) if we are talking about goods in bulk. For the sake of simplicity, we shall assume that we are talking about containerized shipments. The containerization of the goods is done in cooperation with the carrier. In parallel the necessary charge fees should be paid. These fees could include container rental, terminal port charge fees, cargo insurance and customs fees. If there is a multimodal transport all intermediate transshipment fees should be also taken into account.
3. Customs is the government service that is responsible to ensure that all goods imported or exported are correctly identified and declared, follow the national and international or even bilateral rules and that all taxes and duties are collected. Freight forwarders are in general responsible to ensure smooth passage through the various customs and they do this with the help of specialized customs agents (or brokers)²⁴. The latter provide all necessary paperwork and advisory in order to ensure compliance with customs rules and commit the customs clearance procedures.
4. In railway the distinct role of a shipping agent is not always so distinct as in the maritime industry for example. However, this interface role between the freight forwarder and the carrier is responsible to ensure the booking and optimization of the rail loading with the different cargos (e.g. number of railcars, schedules, etc), the necessary documentation, the route optimization (e.g. in case of

²³ <https://www.alchemygts.com/blogs/the-key-roles-responsibilities-in-freight-forwarding>

²⁴ <https://www.sennder.com/glossary/customs-agent>

multimodal transport or railcar resorting) and the tracking of the cargo until its final destination

5. The carrier is essentially the rail operating company that will conduct the transport of the cargo of a single or several freight forwarders / shippers. They are responsible for the availability of the proper railcars, the configuration of the train (depending on cargo), the correct loading, transport and unloading of the containers, the availability of proper engines, the rerouting of railcars (if applicable), the compliance with all railway specific regulation (e.g. technical, safety, rail traffic rules) and the final delivery of goods in the destination terminal.
6. The bank has no different role than in all other aspects of international trade or normal business flow and that is to facilitate all the financial transactions between the different parties.
7. The importer is the specialized individual or company that usually is the receiving end of a cargo shipment. Often it is a different entity than the ordering unit (final client) but not necessarily so. The main responsibility of an importer is to make sure that there is no issue with the customs authorities of his/her country and then to distribute the cargo to its final destination.

4.4. Interfaces

It is generally known that each SC or logistics system has a number of important interfaces with the “outside world”. In intermodal SC, which are largely based on railways, one can expect several more interfacing sub-systems (internal to the railway or / and external) which have to be designed, built and managed efficiently in order to produce a well-functioning system that delivers all the features it promises. In a different case delays and inefficiencies are produced with the tendency to spread towards all levels of the supply chain, creating a ripple effect. Some major interfaces that could create issues follow:

4.4.1. Infrastructure

Obviously the first and foremost are the different constraints set by the infrastructure. Be it the type of railcars (see paragraph 3.5), the different gauges or the differences in voltages, infrastructure shapes the capabilities or the limitations of a railway system. For rail freight apart from all the classic sub-systems of a railway some extra sub-systems (that belong to the infrastructure) can impact the attractiveness or the overall service level. Examples of such sub-systems are all facilities that enable the maintenance and smooth operation of long freight trains like yards, lifting cranes, forklifts for transshipment, temporary (or permanent) storage spaces, parking sidings, maintenance workshops etc

4.4.2. Coordination and communication

Coordination and communication are two fundamental concepts in railway-based supply chains and logistics and have a huge importance for the smooth operations. There is a set of functions that have to be there even before thinking of allowing trains to run on a track and typically these functions have to have the highest possible degree of reliability as they may well be related to the subject of safety. The capability to communicate and coordinate resources certainly depends on the specific hardware. However, when it comes to operations the importance of processes and procedures takes a primary role as all elements of the various sub-systems should be efficiently combined with the available resources in order to produce a resulting service at the desired quality. Poorly designed or executed processes are often a major source of delays that propagates across all the SC.

4.4.3. Time reliability

“Time is money” as the old saying goes and that could not be more valid within a SC context. As mentioned elsewhere rail freight tends to be used in order to transport goods that have some time constraints (e.g. perishables) or for some reason the time of their delivery matters (e.g. seasonal goods). Therefore, the reliability of service is crucial in attracting consignments to freight rail companies. In paragraph 3.2 the average durations of some established routes have been presented but it is interesting to observe

that this duration can fluctuate (forwarding agencies avoid giving a guaranteed time). The main reason is that there is a big number of risk factors that are able to insert delays (enough of them are discussed in several sections of this thesis) into intermodal rail trips and there is not a single coordinating and overseeing agent that can manage them and guarantee trip durations. Although the situation has drastically improved over a decade ago there is still room for improvement across all stakeholders and processes of a SC and this is exactly the objective of inserting new technologies that can help decrease the uncertainty inserted by these factors (such as blockchain).

4.4.4. Damages, complexity of operations

The volume of stakeholders and the necessary functions, that have to collaborate in order to achieve a high-quality service for final clients, is quite extensive as seen in other parts of this thesis. The complexity of operations is a given fact in railway-based SC and certainly increases more when other modes should participate. Efficient processes and procedures play a key role to smooth out all this complexity. Since a lot of operations still depend on humans the probability of an error cannot be excluded although increased automation helps mitigate this risk factor. Another factor that has improved throughout the recent years (but not yet totally controlled) is damages. The reasons could vary from bad weather conditions, improper handling actions (e.g. loading and unloading), technical failures of railway elements, external factors such as theft or vandalisms or cargo-specific risks (e.g. fragility). Whenever damages occur this is certainly a source of disruption for rail freight that could lead to a temporary loss of services. The reasoning is that (depending on the context and severity) it has to be assured that there is no fundamental cause for that damage before resuming operations, and the damage will not repeat itself into a following train.

4.4.5. Port congestion

Port congestion is an issue that appears often in railways and it can be a temporary or a more permanent situation. Ports are essentially depots with some storage facilities where the basic functions of loading / unloading cargo trains occur. Ports are also used in order to “collect” cargo from a region or from secondary lines and feed a main cargo

train. They can act as bottlenecks into railway networks since (by nature) they play the role of a “node” into a network and cannot be easily substituted (by an adjacent node for instance). All kinds of reasons that can create disruptions to a rail-based SC are also applicable in ports but as usual there are some specificities. Their nature is somewhat dynamic; poor route planning or excessive demand for rail cargo can quickly fill them up. If for instance incoming volumes are less than outgoing it can quickly lead to either trains waiting to be unloaded or in extreme cases a complete bypass of the specific port. This scenario underlines the importance of transversal coordination mentioned in paragraph 4.4.2. However particularly bottlenecks that occur due to surges in demand raise the question of integrating forecasting procedures into the SC. The impact of port congestions are usually increased costs (e.g. insurance, demurrage, freight tariffs, etc), delays and propagation of inefficiencies to other modes (e.g. shortage of trucks)

4.4.6. Other constraints

Apart from the above there could be other interfaces which need appropriate management in order not to insert risk factors into the SC operations. Skilled personnel shortage for example although it seems to be a problem of the companies operating in the specific SC in reality it could have deeper roots (e.g. labour market policies, educational system, etc).

4.5. Reasons for delays in supply chains

According to the accumulated experience by various logistics operators some of the top reasons for delays or other anomalies in international trade are listed below. All these do not necessarily have the same severity or weight for rail freight but in an interconnected world the impact is quickly spread.

4.5.1. Geopolitical Risks

When politics work well so do the economies. The interconnection of these two has been proven by multiple studies and historical paradigms. In the recent years the importance of geopolitics has gained momentum and definitely impacts international trade. Two major examples include the increasing tensions in the Middle East region and the sanctions against the Russian Federation. Both of these geopolitical events have profound impacts on supply chains as they happen to be on major trade routes. As a proof the war in Ukraine has strengthened the research for alternative land routes (which in turn gave a boost to the so-called “middle corridor”).

4.5.2. Regulatory compliance / EHS

There are many different levels and subjects of regulation around international trade and rail freight specifically that need to be respected. The issue can become so complex, if not managed correctly, that specific compliance departments exist in all major logistics companies especially because the consequences of non-compliance can be important. The last decade EHS (Environment, Health, Safety) issues have been constantly on the rise and affect vertically all actors in the supply chain. There are several authorities that have the responsibility to verify the compliance to these rules but one of the most important would be the customs.

4.5.3. Railway network capacity

Railway networks have a certain carrying capability (capacity) that actually limits their utilization (the equivalent of port congestion in the maritime industry). This capacity is a combination of technical or geography limitations such as the maturity of their infrastructure (see following point) and regulatory or operational restrictions such as speed limits or works on the line. Given that each country does not treat such issues at the same speed or priority it is easy for trans-border connections that further delays can be generated (as is nowadays the case in the China Kazakhstan border)

4.5.4. Infrastructure maturity and interoperability

Infrastructure differences can be a great source of delays or deficiencies in the whole supply chain. Be it the vertical clearance of lines (not allowing train double stacking for example) or differences in gauge width (a famous example is the rail gauge in Russia being 1.520m but in Central Asia 1.435mm) they force carriers to find costly solutions of interoperability. Infrastructure is typically developed through state-owned companies so the different priorities of the governments also affect the speed that these issues are addressed.

4.5.5. Empty container repositioning

The containers have revolutionized world trade since their integration in everyday activities and have helped smooth the transport of goods from one corner of the globe to the other. However, a rather hidden challenge derives from the imbalance between international trade flows; the volume of trade from east to the west is far bigger than the opposite direction. So, when a container leaves Asia and arrives in Europe for instance this does not necessarily mean that it will return back to its origin soon (because of lack of a load) and so it has to be stacked in some depot in Europe. Given the sheer volume of containers in circulation nowadays this creates a “container imbalance”: thousands of empty containers on the one side and limited number on the side, where the needs are greater. Although there are some solutions to this problem it is understood that a shipment of empty containers is only a costly transport which no one has an interest to bear.

