Application of the Data Pipeline Concept for Improving the Transport Corridors' Efficiency

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Abstract

The article focuses on the problem of improving the efficiency of linked transport processes, such as transport corridors, by improving the performance of information interoperability in such processes. The concept of using data pipelines is considered a basic concept. The scope of the assessment is the humanitarian transport corridor under the Black Sea Grain Initiative. The efficiency of this transport corridor is of exceptional importance in connection with the political and economic situation in Ukraine and its impact on world food security. The main objective of the project was to discover a way to improve the efficiency of this transport corridor through trade facilitation and digital transformation of data exchange and business processes. The international standards, particularly, those provided by the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT), are the ones, that are proposed as a common language for the harmonization of the requirements for such processes. Then the functional approach is proposed by the authors to shift the paradigm of perception for such sets of requirements. This approach was assessed by the authors in their assessment of the United Nations Economic Commission for Europe, which was focused on the practical application of the data pipeline concept. The authors developed further their approach to applying the UN/CEFACT standards and recommendations in general and particularly the data pipeline concept for the practical projects focused on the facilitation of trade and transport procedures. This assessment shows the feasibility of the approach and can be used both as a roadmap for piloting real-world projects and as a basis for further assessments.

Keywords

Data pipeline concept, information interoperability, Black Sea Grain Initiative, digital transformation, data exchange, transport corridors

1. Introduction

Efficient transportation systems are the lifeblood of modern economies, facilitating the movement of goods, people, and information. The concept of transport corridors plays a pivotal role in ensuring the smooth flow of these vital resources. A transport corridor is a designated route or network of routes that connects major economic hubs, and it encompasses various modes of transportation, including roads, railways, ports, and airports. To optimize the efficiency and effectiveness of these corridors, harnessing the power of data and information management is increasingly becoming imperative. This paper delves into the application of the Data Pipeline concept to enhance the efficiency of transport corridors. The Data Pipeline concept is a strategic framework that involves the collection, processing, analysis, and utilization of data to drive decision-making and operational improvements. By implementing data pipelines, the transportation sector can leverage real-time data, predictive analytics, and automation to address critical challenges and enhance overall efficiency. The central thesis of this paper is that the

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systematic integration of data pipelines can lead to significant improvements in the management of transport corridors. As economies grow and the volume of transported goods and passengers continues to rise, the need for data-driven decision-making becomes increasingly apparent. This is particularly important for addressing issues such as congestion, environmental impact, safety, and infrastructure utilization. In the following sections, we will explore the practical applications of the Data Pipeline concept in the realm of transport corridors, including the collection and integration of data from various sources, the analysis and interpretation of this data, and its application for optimizing routing, scheduling, and resource allocation. We will also discuss the challenges and opportunities presented by the implementation of data pipelines, as well as real-world examples and case studies demonstrating the benefits of this approach. Furthermore, this paper will consider the broader implications of applying the Data Pipeline concept in the transport sector, including the potential for improved sustainability, reduced costs, enhanced safety, and a more seamless and interconnected global transportation network. In a world where the efficient movement of goods and people is essential for economic growth and development, the application of data pipelines represents a forward-thinking strategy to address the complex and dynamic challenges faced by transport corridors. The synergy of data and transportation promises a future where the flow of goods and people is optimized, resources are conserved, and the economic and environmental sustainability of our transport networks is ensured. As we embark on this exploration, we aim to shed light on the transformative potential of the Data Pipeline concept in the transportation sector and its role in shaping the future of transport corridor management.

The blockade of Ukrainian seaports caused by the war crisis prevented the export of Ukrainian grain and agricultural products, increasing the risk of famine in multiple countries and raising global food prices. Of Ukraine's thirteen seaports, only three (Izmail, Reni, and Ust-Dunaysk) remained operational, handling around 3% of the country's cargo in 2021. The majority of cargo was transported via maritime routes, with 75% of total cargo turnover and 90% of grain and vegetable oil shipments. Following the February 2022 constraints on land transport routes, there was insufficient capacity to compensate for the loss of maritime traffic. Traditional methods couldn't rapidly expand the transport corridors, necessitating the enhancement of logistics infrastructure efficiency through trade facilitation and digital transformation. The Black Sea Grain Initiative (BSGI), signed between the UN, Turkey, Ukraine, and the Russian Federation in July 2022, unblocked major Ukrainian seaports for grain exports. By December 2022, BSGI enabled exports of over 14 million tons of agricultural products, averting a humanitarian crisis in developing nations and stabilizing global grain prices. The BSGI logistics corridor became vital for Ukrainian exports and holds global significance. In summary, BSGI played a key role in alleviating the situation, emphasizing the importance of efficient logistics in ensuring food security worldwide [1].