4.5.6. Customs processes

Customs are an important node in supply chains acting as a control checkpoint but they are often cited as one major source of delays or unforeseen costs. Their principal role is to make sure that national (or international regulations at some instances), which govern imported or exported goods are well respected²⁵. These rules are applicable to both exports as well as to imports although it is not the same procedures that should

²⁵ https://taxation-customs.ec.europa.eu/role-customs_en

take place. The set of processes to follow in order to go through customs is called customs clearance and varies depending on which goods we are talking about²⁶ as well as the countries of origin and destination. According to logistics companies the top reasons for delays in customs can include (the list is not exhaustive):

- Poor documentation (e.g. missing forms, poor product descriptions, incorrect transaction details etc)
- Wrong product values or quantities
- Inconsistencies between the documents and the actual products
- Not declared items
- Violation of case specific regulations (e.g. restricted items, country of origin under sanctions, etc)

It has to be noted that delays are just the “one side of the coin” in the case of troubled customs clearance; significant extra costs are also to be accounted for (e.g. demurrage charges, detention fees, insurance and contractual penalties, etc), which most of the times cannot be predicted. Also, a major disadvantage of rail freight (as opposed to maritime and rail freight) is that customs processes repeat themselves in every instance of crossing national borders. In the other means the customs processes take place in the beginning and in the end of the transport.

4.5.7. Tracking and Visibility

The timely and accurate tracking of a freight is essential for many parties implicated in the supply chain and especially the receiving end. It is not only an issue of performance but a matter of security as well. However, the localization of a freight within the different phases of handover during a multimodal transport is not always done in a smooth, automatic or optimal way. The reasons may vary from poor coordination between the different parties, poor documentation, poor procedures etc.

²⁶<https://trade.ec.europa.eu/access-to-markets/en/content/customs-clearance-documents-and-procedures>

4.6. Known issues in Eurasia rail transport

All the previously mentioned issues are present within the various railway-dependent SC in the Asia – Europe routes albeit in a varying severity. Different measures have been implemented or are planned in order to address a fraction of them. In their detailed and recent service quality evaluation study that has been done by a group of researchers (Shan et al, 2024) it was found that overall, the main issues still remaining had to do with:

- Reliability of services
- Bottlenecks at border-crossings
- Flexibility regarding the type of cargos
- Various inefficiencies of rail resources.

A slightly older analysis conducted by Jakobowski et al (2018) adds some more dysfunctional aspects of these routes:

- Investment, operational or commercial decisions that are taken under geopolitical influence
- Uneven maturity of the infrastructure among routes and countries
- Relevant volatility of prices
- Lack of standardisation

And it will be seen in the following chapters, there is a technology that can help address the majority of these issues.

5. What is a blockchain?

5.1. Origins of the technology and evolution

Blockchain is probably the most known example of a family of technologies collectively known as DLT (Distributed Ledger Technology). In the various forms of DLT various transactions are conducted, their information stored and shared to the different actors of these transactions without the need of a validating central authority in any stage of the process. This result is reached via the creation of a distributed ledger (database), its synchronization and keeping at various locations (distributed) at the same time. This technology has been the natural evolution and combination of other underlying technologies and methods of bookkeeping. The most known representative of this family of technologies is the blockchain, which was officially introduced to the general public in 2008 as a digital payment system (bitcoin being its “coin”). Since then, many other applications of this technology have been proposed or are under development making it the most popular DLT technology in use today.

There are two basic types of blockchains: public (permissionless) and private (permissioned). The differences and the basic features are summarised in the following Figure 5.1-1.

	Permissionless	Permissioned
OVERVIEW	Open network available for anyone to interact and participate in consensus validation. Fully decentralized across unknown parties.	Closed network. Designated parties interact and participate in consensus validation. Partially decentralized (i.e., distributed across known parties).
ALSO KNOWN AS	Public, trustless.	Private, permissioned sandbox.
KEY ATTRIBUTES	<ul style="list-style-type: none"> ■ Full transparency of transactions, based on open source protocols ■ Development via open source ■ Mostly anonymous, with some exceptions ■ Privacy depends on technological limitations or innovations ■ No central authority ■ Often involves digital asset or token for incentives 	<ul style="list-style-type: none"> ■ Controlled transparency, based on organizations' goals ■ Development via private entities ■ Not anonymous ■ Privacy depends on governance decisions ■ No single authority, but a private group authorizes decisions ■ May or may not involve digital assets or tokens
BENEFITS	<ul style="list-style-type: none"> ■ Broader decentralization, extending access across more network participants ■ Highly transparent, which is beneficial for speed and reconciliation across unknown parties ■ Censorship resistant, due to accessibility and participation across locations and nationalities ■ Security resilience, since attackers cannot target a single repository, and it is costly and difficult to corrupt 51% of the network 	<ul style="list-style-type: none"> ■ Incremental decentralization, but participation from multiple businesses helps mitigate risks of highly centralized models ■ Stronger information privacy because transaction information is only available based on permissions ■ Highly customizable to specific use cases through diverse configurations, modular components and hybrid integrations ■ Faster and more scalable, since fewer nodes manage transaction verification and consensus
PITFALLS	<ul style="list-style-type: none"> ■ Less energy efficient because network-wide transaction verification is resource-intensive ■ Slower and difficult to scale, as high volume can strain network-wide transaction verifications ■ Less user privacy and information control 	<ul style="list-style-type: none"> ■ Limited decentralization because a network with fewer participants increases risk of corruption or collusion ■ Risk of override, since owners and operators can control or change the rules of consensus, immutability, or mining ■ Less transparent to outside oversight, since participants are limited and operators determine privacy requirements
MARKET TRACTION	<ul style="list-style-type: none"> ■ Peer-to-peer ■ Business-to-consumer ■ Government-to-citizens 	<ul style="list-style-type: none"> ■ Business-to-business ■ Business-to-consumer ■ Governments-to-organizations

Figure 5.1-1: Permissionless vs permissioned blockchains (Source: <https://www.techtarget.com/searchcio/tip/Permissioned-vs-permissionless-blockchains-Key-differences>)

5.2. Basic components and features

The basic elements of a blockchain network include:

- Nodes: they serve the roles of network participants and facilitators (validators, miners or a combination) typically organized in a peer-to-peer network)
- Consensus protocol: this is the set of common rules that all nodes follow in order to accept or reject a transaction
- Transactions: these are the actual transaction the information of which should finally get available to all nodes.

- Cryptography: the set of protocols used in order to bundle transactions together in “blocks”, link them together creating a chain of blocks and protect their integrity
- Functionalities: these include (but are not limited to) governance features, smart contracts and decentralized applications (Dapps) capabilities, “bridges” and compatibility with third-party applications etc

The basic advantages of a blockchain are the following:

- Transparency and accuracy
- Increased accountability
- Lower risk of centralized control and manipulation, security
- No single point of failure
- Cost of transactions
- Speed of transactions
- Information availability and efficiency
- Automation of administrative tasks

However not all is ideal in the blockchain world as the following disadvantages have been observed:

- Scalability
- Data storage limitations
- Throughput
- Operational cost and expertise
- Cybersecurity
- Regulatory recognition
- Lack of management comprehension and relevant talent (Khitsane et al, 2024)
- Energy consumption (particularly for older blockchains under the “proof of work” consensus mechanism)

Since the first inception of the bitcoin blockchain there has been a huge evolution in terms of protocols, ideas, new features, connectivity and areas of application. Without

overlooking the disadvantages of this technology that still remain it can be claimed that there have been numerous proposals during the last decade for the application of this technology to various sectors by researchers. This trend is particularly present in the SC where there seems to be a consensus that this technology can immediately address certain inefficiencies of SC. These examples stand out²⁷:

- Tracking and Visibility: it is possible through blockchains to track a product from its origin all the way through its intermediate steps up to its final destination implementing the so-called blockchain-based traceability
- Authenticity assurance: the record keeping of certain product features can help combat counterfeits by taking advantage of one inherent characteristic of blockchains (irrefutability).
- Payment processing: there are several use cases in this domain but with the use of smart contracts the payments can be streamlined and done at minimum delay and cost

Other “problem areas” where blockchain shows good potential to offer viable solutions are (Koh et al, 2020), (Aritua et al, 2021):

- Reduction of paperwork (and subsequent cost)
- Compliance
- Inventory management
- Asset and equipment management
- Communication between “isolated” systems
- Creation of “trust”
- Single and/or informal governance

Apart from the academia some corporates have been also experimenting with this technology. These are some notable examples²⁸:

- IBM Food Trust
- Vechain

²⁷ <https://www.paltron.com/insights-en/the-role-of-blockchain-in-supply-chain-management-scm#use-cases-for-blockchain-in-supply-chain-management>

²⁸ <https://supplychaindigital.com/top10/top-10-uses-of-blockchain-in-supply-chain>

- Provenance
- ChainLink
- DB Cargo

5.3. The eTIR, Efti and other similar initiatives

Various government-sponsored initiatives have been launched in order to tackle some of the transversal issues identified in the SC and offer to all actors some of the inherent advantages of the blockchain without utilizing this technology. This is achieved through various information systems, platforms or regulatory frameworks that are in use. Without getting much into detail all these are useful because a) they help create a culture of technology adoption in order to enhance efficiency in everyday operations and b) they provide valuable ideas and elements to future blockchain-based solutions. Some of them have been already deployed and in use and some of them serve as the basis for new regulatory measures. The central element of all is the tendency to reduce paperwork and digitalize information and data exchange. The following examples stand out:

- eFTI²⁹ (electronic freight transport information): it is a new regulation developed by the EU for all member states to be in place from the end of 2024. It intends to push the member states towards a common framework of freight data exchange in digital form (with varying degrees of access) among all partners into a logistics chain. The privacy and immutability of the data are among other things some basic requirements of this regulation
- eTIR³⁰: This is the paperless version of the global pre-existent customs treaty for the transportation of goods by road (TIR - Transports Internationaux Routiers) that has been active in its current form since 2003. Under this treaty data and declarations for customs are standardized among member states (TIR carnet), the integrity of the cargo is ensured (through custom seals) and taxes are paid to the corresponding states; there is no need for a cargo to be checked each time a border is crossed. According to the accumulated experience the

³⁰ <https://etir.org/about-etir>

paper-based TIR has cut cross-border time by 80% and costs by 38%, implying that the digital version of it has the potential to further enhance these gains. Certain features of eTIR (similar to those found in a blockchain) have proven their worth such as data standardization, tracking and visibility and reduction of administrative effort.

- NCTS³¹: it stands for New Computerised Transit System and is a regulatory framework regarding transit movements within the EU, Norway, Switzerland and Lichtenstein. This framework includes procedures, technical specifications, data structures and interfaces with other EDI systems in order to facilitate efficiently freight transfers among the participating states.
- ACTS (ASEAN Customs Transit System)³²: this is a similar system to eTIR aiming to facilitate the trade between the participating countries. It is based on common and standardized procedures and information exchange between the different customs authorities of the region of ASEAN (Southeast Asia). As the other similar customs agreements (although ACTS is more than that) promote full digitalization of customs declarations and have a single guarantee (for taxes and duties due) across the region.
- Other (trans-)national systems exist as well such as the system 95306 (cargo tracking and e-signatures used by Chinese railways), digital port system (paperless customs exchange internally in China), INTERTRAN (a joint initiative between UIC and RZD for cargo exchange in multimodal transport), WCO and ESCAP initiatives to setup a proper EDI in Asia and Middle-East regions.

5.4. Blockchain and AI³³

Artificial Intelligence is another “buzz” word that promises to produce new benefits for its users and tackle old problems with new solutions. Under the term AI a group of technologies is hidden which mostly enable “machines” or “programs” or “agents” to

³¹ https://taxation-customs.ec.europa.eu/online-services/online-services-and-databases-customs/new-computerised-transit-system-ncts_en

³² <https://acts.asean.org/acts>

³³ <https://link.springer.com/article/10.1007/s10479-023-05169-w>

take decisions on their own and have a certain degree of intelligence and autonomy. The interaction of blockchain with AI indeed shows a great potential for supply chains. Especially areas like data mining (from all stored data in a blockchain), energy consumption (for the operation of the blockchain), improvement of trust level between partners, demand forecasting, decision decentralization and others can be mutually beneficial for both technology families. As a result, supply chain participants can have a high-quality solution to address the challenges they have in their domain³⁴.

The interaction between the two technology families could benefit both of them in terms of creating advanced versions of the current models. For instance, a blockchain protocol with an AI-based consensus mechanism could be presented sometime in the future to support dynamic multi-transaction environments. Currently there is a technological race as to which nation will prevail in the AI domain but it is certain that any developments will greatly influence (and be influenced by) the wider adoption of the blockchain in various sectors. This combination is expected to become a leading trend in SC very soon (Sarkar et al, 2024).

5.5. Blockchain and IoT³⁵

Blockchain is not the only technology that can benefit supply chains but its value can be enhanced if it is combined with another emerging (if not already established technology) the Internet of Things (IoT). This technology describes a group of terminal devices / sensors along with their communicating and analysis software that gather data and information all the time in order to transmit them to other applications for their further usage and manipulation. The interface of IoT with blockchain can unlock true value for supply chains. Some of the ways to unlock and generate new value are the following:

- Blockchains can serve as a shareable, transparent, permanent and irreversible source of storage of IoT generated data and information. For instance, GPS data of a transport can be record in a blockchain and serve as a proof of the way a

³⁴ <https://appinventiv.com/blog/ai-in-blockchain/>

³⁵ <https://www.appventurez.com/blog/iot-with-blockchain>

load follows for years to come. This means that the limited storing capacity of IoT devices is overcome

- Operational processes may be fully automated or at least supervised by a minimum of personnel; thus, making possible the use of the people in more productive roles
- The collective follow-up of all generated data becomes easier since by default a blockchain timestamps the data inside its blocks. This can facilitate audit and control processes
- Naser (2018) focused more on the benefits that blockchain could bring to the railways (which are mentioned elsewhere in this thesis) and among others it was concluded that cloud server maintenance costs could be a contribution of the blockchain to IoT. Nevertheless, patience may be needed until full adoption demonstrates these cost savings.
- Alam (2022) analyses in a more general perspective the potential applications of blockchains when combined with IoT and the findings reinforce the belief that railway-based SC could benefit a lot from the wider application of these technologies since modern SC have the “perfect setup” for these technologies.

6. Applications of a blockchain on rail-based supply chains and their promised benefits (real examples) / existing solutions

6.1. Theoretical applications and expected benefits of the blockchain adoption in supply chains

In their informative paper Tardivo et al (2023) have conducted a literature review and mention several potential uses of blockchain that are expected to address known issues within railway-based supply chains. It is not surprising that most of the expected solutions attempt to address the basic issues that supply chains face nowadays as they have been presented in chapter 4. In short, the blockchain can mainly provide solutions to the following issues:

- Transparency and consistency of information particularly in cross-border passages or intermodal transport
- Tracking and visibility of freights from start to finish
- Enhancement of the degree of automation through the whole supply chain (this is mostly related to the implementation of smart contracts)

In accordance with them other groups of researchers³⁶ (Orienkohe et al, 2024, Shamsuddoha et al, 2022, Sharma,2022, Bal et al, 2021) agree that blockchain inherent features could provide good answers to the following real-world cases observed in modern day supply chains:

- Proof of origin, authenticity of product especially in industries that suffer from counterfeits
- Ethical sourcing
- Increased security
- Heavily regulated industries where compliance is of great importance
- Inventory management
- Automated payments (with minimum of intermediaries)
- Sustainable financial management

³⁶ <https://www.fepbl.com/index.php/ijmer/article/view/714/902>

Based on the above and what has been presented in the previous chapter these researchers intelligently give a description in which type of supply chains the blockchain technology would provide the biggest benefits (Chang et al, 2022): *“However, as supply chains expand, they become more complex. Consequently, traditional supply chains lack traceability and transparency, which becomes an industry-wide challenge causing painful inefficiency with delays, errors, and increased costs. To address this issue, supply chain participants need a unified view of data while still verifying transactions independently and privately, e.g., production, shipment, delivery, and sales”*

6.2. Are blockchain benefits real?

The quick and short answer is...it depends on the context! But after a deeper analysis the answer is almost always definitely positive. Not all blockchain benefits are necessary to every industry or apparent from the very first days since adoption. Additionally, some of the promised benefits may have been achieved already through other technologies. However, executives or decision makers should educate themselves and acquire a wider perspective and examine all parameters since an investment in the blockchain technology can impact fundamentally the known business models as well as the mentality of the regulators (Aritua et al, 2021) and act as an enabler for future key technologies. Transversal issues in the SC have been discussed in previous chapters and some consequences from the adoption of blockchain for the companies taking this initiative are the following:

Problem area	Definition	Short term impact	Long term impact
Transparency	The fact of providing visibility and disclosure to different stakeholders regarding the information of the SC ³⁷	<ul style="list-style-type: none"> - Reliance on technology for data capture - Change management regarding internal processes and operations - Cross-team synergies 	<ul style="list-style-type: none"> - Compliance and governance changes - Increase of company reputation and trustworthiness

³⁷ <https://hbr.org/2019/08/what-supply-chain-transparency-really-means>

			- Attractive to investors and talent
Consistency of information	The fact to obtain (and share) information that are accurate, complete, uniform and reliable	<ul style="list-style-type: none"> - Change management regarding internal processes and operations - Reinforcement of data validity controls - Standardization 	<ul style="list-style-type: none"> - Upskilling in Big data analytics and data mining - Improved decision making - Efficiency gains
Tracking & visibility	The ability to track all steps of a flow within the SC as well as the ability to monitor and understand all side activities in the supply chain	<ul style="list-style-type: none"> - Integrate all departments and 3rd parties under a common platform - Increased level of customer service 	<ul style="list-style-type: none"> - Improved commercial strategy - Marketing and business development benefits - Operational efficiencies
Task automation	The fact to standardize and automate tasks / processes (with or without the presence of people)	<ul style="list-style-type: none"> - Reduction of process “red tape” - Efficiency and time gains - Cost gains 	<ul style="list-style-type: none"> - Quality of service - Reliability and trust to the “system”
Proof of origin	The ability to prove irrefutably and indisputably the origin of a raw material or product	<ul style="list-style-type: none"> - Smaller need for control processes - Ethical sourcing 	<ul style="list-style-type: none"> - Reliability and trust to the “system” - Compliance - Response to customer needs
Inventory management	The fact to monitor, manage and optimize the inventory levels of a company in order to serve business objectives	<ul style="list-style-type: none"> - (Almost) real-time inventory levels - Agility in the SC 	<ul style="list-style-type: none"> - Competitive or/and strategic advantages - Cost savings
Decentralised governance and control	The regime where multiple stakeholders take decisions or/and control a set of processes	<ul style="list-style-type: none"> - Delegation of authority - Change management regarding processes 	<ul style="list-style-type: none"> - Structural organizational changes - Resilience - Sustainability
Transaction cost	The total cost in order to initiate, execute and confirm a transaction between 2 parties	<ul style="list-style-type: none"> - Cost savings 	<ul style="list-style-type: none"> - Customer satisfaction - Competitive or/and strategic advantages
Transaction speed	The total time that it takes between the initiation until the confirmation of execution of the specific transaction between 2 parties	<ul style="list-style-type: none"> - Customer satisfaction - Efficiency gains 	<ul style="list-style-type: none"> - Competitive or/and strategic advantages