2. Literature review

To ensure the effective operation of the Black Sea Grain Initiative, it is imperative to address several challenges concerning security, technological and business process coordination, and information exchange within the framework of the initiative. This, in turn, necessitates the development and application of suitable methods and scientific approaches for project management and the advancement of transport information infrastructure. The articles [2, 3] delve into scientific approaches aimed at reducing ship information security risks, providing maritime transportation safety, and optimizing the functioning of sea grain terminals, all of which are pertinent to the BSGI context. The modern methodologies for fleet management and enhancing maritime transportation efficiency can be found in the studies [4, 5]. However, these works may not encompass several crucial aspects related to the coordination of information flows. Safeguarding the information and environmental integrity of maritime transportation is a critical aspect of implementing the Black Sea Grain Initiative. Numerous promising ideas and approaches in this realm have been put forth in the articles [6–8]. For instance, [6] outlines

approaches for detecting cyber threats and provides a probabilistic assessment of ship cybersecurity, founded on a comprehensive evaluation of shipboard critical equipment and systems' vulnerabilities. The papers [7] are focused on the development of methodologies for managing environmental logistics systems, particularly under conditions of uncertainty. The issue of adaptive knowledge management within the framework of engineering company project activities is addressed in [9].

For the effective operation of the BSGI, the organization of information flow management processes holds paramount significance. The exploration of modern project-oriented approaches in this context shows great promise. The articles [10, 11] delve into these pertinent issues. The models for assessing the cognitive readiness of managerial teams in the implementation of infrastructure programs and practical aspects in measuring the effectiveness of project trajectory based on Markovian models are studied in [10, 11]. The self-tuning dynamic system of project management is developed in [12] based on a project representation as a dynamic system, whose attractor is the point of synchronization in the phase portrait. The entropy paradigm of project-oriented organizations management and portfolio structure dynamics of the organization development taking into account information entropy were studied in [13, 14]. Article [15] deals with SMART intelligence models in application to innovative project management.

A thorough examination of scientific and informational sources reveals that various methods and approaches exist to effectively address specific challenges arising in the context of the Black Sea Grain Initiative. Nevertheless, comprehensive strategies for managing and optimizing the entire transport infrastructure within the framework of this initiative have not received adequate development. Notably, one of the most pressing and underexplored issues pertains to the effective integration of diverse information systems within the BSGI framework. Solving this problem holds immense practical significance for the entire global transportation industry, with a particular urgency for the BSGI. Facilitation of the trade and transport procedures is in the primary area of interest for the United Nations Economic Commission for Europe (UNECE), thus providing a valuable set of standards and recommendations.

Many scholars and practitioners consider the utilization of data pipelines for facilitating the interaction of information platforms with substantial variations in data structure as a highly promising approach. There is ongoing active research in this field, with several noteworthy articles contributing to advancements in this area. Specific details about the achievements in this direction can be highlighted. The data pipeline concept was first introduced in [16] and further developed by the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT) within its "transport and logistics domain" [17]. The concept of the data pipelines for both business-to-business (B2B) and business-to-government (B2G) interaction is described in detail in [18]. The concept of the data pipelines is an effective concept for creating a seamless transfer of the data within complex linked processes. Such a concept is developed in [19] in an application the event logs processing. The focus of this work is on developing the approach to apply the data pipeline concept to the intersystem interaction in the transport context, where we can consider, that all the nodes of such interaction have some own implementation of the information systems, that are supplier and consumer of the data in such interchange. Such real-world context elicits a set of issues, that are: different levels of the growth of the participants' IT solutions, different implementations, including data models, code lists, and other assets, and different legal requirements. Another important consideration is the economic efficiency of data interoperability. Canonical approaches in most cases lead to a huge IT development and compromise the advantages from savings, that such interoperability can provide. However, certain aspects of this matter still lack comprehensive theoretical exploration, which, in some instances, complicates the practical implementation of data conveyor technologies for orchestrating the interplay of information systems in support of maritime transportation. This article is primarily dedicated to the study of this predicament and the formulation of solutions, aiming to address these critical gaps and challenges.

3. Data pipeline concept

The assessment involved an examination of the existing document flows essential for clearing goods within the BSGI. This entailed gathering the documents utilized for BSGI clearance, extracting data from each document, and aligning it with the UN/CEFACT Multimodal Transport Reference Data Model (MMT RDM).