Table 6.2-1: Benefits of a blockchain based SC upon organisations

The above table presents the short- and long-term impacts following the adoption of a blockchain technology in the SC. These impacts may look a bit abstract or theoretical but the findings of Sarkar (Sarkar et al, 2024) confirm the value of blockchain inside the SC and reinforce its propagating impact within organisations. Specifically, through their extensive study (despite its limitations) the following effects have been observed:

- a reduction in fraud of up to 40%
- efficiency gains of up to 30%
- significant time gains in supply chains (regardless of industry) that have adopted blockchain-based solutions
- serious monetary advantages with a positive Return on Investment since the first year of the adoption

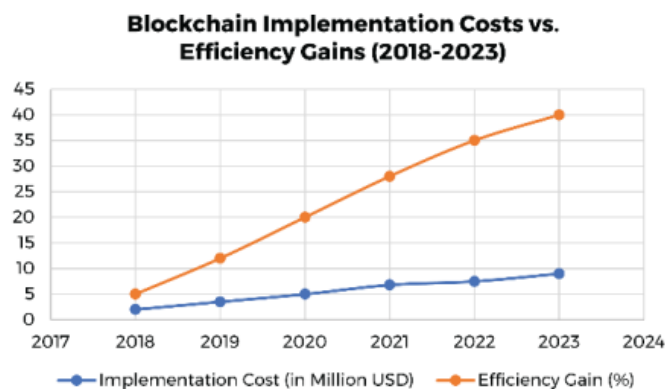


Figure 6.2-1: Relationship between blockchain implementation cost and efficiency gains (Source: Sarkar et al, 2024 (p.8, Figure 2))

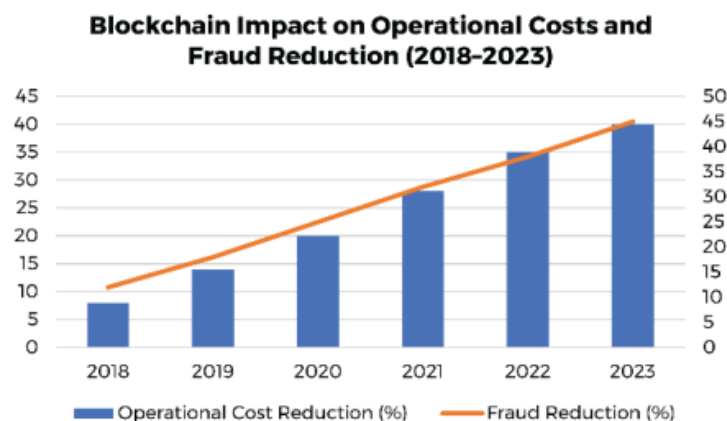


Figure 6.2-2: Benefits of observed cost gains and fraud reductions (Source: Sarkar et al, 2024 (p.9, Figure 3))

6.3. Current pilot applications of blockchain

There is a growing number of pilot projects (both in the logistics industry as well as within the wider supply chain management domain) through which companies explore the benefits of this new technology. The adoption of these blockchain-based solutions into the supply chain (and especially where the railway is involved) is not to be taken as a surprise given the promised benefits of this technology. A comparative study³⁸ has revealed (but has also been confirmed from the author's own research) that the first target of blockchain-based solutions is to simplify or automate paper-based processes. The following examples have been identified (the list is not at all exhaustive).

a. in non-railway-based SC

- Tradelens: this has been an initiative of the shipping giant Maersk that made headlines at the time of its inception in collaboration with IBM in order to track cargo and exchange necessary documents among parties (including customs). This initiative run for several years but is now discontinued due to lack of scaling among other critical actors and particularly freight forwarders³⁹, which is one great lesson for future such endeavours
- MediLedger: serving the pharmaceutical industry this blockchain solution has been developed in order to secure the authenticity of the returned products to wholesalers and combat counterfeits by efficiently tracking them. This initiative has been taken as a response to regulatory pressure regarding disposal of medicine. The platform has been evolving in order to offer new 52services to the industry such as data management for contracts
- Tracr is another blockchain based solution used by the diamonds giant DeBeers in order to track the origin of each diamond and therefore avoid the so called "conflict diamonds". The blockchain is used in order to store in a permanent way information such as origin of the diamond, weight of stone, method of manufacturing, etc

b. in railway-based SC

³⁸ <https://www.sciencedirect.com/science/article/pii/S2352146523009018>

³⁹ <https://piernext.portdebarcelona.cat/en/technology/the-closure-of-tradelens/>

Cargo railway companies have been also experimenting with this technology either by developing their own initiatives in-house or through a partnership with an external entity:

- Russian railways (RZD) partnered with Fesco⁴⁰ for rolling stock maintenance as well as for cargo tracking and smart contract development (at a later stage)
- The Russian Research Institute of Railway Transport has developed a pilot blockchain solution for the cargo transportation monitoring platform (Schelkov, 2022).
- DB Schenker, the logistics arm of the German railway giant Deutsche Bahn has developed in partnership with academia (University of Oldenburg) the digital form of the Bill of Lading through the spin-off Haptik.
- Dutch Railways and CargoLedger (used for real-time cargo tracking)
- CargoX is a blockchain courier service enabling the digital ownership and transfer of documents from one entity to another. Blockchain technology enables them to issue and transfer documents accompanied by proof of authenticity and proof of ownership. Their flagship application is the electronic Bill of Lading (eBL).

6.4. Blockchain as a payment system

As mentioned in 4.1 money flow consists one of the three basic elements of any SC. There is always a need for payment transactions within the activities of a SC. This need matches ideally with the historically first and most known application of the blockchain technology; a payment system. 2024 has been one more pivotal year for this asset class given that the first ETFs have been approved and a lot of regulatory work has been done in the background; all these are signs that this technology shall take a central place in the current financial system. Another interesting development is directly linked with the mega-trend of the digitalization of global supply chains and has to do with the fact that the blockchain (through its cryptocurrency applications) are starting to be recognized or used as a transaction and settlement system for international payments.

⁴⁰ <https://www.globalrailwayreview.com/article/126158/russian-railways-digital-freight-transportation/>

An impressive example is that of Russian Federation, which plans (if not urges) its companies to conduct cross-border payments ⁴¹when they buy goods using cryptocurrencies as a way to overcome the difficulties they face from western sanctions (and particularly the control over international payment systems such as SWIFT).

6.5. The case of Vechain^{42, 43}

Vechain is one of the many blockchain-based projects that exist in the market since 2015. It originates from China but has gone international almost from its start with a substantial client base. What makes it distinct from other projects apart from its technical novelties (compared to similar blockchain projects of the same generation) is that from the very beginning it has been designed in order to have supply chain applications. In the past years it has evolved into allowing for the creation of smart contracts and integrating with IoT and RFID devices in order to enhance its tracking capabilities. Through these features several real-life use cases have been developed and partnerships with real companies established. The most notable examples are:

- DNV GL for food and healthcare industry tracking
- BMW to combat mileage fraud in vehicles
- PWC (and Walmart China) to track product whereabouts

6.6. Generic “Blockchain Potential” Evaluation Framework

In the paragraphs that follow an evaluation framework is proposed regarding the blockchain potential of any given route. The idea is to evaluate in a qualitative way the added value (presented under the form of expected benefits, opportunities and even risks) that the full-scale introduction of a blockchain-based solution would mean for the abovementioned routes along the Eurasian trade corridor. This framework should be considered as a tool for a preliminary assessment before investing in blockchain technology and is intended to help decision makers during their evaluation process.

⁴¹ <https://index1520.com/en/analytics/tsifrovye-platezhi-dlya-transgranichnykh-raschetov/>

⁴² <https://www.investopedia.com/terms/v/vechain.asp>

⁴³ <https://tangem.com/en/blog/post/vechain-in-tangem/>

In its essence this tool is influenced from the work of Irfani et al (2019) and Berneis et al (2024) with some elements originating from the research work of Aritua et al (2022) and Shan et al (2024). All these are adapted in order to suit the context of this thesis.

The framework goes through a 3-level evaluation process. Each level is constructed around a central objective / question and feeds its successor.

Q1 (Level 1): Is the application of a blockchain worth considering?

Q2 (Level 2): Is the application of a blockchain feasible?

Q3 (Level 3): What should be considered for the implementation of a blockchain?

The following figure conceptually demonstrates this process:

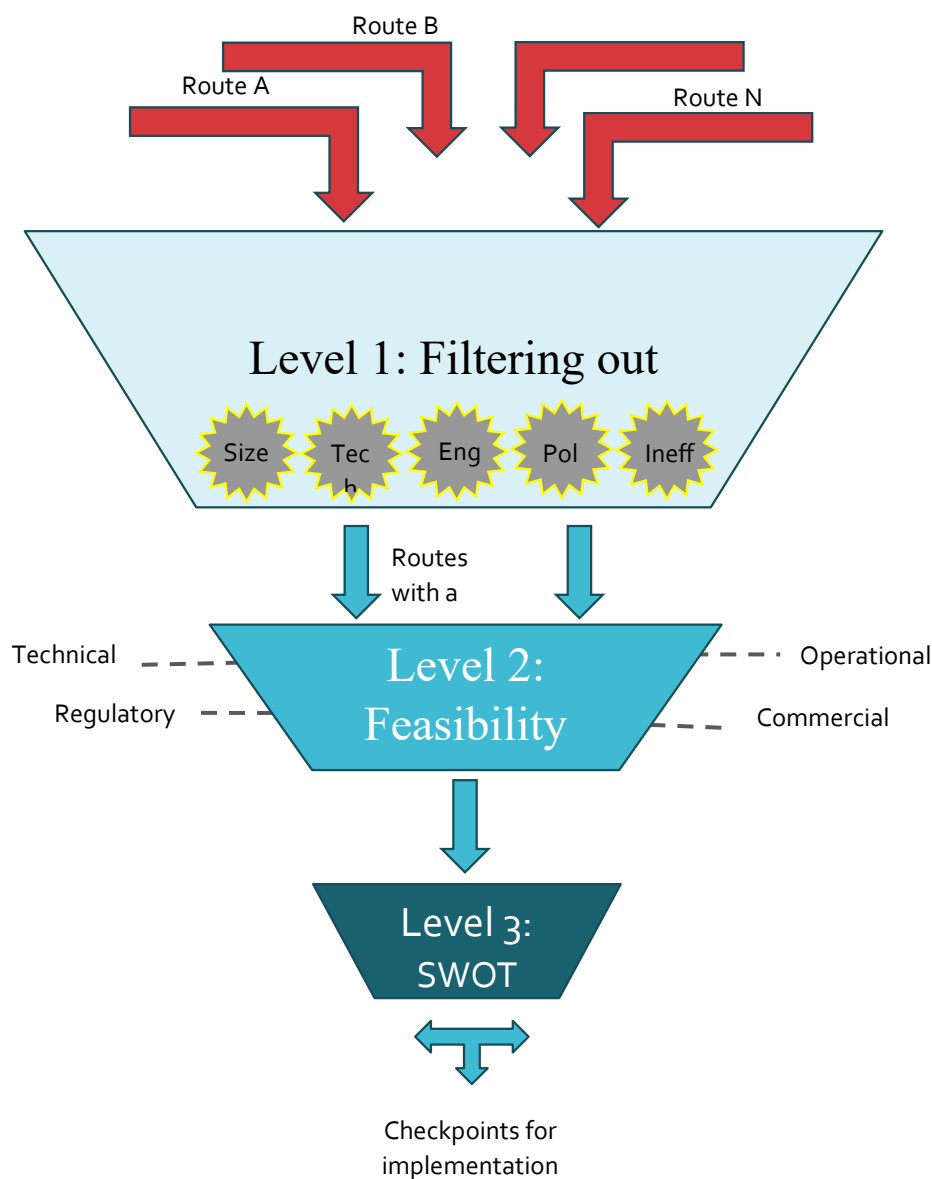


Figure 6.6-1: Blockchain applicability evaluation framework

1. The first level examines the candidate routes on their blockchain applicability potential; that is if their profile seems to justify the investment to develop a blockchain solution. Its aim is to quickly filter out and exclude the corridors or routes where it is obvious that blockchain would need the maximum effort to demonstrate its benefits or the preconditions for its application are immature. In order for a corridor to be considered successful, a number of pertinent “go/no go” assessment criteria are proposed.
2. The second level would only be applicable to the corridors which still “exist” into the evaluation framework and it resembles an initial feasibility analysis. This level attempts to assess operational and technical aspects “hidden” under the following question: “What would be some expected benefits in logistics performance of this corridor under the assumption of a blockchain existence in operations”? A ranking system is used in order to classify the corridors in terms of expected benefits
3. The third level would focus on the top classifying corridor, that is the one that demonstrated the greatest maturity (in terms of prerequisites and benefits potential) and produce some basic inputs for the implementation plan that shall follow. In order to achieve this a more detailed SWOT analysis is conducted with the aim to dive deeper into implementation details and uncover the main threats and risks that would jeopardise (if not managed) the maximization of the expected benefits.

6.7. Generic evaluation framework assumptions, limitations and constraints

The following have to be taken into account while working with / assessing the results of the proposed framework:

- All outputs (rankings) extracted from each criterion (regardless of level) do not come as a result of feedback from market participants. They rather reflect the best possible judgement regarding the level of achievement of each criterion.
- The framework is intended to be used as an unofficial evaluation tool and any decision based on it should be in parallel verified by real data (as practically as possible)
- Wherever real data have been used they have been sourced from several other research papers and their validity or accuracy is assumed to have been done by

the authors of these papers. It is also acknowledged that some of them may not be necessarily up-to-date

- All criteria and sub-criteria carry equal weights for reasons of simplicity. However, the usage of weights could help the framework adapt better to the needs of the stakeholders but this in turn requires a better understanding of all the stakeholders involved. Equally a change in weight could alter the results of the framework
- Criteria that are non-numeric carry by default a subjectivity element that could alter some of the results. However, in their current application the best possible judgement has been applied.
- The evaluation results include some other types of possible sources of bias: measurement errors, outdated information, the time dynamics and horizon of the evaluation, the way that criteria are combined to give a final outcome.
- The existence of other disrupting technologies that will address the same issues or initiatives already launched to address current issues has not been factored in. Any such implementation could alter the evaluation of certain criteria or alter the overall result

6.8. Application of the framework

Q1 (Level 1)

A trade route (or corridor) is a favourable candidate for the development of a blockchain application surrounding part or the whole of its operations, if it responds well to the following eligibility criteria (collectively known as S.T.E.P.I.B.):

- a) **Size:** it shows enough size or is bound to generate enough traffic in order to justify necessary investments. Size and traffic are measured in terms of number of transactions, which in turn depends on the number of stakeholders, the degree of interactions between them and the length of the route
- b) **Technology:** there are other enabler technologies (compatible with the blockchain) in place or at least a culture of technological change in the majority of the stakeholders. Under this criterion the degree of interoperability is also examined.

- c) **Engagement:** it has enough active stakeholders with common interests (or at least willing to align their business models) in order to diffuse the effort and share the blockchain benefits and development costs
- d) **Policies:** it has supportive decision makers towards the mega trend of the digitalization of supply chains, who are open to adopt relevant policy changes and enforce favourable legislation and standardization.
- e) **Inefficiencies:** it has a series of identified and verified problems that can be addressed from a blockchain application (at least in theory)
- f) **Benefits:** it shows high probability to generate an array of benefits

Specifically for the criterion (f) what has been mentioned in paragraphs 5.2 and 6.1 (as the main benefits of a blockchain based solution) can guide us on what type of benefits to seek. A blockchain can provide measurable improvements in areas such as:

- Transparency and consistency of information particularly in cross-border passages or when intermodal transport is part of the journey
- Tracking and visibility of freights from start to finish
- Enhancement of the degree of automation through the whole supply chain (this is mostly related to the implementation of smart contracts)
- Lower risk of centralized control and manipulation
- No single point of failure and contingency
- Lower cost per transaction
- Information availability (current and historic)
- Automation of tasks or transactions (smart contracts)
- Additional “multiplier effect” benefits through the interface with other emerging digital technologies and especially IoT and AI.

Although the above list is not exhaustive it captures the majority of the benefits that a blockchain could offer in the case under examination. The information presented in the tables of this level have been sourced from different research papers and reports (see References). Their analysis integrates the personal views and judgements of the author. Details regarding the individual scores per criterion can be found in the Appendix A: Scales of criteria for the framework.

The outcome of the Level-1 analysis should be a “GO / NO GO” in order to introduce an overall blockchain based solution. The following Table 6.8-1: Analysis of selected routes according to S.T.E.P.I.B eligibility criteria presents the conclusion from the application of each criterion as well as the final verdict. It can be observed that the Northern and Middle corridors are the best candidates for the application of a blockchain-based solution in their daily operations. They present the most balanced profile according to the S.T.E.P.I.B criteria.

Trade route	criterion A: Size	criterion B: Technology	criterion C: Engagement	criterion D: Policies	criterion E: Inefficiencies	Criterion F: Benefits	Result
Northern	High (4): both for intra-country and transit traffic this corridor is the main rail connection for intra continental trade generating numerous transactions	Mature (1): established route with information systems in place. Strong culture of technology improvements	Medium (2): dominated by Russia entities	Supportive (2): Strong support from governments (Russia, China) Pilot projects on digitalization ongoing	Favourable	Medium to High	GO
Middle	High (4): alternative route (but rising) mostly used for regional trade between participating countries and not for transit trade	Immature (0): rising route with some information systems in place. Culture of technology improvements	High (3): a lot of countries are involved as well as international organizations (e.g. EBRD)	Supportive (2): Strong support from participating governments (OSJD and EAEU)	Favourable	High	GO
Southern	Normal (3): mainly used for local traffic	Immature (0): Critical technologies lacking as corridor is not yet mature	High (3): more countries are involved	Not clear digitalization strategy	Uncertain	High to Very High	NO GO

Table 6.8-1: Analysis of selected routes according to S.T.E.P.I.B eligibility criteria

It is worth exploring a bit more the criterion E (Inefficiencies), which is a composite one; it consists of a series of inefficiency categories against which each route is evaluated. The less problems are identified the better for the specific route. It means that a) this route is more “blockchain-ready”, b) the application of a blockchain-based

solution has a higher probability to produce meaningful results and c) there is a higher match potential between the “as-is” and the “future-to-be” status. These potential benefits are further explained within the criterion F (Benefits).