The MMT RDM currently stands as the sole fully functional data model integrating data from all transport modes [20, 21]. Within the hierarchy of UN/CEFACT data models, the MMT RDM enables the comprehensive presentation of information exchanged in trade and transport operations across the entire supply chain, both administratively and commercially. It additionally facilitates the transformation of data from trade and transport documents into the data model format of the World Customs Organization (WCO DM), thus ensuring a complete data cycle within the supply chain. This model builds upon a harmonized data dictionary – the UN/CEFACT Core Components Library (UN/CEFACT CCL), which facilitates precise links to entities within specific domain areas and the transformation of these entities between domains or jurisdictions. The crux of the assessment revolves around employing UN/CEFACT standards and assets, including the MMT RDM, as a cohesive set of prerequisites for harmonizing data originating from diverse trade operations, transport modes, and jurisdictions. The fundamental data structure directly hinges on the MMT RDM. By employing a single data model for a holistic view of a logistics corridor as an integral component of an international supply chain, the practical application of the data pipeline concept becomes feasible. This assessment explores the feasibility of practically implementing the data pipeline concept in compliance with UN/CEFACT recommendations and standards, along with proposing a method to ease the harmonization challenge.

In alignment with the data pipeline concept, data is acquired at its source and only once. It is then reused throughout the supply chain, regardless of the mode of transport or the party or regulator requiring access to this data. The primary principles of the data pipeline concept are as follows:

- Acquiring data from the appropriate source, at the correct location, and at the right time,
- Gathering data once for multiple uses within the supply chain,
- Introducing data to the pipeline at the source,
- Data is solicited from the pipeline upon demand and subsequently transmitted to the recipient following an assessment of their responsibility.

The primary aim of data pipelines is to enhance data quality and ensure its seamless transmission within the supply chain information flow by shifting from a "documentary" exchange model to one that supports international trade based on "datasets." The key distinction between these concepts is that the documentary model relies on a structured (paper or electronic) document format, while the dataset model conveys information in flexible structures, known as datasets (business information entities and aggregated business information entities - BIE and ABIE). These can be generated on the fly to meet specific business process requirements upon a recipient's request. For the practical implementation of the data pipeline concept in a specific logistics corridor, the readiness level of the IT systems of its participants is of paramount importance. The study assessed the adoption of UN/CEFACT standards in the documents and procedural requirements for goods clearance within the BSGI, encompassing 17 types of trade and transport documents across six domain areas, including maritime bills of lading, road consignment notes (CMR), railway consignment notes (SMGS), and more.

4. The approach definition

Here we offer our views on a possible approach to the practical application of the concept of UN/CEFACT data pipelines for the BSGI corridor. This approach is based on the definition of the concept of data pipelines in the White Paper Data Pipelines, Business Requirements Specification (BRS) Data Pipeline Carrier Pipeline Data Exchange Structure (PDES) [23], as noted in previous works of the authors.

The key principle of this approach is to present the data pipeline not as "another" information system that unites the participants in the supply chain, but as a harmonized set of requirements that define interfaces for the interaction of existing IT solutions of the participants.