The following Table 6.8-2: Profile of selected routes (criterion E: inefficiencies) elaborates the criterion E in more detail. It breaks down each corridor into “problem areas” and highlights some main issues that have been identified per area.

Corridors	Infrastructure Maturity	Operational Interfaces	Intermodal / Intramodal	Length / Territories	Risks identified	Overall
Northern	High: the majority of the route is based on the Trans Siberian route which has a good infrastructure and good amenities	Change of gauge required at least in two points, good connections with Central Asia countries	No except for the ending Russian eastern ports (Vladivostok,	Around 12.000km end-to-end, main branches Kazakhstan, Mongolia, Manchuria	Financial viability: Dependency on Chinese subsidies Operational dependency: based on Russian network Geopolitical tensions	Favourable
Middle	Medium: parts of the corridors are under upgrade or development, not homogenous maturity across countries	Change of gauge and change of modes	Yes (Kaspian Sea)	Crosses Kazakhstan, Armenia, Ajerbaijan, Georgia, Turkey	Operational performance: many crossings of borders, intermodal inefficiencies make it slow Financial viability: dependency on international investments, probably attractive for regional or local trade	Favourable
Southern	Low: parts of the infrastructure are still in planning mode	Change of gauge and change of modes	Yes (Black Sea or Kaspian Sea)	Crosses Kazakhstan, Kyrgystan, Uzbekistan, Ajerbaijan, Turkmenistan, Iran, Armenia	Financial viability: lack of investment support until very recently Operational inefficiencies hamper its attractiveness Differences in pricing models, legal regimes	Not Favourable

					Geopolitical tensions	
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Table 6.8-2: Profile of selected routes (criterion E: inefficiencies)

The following Table 6.8-3: Expected benefits of blockchain introduction for selected corridors (criterion F: Benefits) shows the expected benefits per corridor after the introduction of a blockchain-based solution in the specific corridor. The focus is mainly on the problem areas where issues have been identified (criterion E) and it is known that blockchain could contribute the most; the absence of other potential advantages does not imply that they do not exist. The score per criterion as well as in total is also presented marked (see Appendix A for the details).

	Transparency	Tracking & Visibility	Degree of automation	Control	Points of failure	Cost	Information availability	Multiplier effect benefits	Overall Match
Northern	High (3)	Medium (2)	Medium (2)	High (3)	High (3)	Low (1)	High (3)	High (3)	Medium to High (2,5)
Middle	High (3)	High (3)	High (3)	High (3)	Very high (4)	Medium (2)	High (3)	High (3)	High (3)
Southern	Very high (4)	High (3)	Very High (4)	High (3)	Very high (4)	High (3)	High (3)	Low (1)	High to Very High (3,125)

Table 6.8-3: Expected benefits of blockchain introduction for selected corridors (criterion F: Benefits)

Q2 (Level 2)

Any route that achieved a positive result in Level 1 (“GO”) undergoes a different type of assessment in Level 2. A deeper evaluation of the practical aspects impacting logistics performance is being studied. That leads to a classification of the corridors under assessment as per their feasibility, which should be in sync with the criterion E of Level 1.

But how is logistics performance defined? Although ideally the performance is measured as a combination of cost and time gains, a more simplified approach will be followed in this model, which is based on time and operational benefits. The main reason for not evaluating the cost aspect is the lack of reliable quantitative data in order to conduct a cost analysis of the two states (“before” and “after” the blockchain).

Time benefits shall be assessed by using the following “delays tree” as a set of sub-criteria. This “delays tree” is specifically relevant to the China – Europe railway routes and demonstrates the most common root causes for delays and cost overruns as they

have been captured and observed during numerous railway trips (eastbound or westbound) for several years. It has been constructed on the basis of bibliography analysis and is based on real data (World Bank, 2023). The findings confirm and follow the major sources of delay as presented in paragraph 4.4 with some specificities. All major root causes are organized in groups depending on the actor that should mainly act in order to address them.

Although this list is not exhaustive these root causes can be considered accountable for the vast majority of operational inefficiencies and delays. In the recent years several actions have been undertaken by the corresponding actor (see paragraph 3.10) in order to address (partially or in total) the corresponding root cause but the information is not always publicly available. As a result of this an evaluation error may be inserted in the scoring.

Source of delay	Impact Description
Technical	
Gauge (transshipment)	This source of delay is inelastic as it is imposed by the technical status of the network. The gauge of the railway network in Russia and all ex-Soviet democracies e.g. Belarus and part of Poland is 1,520 mm as opposed to the gauge in China and the rest of Europe where the standard 1,435 mm gauge is used. This difference calls for unloading / loading operations to compatible railcars as double-gauge railcars do not really exist and it is expensive to build enough of them. The time of transshipment depends on the length of each train, the type of cargo (containerized or bulk) and the available facilities (e.g. cranes, forklifts, etc) but under ideal conditions it takes between 10-12 hours
Interoperability of rolling stock / signalling / communications	This is a global issue especially important with trains that cross multiple borders. The railway networks in East and Central Asia are not made on the same specifications as those in Europe for instance so interoperability issues exist in multiple levels (different sub-systems). Multiple transnational working groups are working together to address them but progress is being slow. Poorly addressed interoperability issues can have operational, cost and safety impacts with the extreme case being the total halt of operations.
Regulatory	
Customs clearance (cross border)	This is a major source of delays with sometimes unpredictable results. Customs operations are still heavily paper based in this area despite the significant efforts undertook by countries as well as international organizations to cut the red tape. Possible reasons for delays could be erroneous data entries, disagreements on classification of some goods between countries, wrong values of goods, errors during reconsignment etc. The creation of customs unions in the area (e.g. Eurasian Union) has significantly improved cross-border customs clearance.
Sanctions (physical inspections)	A new source of delays has appeared in the recent years as a result of the sanctions imposed by the western countries upon entities related to the Russian federation. It has been reported that trains are stopped for physical inspections (so as to ensure that sanctioned goods are not transported) and this adds to the total transport time

CIM / SGMS Consignment	The countries through which cargo trains pass do not accept the same consignment notes. SGMS is recognized by Eastern European, Central Asian countries and China whereas the CIM by the Western countries. Freight forwarders have to do a process known as “reconsignment” which definitely adds to the bureaucracy of the transit. The problem has been identified and since 2006 a combined consignment has been agreed. Although it has been gaining in popularity it is not being applied 100%.
Types of cargo	The types of cargo can add delays on a trip and especially the restricted or the dangerous goods when they are not properly declared. Another parameter is whether the cargo is found in containers (in which case any handling is faster) or bulk (in which case all handling is slower and more expensive)
Operational	
Commercial Speed	The commercial speed of a cargo train depends on many factors but the basic ones are the capabilities of the infrastructure and operational conditions or limitations (which are by nature dynamic).
Container & Railcar availability	The chronic imbalance on the flow of trade (eastbound vs westbound) is not set to change soon so the phenomenon of containers availability will not disappear so easily. By container and railcar availability it is meant to have the right wagon, at the right place at the right quantity the moment of request. Although some solutions that alleviated the problem have been applied it seems that a better tracking of containers could be one of the most promising solutions
Cargo handling	The time to handle the cargo depends on the operational efficiency of each carrier (trained personnel) and at a lesser extent on the means available to execute all handling activities. It seems that the absence of qualified personnel is the main risk on this delay source not excluding operational inefficiencies that might still exist in certain carriers.
Line Capacity	The line capacity depends on infrastructure constraints but also on operational conditions that are dynamic. Recently a new
Bottlenecks in ports / terminals	A major source of delay that can be a localized combination of many other sources. The capacity or the efficiency of terminal ports is particularly apparent upon leaving Asia and entering Europe and this is the reason that the European Commission has taken swift action for the construction of new terminals
Information sharing (EDI)	Connected to other sources of delay there is a big mega trend for the digitalization of supply chains but many regional and local initiatives to harmonize data exchange systems and standardize data. An efficient data exchange is of great importance especially in cross border environments and customs operations as well as the whole supply chain since data are the basis for transparency and information flow. There is a consistent effort by multiple actors to minimize paper documentation and pass on to an electronic documentation system
Technical Inspections, Engine changes, Reconfiguration	In some cases, operational procedures or other reasons may impose the stop of a train for technical inspections (e.g. when a train enters the Chinese territory), in order to change locomotive (for any reason) or to redeploy the railcars (especially in intermediate terminal ports or in smaller yards). There is no clear pattern whether these happen on a regular basis but it is evident that each one of these reasons can create an extra delay.
Commercial	
Tariff (per km)	The cost per km in order to transfer a single container varies and is subject to multiple factors (internal to the supply chain or external). A high tariff may be discouraging for a forwarder and may lead to choose a competitive means of transport.
Reliability of service (timetable)	The reliability of cargo rail services has been highlighted as a major factor by forwarders in order to choose rail for their transports. Although it is basically the responsibility of the operator to ensure a reliable service it

	has to be noted that many factors can affect the reliability of a service not all under the control of an operator.
Subsidies	Many rail routes from China had been (and some are still nowadays) subsidized by the Chinese government as part of the BRI initiative activities in order to generate the necessary stimulus for the development of these corridors. Changes in these subsidy programs certainly impact the viability of these routes with the extreme case being the cancellation of the corresponding routes

Table 6.8-4: Presentation of criteria for Level-2 evaluation

Given the above, the application of a blockchain-based solution would certainly offer some improvements in the corridors under evaluation as summarized in the following Table 6.8-5. Some sources of delays and inefficiencies cannot be remedied by the insertion of a blockchain (they are indicated as “no impact”).

Source of delay	Northern route	Middle route
Technical		
Gauge (transshipment)	No impact (0)	No impact (0)
Interoperability of rolling stock / signaling	No impact (0)	No impact (0)
Regulatory		
Customs clearance (cross border)	Medium (2)	High (3)
Sanctions (physical inspections)	High (3)	High (3)
CIM / SGMS Consignment	High (3)	High (3)
Types of cargo	Medium (2)	Medium (2)
Operational		
Commercial Speed	No impact (0)	No impact (0)
Container & Railcar availability	Medium (2)	Medium (2)
Cargo handling	Low (1)	No impact (0)
Line Capacity	Medium (2)	Low (1)
Bottlenecks in ports / terminals	Low (1)	Low (1)
Information sharing (EDI)	High (3)	High: It has been reported that the mere fact of pre-electronic declaration has saved almost 1.5 days of transit (3)
Commercial		
Tariff (per km)	Low (1)	Low (1)
Reliability of service (timetable)	Low (1)	Low (1)
Subsidy	No impact (0)	No impact (0)
Total	21	20

Table 6.8-5: Level-2 analysis results – Degree of impact of a blockchain

It can be observed that the benefits expected for both corridors are almost identical. The “Northern” corridor has a narrow win, which is a logical output. Given that the solutions to the identified issues depend on implementations of multiple organizational and policy levels, it would be absurd to expect that a blockchain based system could fix all

issues. However, it is certain that it can provide significant improvements to some (directly or indirectly) areas. The fact that the Northern corridor will benefit the most comes from the fact that it is the most utilized; therefore, attention and solutions to the identified issues are ahead in relation to the Middle corridor.

Q3 (Level 3)

The final evaluation level aims to dive deeper into the application of the blockchain for the most promising corridor by presenting the whole spectrum of positive and negative aspects of the corridor's operations after the integration of the blockchain. The tool to be used is the well-known SWOT analysis. The objective is to enumerate the risks, the threats and the opportunities of a corridor operating on blockchain solutions. If the risks can be managed, the threats neutralised and the opportunities mastered through appropriate measures, the return on investment on this technology will be maximised.

By the term “integration of the blockchain” the following setup should be envisaged: there is a common information system that is shared among all major stakeholders operating on this route and the sharing of information is extensive. Access right to all transactions is well defined among stakeholders. A blockchain underpins all transactions regardless of whether they are made manually or automatically (through smart contracts for example) or through several interfaces. The type of blockchain (public or private) as well its infrastructure (nodes, protocols) are not evaluated but it is assumed that all stakeholders have agreed on an optimum design and implementation and there are no frictions of that kind. The type of transactions that are kept on the blockchain include all payments, movements of goods and equipment, official approvals or clearance stamps from customs at a minimum. All transactions are accompanied by their timestamps and are correctly represented on the blockchain (through the creation of appropriate tokens). Appropriate tools for the continuous monitoring and exploration of the blockchain are available to all.

A good example of integration of the blockchain in real operations comes from the work of Pokrosvskaya et al (2023), who shares some of what is going on in the Russian Railways regarding their ambitious digitalization agenda (DTS-2025) and how blockchain has been revolutionizing aspects of their internal operations. A conceptual

algorithm that is used in order to decide if a process needs to be supported by a blockchain is what is shown in Figure 6.8-1. Similarly to what has been proposed in the Level 1 of this framework (just with a different set of criteria).

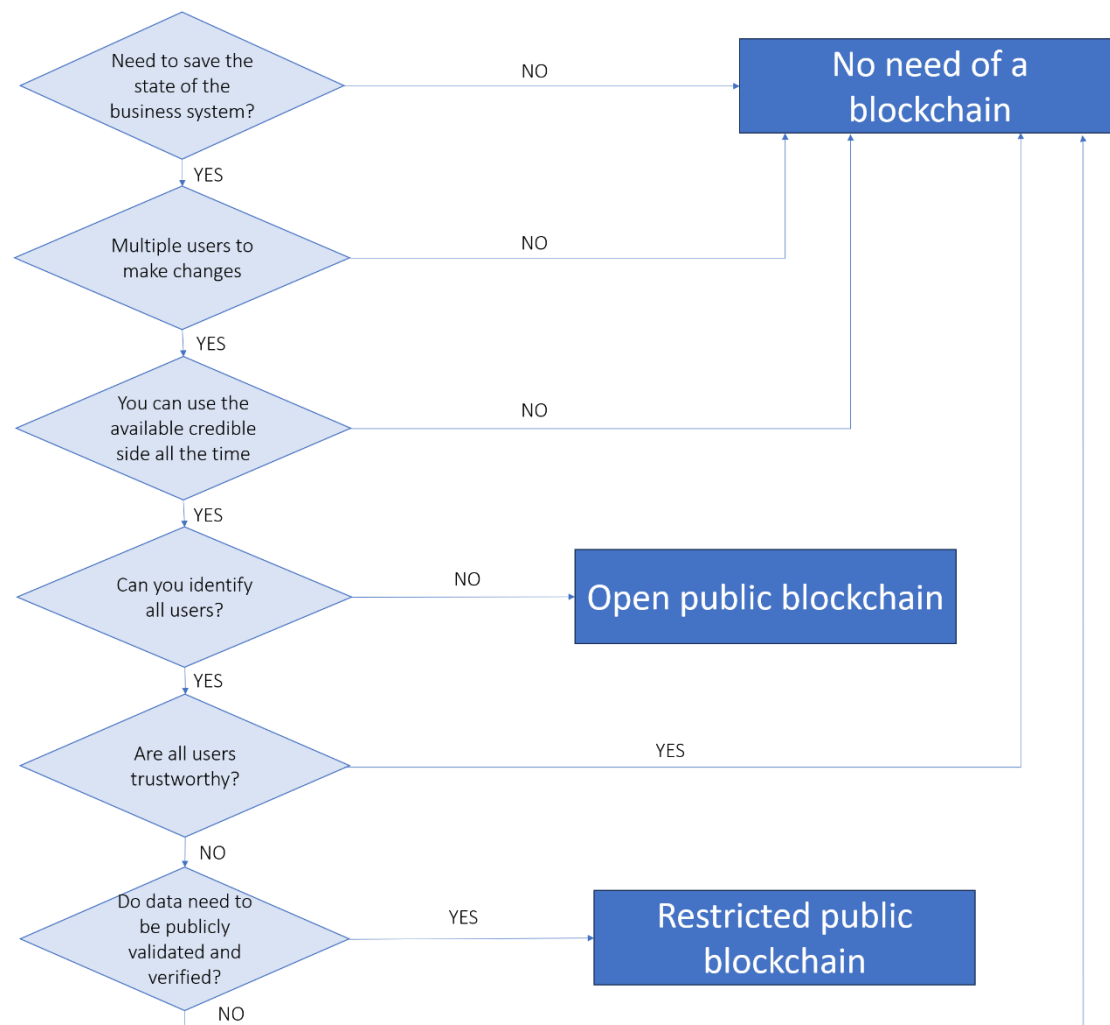


Figure 6.8-1: Algorithm for selecting processes to be put onto a blockchain (Source: Pokrovskaya et al, 2023 (p.6, Figure 2 remastered))

The second level of the framework names the “winner” for the application of a blockchain solution; this is the Northern corridor marginally. Due to its higher overall maturity, the implementation of a blockchain-based solution is more viable. A possible next phase would be to build an implementation plan detailing the different phases for its setup as well as the various budgets per stakeholder (it could be called the “design phase”). With this objective in mind, some basic aspects of this “road to implementation” can be better highlighted and properly addressed (when the time comes) by using the well-known SWOT tool. The exercise below shall endeavour to

project in to a future Northern Corridor, with a fully integrated blockchain surrounding its operations. The term “correctly” refers to a series of details that need to be studied better in order to unlock the full blockchain potential and avoid any pitfalls during the implementation. These details take the form of questions or comments in Table 6.8-6 below.

The focus of the reader should fall on the “Weaknesses” and “Threats” tabs. Weakness is an identified inefficiency with a possible solution in place (or not), which usually is under our control. On the other hand, a threat is a risk that has not been fully studied yet or the mitigation measures are not fully existent or it may be coming from external factors outside of our control. The role of any decision maker or system analyst is to try and minimize the impact of these two groups. When this is done it is easier to exploit the opportunities that may exist but are yet to be realized (because for instance they could need some time to self-develop). Especially for the integration of innovative technologies like the blockchain it is important to “do it right” from the beginning.

As a finishing note the dimension of costs needs to be taken into account. Although the framework in this thesis does not include any cost information it remains probable that when inserting cost information, the SWOT tool may produce different results.