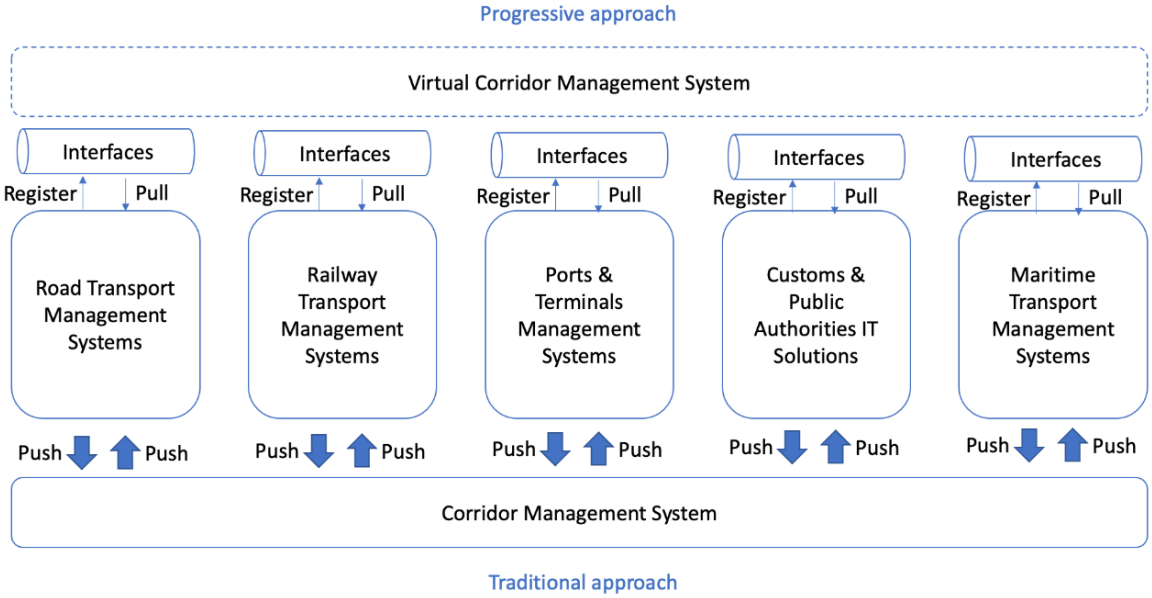

Figure 1: Approach definition

Thus, instead of confrontation and competition with the numerous IT solutions on the market today, used and promoted by both private parties and governments, we propose a cooperation approach that considers the interests of all parties involved. The UN/CEFACT Reference Data Model Hierarchy and the Core Component Library (CCL) are considered a common language for information exchange among participants from different modes of transport and jurisdictions. At the same time, the reference data models play the role of an information structure, and the Core Component Library the role of a dictionary. This makes it possible not to create another data model illustrating the concept of a pipeline, but to inherit it from the canonical UN/CEFACT model, recognized as an international standard. It is important to note that the mechanism used in UN/CEFACT for profiling models for a specific domain can be successfully applied in this case as well.

The technical implementation of the approach implies the use of a distributed ledger to register data sets in the pipeline, and such registration should include a unique and unambiguously identifiable link to the source of such a data set. Such a reference, no doubt, can serve as a decentralized identifier DID [23, 24].

As seen from the illustration in Figure 2, interaction with existing IT solutions of supply chain participants is harmonized in the form of an application programming interface (API). Such API can be domain-specific or even specific for a certain IT solution. The function of such API is to harmonize the specific domain-area presentation of the data sets with the canonical requirements of the Virtual Corridor Management System. Due to the assumption that domains are also utilizing the UN/CEFACT reference data models (with profiling), such harmonization can be implemented as a transformation function over the original dataset.

By proposing UN/CEFACT tools as standards for defining the formats and structures for datasets passing through the APIs in a data pipeline, the authors deliberately try to maintain technological neutrality in the implementation of a distributed ledger. To date, several technologies can be successfully used to build such a ledger - including distributed file systems, blockchain projects, and Internet domain name systems (DNS).

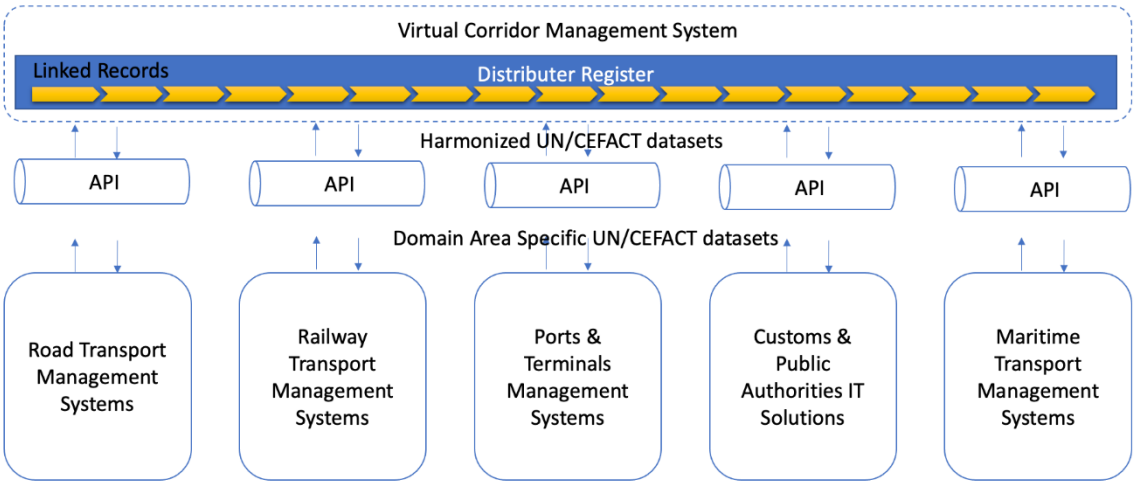

Figure 2: Approach implementation vision

Considering that the described approach correlates with the principles declared during the implementation of the EU eFTI Regulation [25], the idea of using the European blockchain infrastructure for such a registry looks promising. At the same time, for this study, it is sufficient to understand the general architecture of the approach, while practical pilot projects will be determined by the requirements of their participants.

4.1. The approach application roadmap

The approach described in the assessment is based on the harmonization of requirements for the integration of existing IT solutions on a particular corridor using UN/CEFACT global standards. Thus, the roadmap for the practical application of the approach can be presented in the form of three main stages:

1. Identification of the specifics of a particular corridor
2. Building a peer-to-peer network of access points (or using one of the existing ones)
3. Implementation of a corridor-specific data access layer (distributed converters)

4.2. Identification of the specifics of a particular corridor

This is the analytical part of the assessment. It uses business analysis, data analysis, and compliance analysis methods.

1. Determine the scope and boundaries of the project.
2. Determine the composition of the information flow in this corridor:
   a. Identify documents or datasets relevant to the digitalization project,
   b. Identify the interaction processes,
   c. Identify possible IT solutions for the digitalization of the information flow (existing, developed, planned),
   d. Determine the degree of adoption of standards (international, UN/CEFACT, etc.) in IT solutions within the scope of the project.
3. Specify the details of the information flow of the corridor:
   a. Select/collect datasets from documents,
   b. Map datasets to Reference Data Models,
4. Create an information model for this corridor:
   a. Profile the Reference Data Model for project tasks,
   b. Describe the event model,
   c. Define the Business Requirements Specification (BRS) details.

In this assessment, the scope of the project was limited to the BSGI transport corridor. The data analysis and business analysis performed during the assessment helped the author to identify the main information flow, the list of documents, and the datasets from these documents. This allows us to map the data with the reference data model that is the UN/CEFACT MMT and to propose a subset (profile) of such model for the project scope. The detailed report of the assessment and project deliverables is accessible on the www.unttc.org site.

The important part of the concept and valuable part of the assessment is the compliance analysis of the UN/CEFACT standards adoption level of the IT solutions in the scope of the project. The importance of this work is caused by the hypothesis described earlier that domain-specific IT solutions can present the dataset in the UN/CEFACT profiled data models. Compliance analysis uses the UN/CEFACT Recommendation 36 on interoperability among (electronic) Single Window systems [28]. The recommendation identifies five degrees of acceptance of the standard:

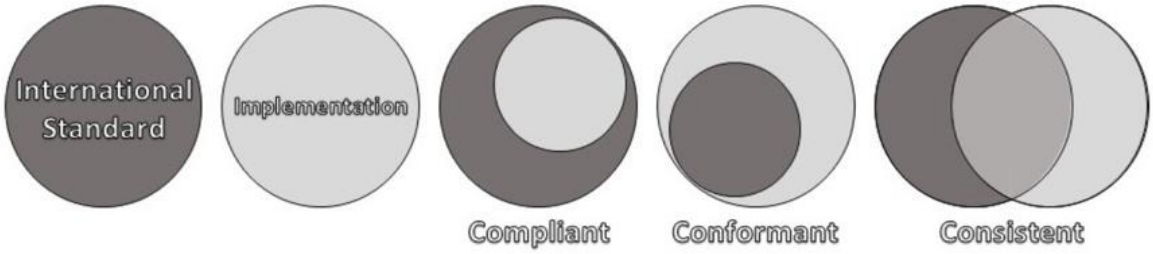

Figure 3: Degrees of adoption of international standards in cases of implementations

We can talk about compliance (compliant) when the implementation of a particular solution is determined solely using the terms adopted for a particular standard, and within its scope. If, when implementing a particular solution, one or another standard is entirely used and additions are included on its basis, then we can talk about conformity (conformant). In this case, it may turn out that new additions are functionally incompatible with other solutions since they are not covered within the specified standard.

When implementing a particular solution, only separate parts of a standard are used, and additions are included on this basis, then we can talk about consistency (consistent). However, even in this case, it may turn out that additions are functionally incompatible with other solutions since they are not covered within the specified standard. Moreover, due to the use of only part of the specified standard, it may well turn out that the other party using the same standard will not be able to adapt to this solution, since certain parts of the standard will be missing in such an "agreed" solution.

Based on the methodology proposed above, the compliance analysis of the adoption of standards was carried out considering this gradation. For the convenience of analyzing the documents involved in the work of the grain corridor, the analysis is divided by mode of transport.