Strengths	Weaknesses
<ol style="list-style-type: none"> 1) Excellent “live” tracking of cargo and rolling stock including transshipments <ul style="list-style-type: none"> • Up to which level? • Tracking of all types of rolling stock? 2) Excellent tracking of containers <ul style="list-style-type: none"> • Replacement or integration of existing tracking technologies? • Tracking of container contents as well? 3) Seamless (or at least very quick) customs clearance and cross-border transits <ul style="list-style-type: none"> • Fully automated via smart contracts? • All interfaces with various customs offices taken into account? 4) Cost and performance advantages of process improvements <ul style="list-style-type: none"> • “Ripple” effect across the supply chain • Cost savings in the long run • New revenue streams 	<ol style="list-style-type: none"> 1) Organizational processes may not be in sync with the spirit of a blockchain <ul style="list-style-type: none"> • Confidentiality issues could limit the sharing of data • Legacy systems may require extensive IT resources / integration with existing systems 2) The longest route compared to the other two corridors (which could be compensated by operational improvements) <ul style="list-style-type: none"> • More transactions compared to other routes can lead to over dimensioning? 3) Increased cargo handling effort, blockchain to optimize up to an extent 4) Legal implications <ul style="list-style-type: none"> • Are legalities well defined in a distributed ledger environment? • Are insurance companies in sync? • Are there intellectual property issues? 5) Technical decisions to be aligned with strategy

	<ul style="list-style-type: none"> • Permissioned vs permissionless blockchains • Are performance requirements clearly set?
Opportunities	Threats
<p>1) Analysis of operations all along the supply chains and unlock of “hidden” issues / operational efficiency improvements</p> <ul style="list-style-type: none"> • Cooperation with data analysis technologies <p>2) Enhancement of big data analytics and forecasting leading to proactive management of the whole supply chain</p> <ul style="list-style-type: none"> • Integration and multiplier effect with other disrupting technologies that emerge <p>3) Automation of tasks and reallocation of resources</p> <ul style="list-style-type: none"> • Reskilling of personnel 	<p>1) Availability of railcars and containers</p> <ul style="list-style-type: none"> • Capacity management to be revisited <p>2) Geopolitical tensions</p> <ul style="list-style-type: none"> • External factors that could impact heavily any investment and any implementation <p>3) Capability to scale</p> <ul style="list-style-type: none"> • Possible to absorb changes in corridor (e.g. new routes, stakeholders)? <p>4) Regulatory status</p> <ul style="list-style-type: none"> • Is regulation homogenous across all stakeholders and jurisdictions? • Tax reporting • Financial auditing <p>5) Data management</p> <ul style="list-style-type: none"> • (Cyber)security • Data protection vs data sharing <p>6) Technological evolution</p> <ul style="list-style-type: none"> • Newer or better technologies that address the same issues • Quantum computing <p>7) Governance model</p>

Table 6.8-6: SWOT analysis of the "Northern" corridor

6.9. Additional resources concerning blockchain implementation

There are numerous resources publicly available regarding the implementation of blockchain-based solutions and there are also many open-source projects that allow the users and the organisations to setup a pilot blockchain rather quickly. As all enterprise-wide information systems a blockchain solution needs to be designed carefully following recognised methodologies and industry practices. Due to the rapid technological advancements in this field, it is advisable to follow a robust risk management process in parallel with monitoring the technical activities. A good starting point for the design and implementation of blockchain solutions specifically addressed to SC is the blockchain kit⁴⁴ of the World Economic Forum.

⁴⁴ <https://widgets.weforum.org/blockchain-toolkit/index.html>

7. Conclusions and further research

The aim of this thesis has been to explore and potentially confirm the value that blockchain, a relatively new and disruptive technology, could bring to global supply chains and in particular those that are served by railways. In doing so the effort has been concentrated to go beyond the alleged benefits of this technology and find real use cases of its value proposition. Through an extensive literature review it has been possible to confirm the dynamic and disruptive nature of this technology and the large potential it carries for the domain of the supply chain and particularly for its logistics part. Many entities have either integrated blockchain in their daily operations (through pilot projects) or are actively planning to do so. However, it has not been possible to source evidence that quantify the tangible results of these implementations due to the short life or confidentiality of all these implementations.

The analysis focused on the East – West trading routes and in particular from China to Europe as these represent a major land-based corridor for global trade with a lot of ongoing investments regarding railway infrastructure. The particular interest to railway freight within this trading zone comes from the fact that rail freight is a rising alternative to the established maritime route, as trading figures show. The sheer fact that such an extensive rail network crosses so many different countries and involves a multitude of stakeholders and regulatory regimes makes the integration of the blockchain into the daily operations an attractive option with tangible and immediate benefits but at the same time a real challenge that carries several risks. The main benefits that can be expected are first on the operational level, then on a more strategic and all these add up to significant commercial gains. There are high chances that cost savings exist almost from the very beginning of the investment. This conclusion has been confirmed by the application of the evaluation framework that has been proposed elsewhere in this thesis. Through this evaluation method has it has been demonstrated that some basic prerequisites need to be satisfied in advance in order to justify and derisk the launch of blockchain initiatives.

Upon analysis of the research material some major points of attention and deficiencies have been discovered, which could also serve as ideas for further research. The first and foremost is the existing imbalance between the different countries and regions in

regards to their policies and priorities concerning railway digitalization and infrastructure building. The China-driven BRI is a major catalyst that pushes forward the necessary upgrades but is not enough on its own. Different approaches (for instance the top-down policy approach in the EU area vs the bottom-up market-driven approach in the Central Asia part) seem to fail to produce a coherent international strategy for the integration of blockchain in current global supply chain initiatives. Moreover, the absence of a common international coordinating body (the existing international bodies are mostly sectoral) combined with the youth of this technology is partially responsible for the absence of some global guidelines and standards regarding the implementation of blockchain-related projects in supply chains. Therefore, the creation of guidelines and the standardization (on several levels policy, technical, legal) is certainly an area of possible academic research.

It remains to be seen whether some routes can be financially viable without direct or indirect subsidies from the Chinese government (Jakobowski et al, 2018). Under this perspective the exact costs of developing and running a blockchain are not very clear, as available data seem to not be publicly available or are not reliable. The financial benefits from integrating blockchains into everyday operations has also not been quantified (although conceptually they exist). As a result, the financial evaluation for the adoption of blockchains by organizations remains still an area for further research provided that many implementation details are clarified. The factor of geopolitics adds another level of complexity and can easily cancel the benefits even of the most well-studied investment or / and implementation. This factor may come in different forms such as emergency regulations, sanctions or trade wars. Its unpredictable nature makes it difficult to mitigate the risks associated with the development of blockchain projects within the supply chains.

The multi-level and multi-criteria evaluation framework that has been proposed in this thesis could also generate some further research work. Both in terms of the criteria and their significance that it uses as well as the results that it produces, it could be tweaked in order to produce more quantifiable or strategically aligned results. A detailed stakeholder map (per route) with their detailed needs in terms of transactions could provide the basis for an improved version of the framework. Criteria that align better with the strategy of each individual stakeholder (and thus may carry a different weight

between stakeholders) could be inserted and used to assess the value proposition of blockchain projects.

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9. Appendix A: Scales of criteria for the framework

The following scales apply to each criterion of the framework presented in Chapter 6.

Level -1

Possible outcomes and values:

- ✓ Overall Result:
 - *GO if the corresponding scores of more than half the sub-criteria belong to their upper 50%*
 - *NO GO if the corresponding scores of less than (or equal to) half the sub-criteria belong to their lower 50%*

- ✓ Criterion A: Size
 - *Very Low: 1*
 - *Low: 2*
 - *Normal: 3*
 - *High: 4*
 - *Very High: 5*

- ✓ Criterion B: Technology
 - *Immature: 0*
 - *Mature: 1*

- ✓ Criterion C: Engagement
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*

- ✓ Criterion D: Policies
 - *Hostile: 0*
 - *Neutral: 1*
 - *Supportive: 2*

- ✓ Criterion E: Inefficiencies
 - Sub-criterion 1: Infrastructure maturity
 - *Low: 0*
 - *Medium: 1*
 - *High: 2*
 - Sub-criterion 2: Operational Interfaces
 - Sub-criterion 3: Intermodal / Intramodal
 - *No: 0*
 - *Yes: 1*
 - Sub-criterion 4: Length / Territories
 - Sub-criterion 5: Risks Identified
 - Overall result:

- *Favorable if numeric sub-criteria scores belong to the upper 50% of their values and non-numeric are considered as not adding unmanageable risks*
- *Not favorable if numeric sub-criteria scores belong to the lower 50% of their values and non-numeric are considered as adding unmanageable risks*

✓ Criterion F: Benefits

- Sub-criterion 1: Transparency
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*
- Sub-criterion 2: Tracking & Visibility
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*
- Sub-criterion 3: Degree of automation
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*
- Sub-criterion 4: Control
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*
- Sub-criterion 5: Points of failure
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*
- Sub-criterion 6: Cost
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*
- Sub-criterion 7: Information availability
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*
- Sub-criterion 8: Multiplier effect
 - *Low: 1*
 - *Medium: 2*
 - *High: 3*
 - *Very high: 4*

✓ Overall match values show the average value of the line

Level – 2

- ✓ Possible values:
 - *No impact: 0*
 - *Low: 1*
 - *Medium: 2*

- *High: 3*
- *Very high: 4*
- ✓ Total values show the sum of all criteria. The elements are classified in terms of their total achieved value

Author's Statement:

I hereby expressly declare that, according to the article 8 of Law 1559/1986, this dissertation is solely the product of my personal work, does not infringe any intellectual property, personality and personal data rights of third parties, does not contain works/contributions from third parties for which the permission of the authors/beneficiaries is required, is not the product of partial or total plagiarism, and that the sources used are limited to the literature references alone and meet the rules of scientific citations.