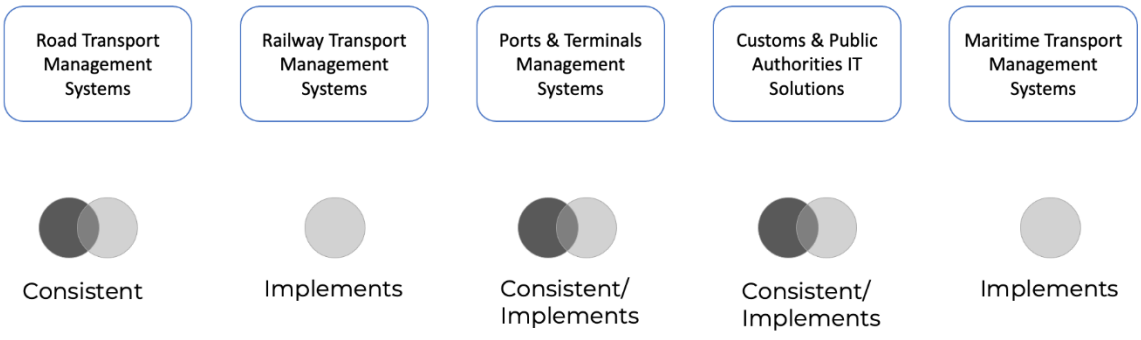

Figure 4: Degree of the standard acceptance evaluation

4.3. Building an Access Point Peer-to-Peer Network

The high level of mistrust between parties involved in the transportation process in general and transborder interaction in particular was described in [21]. The feasible solution to such an issue could be an equal-rights network (of IT solutions) – a pear-to-pear network. The key advantage of such an approach is the absence of a single central point of making decisions (or central authority point) and thus – the equal rights and requirements for all parties – both public and private independently from their residence.

The key advantage of the authors' approach to harmonize the requirements for the existing IT solutions is that the peer-to-peer network of access points can be either created specifically for the task of digitalizing a certain transport corridor, or one of the existing similar networks can be used. As an example, we can cite the concept of a digital global network of logistics and transport providers in the framework of IATA's OneRecord project [27]. The concept of nodes in the implementation of the European eFTI Regulation can also be applied as such a peer-to-peer network.

The basic architecture of the peer-to-peer access point network includes four layers:

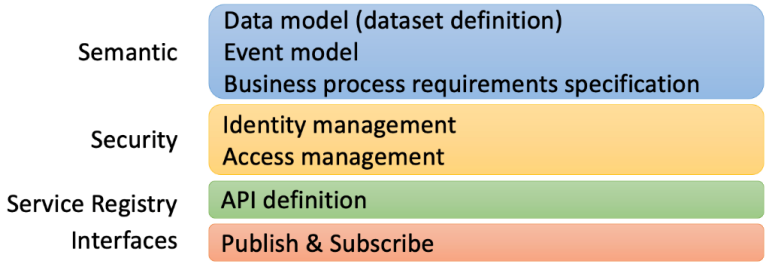

Figure 5: The layers of the access point architecture

The semantic layer is determined by the deliverables of the previous stage. The datasets formed on it become information entities for exchange within the framework of the network that is being created. The creation of a node (access point) in such a network can be described by the following sequence of actions (as an illustrative example):

1. Define a distributed identity schema for Information Entities (datasets),
2. Define the Security and Access Control mechanism for the Information Entities,
3. Create basic structures for storing information about the process of interaction in the network in the form of distributed registers (ledgers),
4. Implement the underlying API for the Information Entities defined in the previous stage.

4.4. Implementing a corridor-specific data access layer

This stage is necessary to link the universality of the peer-to-peer network, the functional completeness of reference data models, and the specifics of implementations of certain IT solutions in a particular corridor.

Depending on the results of the assessment of the level of adoption of standards, carried out at the first stage, the functionality and complexity of the implementation of distributed converters may differ significantly. In the simplest case - when a specific IT solution is implementing the standard - it is possible to organize direct access to data. In the case of the BSGI transport corridor, a high level of standards adoption was detected.

The functionality of distributed converters can be described as follows:

1. (optional) Transforming the internal identifiers into decentralized identifiers by the identification scheme adopted in the peer-to-peer network,
2. Maintaining the canonical "interface" data model,
3. Transforming the data structure between the canonical structure of the reference model and the internal representation of a particular IT solution,

4. Harmonization of non-standardized code lists,
5. Transforming the data format between an internal representation and one that is supported by a peer-to-peer network,
6. Transforming the API calls,
7. Transforming security layer requirements.

4.5. Overall data pipeline process mapping diagram for the BSGI

To illustrate the overall process mapping for a data pipeline implementation in the Black Sea Grain Initiative (BSGI) we use the documents listed in Table 4 and put them in a data pipeline diagram, as was developed in [18].

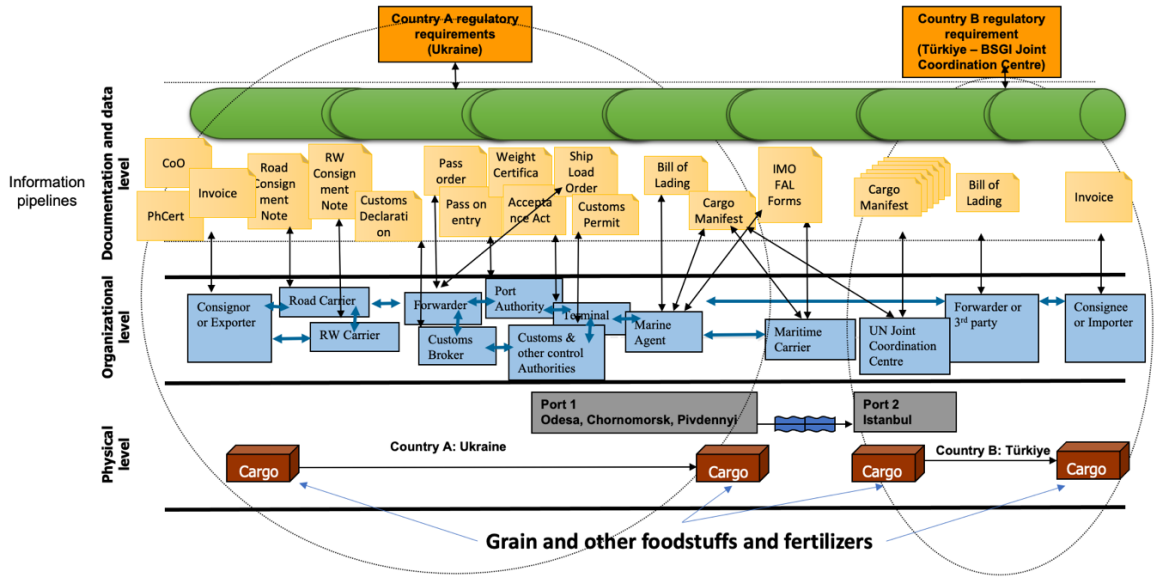

Figure 6: Data pipeline process mapping in the BSGI transport corridor

It is important to mention that paperless information flow is supposed to interpret the documents as the datasets. Moreover, the mapping of such datasets to the canonical reference data models of UN/CEFACT allows us to operate with datasets as separate classes, that provide fine-grained data access control. The data structure for exchange along the possible data pipeline will be defined by the Multimodal Transport and other UN/CEFACT reference data models.

4.6. The functional transformation

The key factor to ensure the interoperability of the parties' interaction with the data pipeline without the need to develop a specific solution for such interaction is the usage of the UN/CEFACT profiles of the reference data model for a specific domain area. In this case, the semantic requirements are fully consistent since the domain area is a subset of the canonical DM requirements. Thus, the transformation from the domain dataset to the pipeline dataset can be realized due to the functional completeness of the canonical model, the reverse transformation is also realized due to the functional completeness of the profile for a specific subject area (i.e., attributes that are not reflected in the profile of a specific domain are considered as non-functional in the scope of this domain). For transforming the representation formats of data sets - the transformation is implemented as a subset, which is the intersection of sets of formats supported by both the domain area and the data pipeline. In any case, there is at least one representation format that is guaranteed to be supported by both scopes, namely the official schema publication format for the canonical data model and domain profiles.

The feasibility of this hypothesis to use UN/CEFACT standards for a specific transport domain is shown earlier in the compliance analysis description. To formalize this process, the distributed converters approach is proposed by the authors.

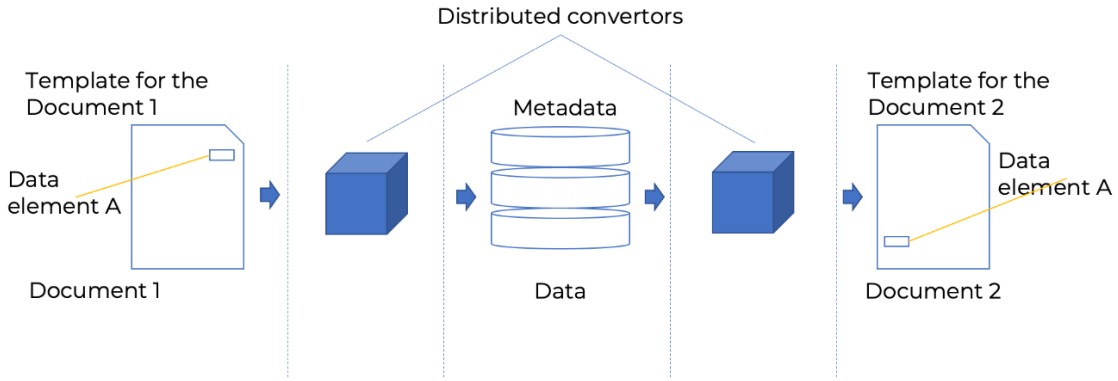

Figure 7: Distributed conversion concept

The documents involved in the process of informational interaction can be represented as a data set from these documents or a set of data attributes:

$$D = [A^1, A^2, \dots, A^N]. \quad (1)$$

The presentation of the document in the particular jurisdiction (we assume the jurisdiction not only as a national but also as a modality of transport) can be described also as a set of requirements:

$$R = [R^1, R^2, \dots, R^M]. \quad (2)$$

The process of the informational interaction in that case can be represented as a function over such sets of attributes:

$$P = F(D, R). \quad (3)$$

The transformation of the data attributes always is caused by the transformation of the particular subset of requirements that influence such attributes while changing the jurisdiction. Thus, the interaction process can be presented as a function over the set of requirements (that is in its turn a set of functions over a set of data attributes):

$$P = F'(R), where\ R = [F_1(D_1), F_2(D_2), \dots, F_M(D_M)]. \quad (4)$$

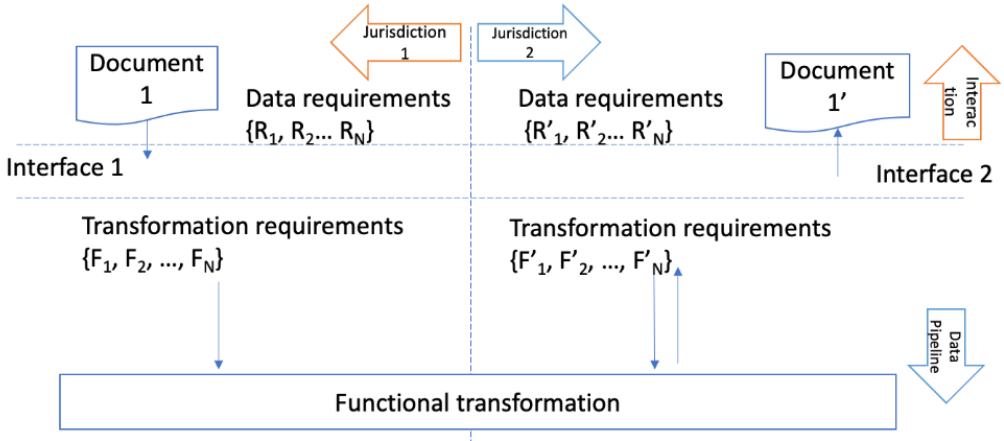

Figure 8: Functional transformation of the requirements within the informational interaction process

Such functions F_1-F_M are the transformation requirements for the data requirements. Due to this, such requirements can be described formally. Harmonization of such requirements description lets us consider them as input parameters for the universal "transformation" function, that executes such converting. As a practical example for describing both sets of requirements, the Extended Markup Language (XML) is proposed, which allows to use of an XSLT transformation for describing the transformation algorithm. The execution of such transformation can be easily implemented in different IT solutions including open sources.

5. Research results and discussion

The article emphasize the significance of the transport corridor in the context of Ukraine's political and economic situation and its global impact on food security. Introduce the use of data pipelines as a fundamental concept for enhancing information interoperability in transport processes. Discuss the adoption of international standards, specifically those provided by UN/CEFACT, as a common language for harmonizing requirements in transport processes. Highlight the importance of standardized communication in improving interoperability.

Highlight for discussion how the assessment serves as a basis for future research and assessments in the field. Discuss potential areas for refinement and improvement in the application of the data pipeline concept.

6. Conclusions

The article proposes a new approach to raising the productivity of information interoperability through its harmonization in general and, particularly, the data pipeline concept for practical projects focused on the facilitation of trade and transport procedures. The other deliverables are the dataset for the BSGI transport corridor, mapped with the canonical UN/CEFACT reference data model, compliance analysis results, bottlenecks elicitation, and recommendations. The efficiency of informational interoperability in such complex processes as transport corridors is essential and the approach to formalize the operations with the sets of requirements is a promising way for facilitating this problem. The application of the acknowledged international standards is a valuable boost for the harmonization of these sets. This assessment shows the feasibility of the approach and can be used both as a roadmap for piloting real-world projects and as a basis for further assessments.

The future of transport corridors, and the integration of data pipelines will be instrumental in addressing the growing demands of global trade, population mobility, and environmental sustainability. The synergy between data and transportation offers a pathway to enhance operational efficiency, reduce costs, and minimize the environmental impact of transportation systems. The strategic integration of data pipelines into transport corridor management is more than a concept; it is a necessity. It is a commitment to optimizing the flow of goods and people, reducing resource consumption, and ensuring the long-term sustainability of our transportation networks. The journey towards achieving these goals will require collaboration between government agencies, private industries, technology innovators, and research communities. Together, we can harness the transformative power of data pipelines to unlock the full potential of efficient and sustainable transport corridors.

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