Logistics Ontologies Landscape: Challenges, Gaps, and Opportunities for Improved Representation

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Abstract

Data standards are essential for coordinating logistics information across diverse stakeholders. This report explores the role of ontologies in shaping logistics data structures and enhancing interoperability. By assessing current logistics ontologies, it identifies challenges and gaps in data representation, aiming to describe the current state of logistics data standards.

Introduction

Data standards are crucial for organizations for coordinating, sharing, and communicating information among stakeholders. Logistics needs to track provenance information across all the different companies involved in the loop, which means that for exchanging information they will have to use aligned protocols and data standards to achieve this purpose. The responsibility of organizations is to describe holistically not only the external logistical aspects, but also the complex internal processes involved in their operations. These internal processes are responsible for facilitating the seamless flow of goods and services, enabling comprehensive strategic analysis. By accurately representing and understanding both internal and external logistics processes, organizations can gain valuable insights into their operations, identify areas for improvement, and optimize their overall supply chain performance.

An ontology is a formal representation of knowledge that defines the concepts, relationships, and properties within a specific domain. In logistics, ontologies can be used to model and standardize data elements, attributes, and their interconnections. By facilitating alignment between logistics actors, ontologies create an environment where data structures and definitions are shared, speeding up data exchange and strengthening data interoperability.

By examining the current landscape, this research report aims to offer an overview of the scope, coverage, and applicability of ontologies in the logistics domain. It seeks to identify any challenges and gaps that exist in the representation of logistics processes. The goal is to gain a better understanding of the current state of logistics ontologies.

General ontologies

Before delving into domain-specific ontologies, we first examine initiatives that provide a broader overview of logistics since one of the shortcomings of most ontologies is to be developed for specific applications [1]. This initial analysis lays the foundations for further exploration of specific ontologies that focus on distinct aspects of logistics.

The Federated platforms[1] produced a semantic representation[2] intended to provide an upper ontology for the logistics domain without regarding more specifically into modalities such as the way of transportation. The ontology's architecture includes various modules with business service, digital twin, event, physical infrastructure and classification to form a cohort of seven interconnected ontologies including OneRecord,[3] which focuses on shipments, and ERA ontology[4] which specifically addresses railway infrastructure and vehicles. However, this model lacks informative documentation about the ontology and the choices used in its development, and internal processes are also not represented in this model.

Logistics is a subset of the supply chain domain, and it consists in supporting the movements and supply of goods. This means that the initiatives to represent and enhance the understanding of supply chain can be applied to logistics. The Supply Chain working group of the organization Industrial Ontologies Foundry[5] is focused on creating, extending, and merging ontologies for the domain of supply chain and logistics and they developed the Supply Chain Reference Ontology (SCRO) [1].[6] This ontology was used in different domains such as biomedical or agri-food domains [2].

The work conducted by [3] highlights several weaknesses in the representation of ontologies within the context of supply chain. These weaknesses primarily revolve around a lack of understanding of the reality of supply chains and a limited analytical depth. Additionally, there is an absence of clear definition of material and services traceability, a lack of standardization for equivalent objects and data properties, and no initiative for integrating existing ontologies, despite what is recommended [4]. Building upon the findings of [3], the authors of [5] concluded that the coverage of supply chain ontologies is heavily fragmented and concepts such as warehousing, events or services are under-represented.

Internal Logistics

After delving into ontologies with a broader understanding of logistics, it appears that some aspects related to internal logistics were not considered. However, amidst this gap, several noteworthy initiatives have emerged that aim to bridge the gap, making them worthy of our attention.

In [6], the authors propose an extension of the Manufacturing Systems Ontology (MSO) for the design of internal logistics resources and warehousing aspects, rather than focusing on manufacturing processes or inter-organizational logistics as other ontologies do. The authors conducted a thorough comparison of 30 ontologies with a logistics focus. Their analysis revealed that most of these

[1] https://www.federatedplatforms.eu

[2] https://github.com/Federated-BDI/FEDeRATED-Semantic-Model
[3] https://onerecord.iata.org/cargo
[4] https://data-interop.era.europa.eu/era-vocabulary/
[5] https://industrialontologies.org/supply-chain-wg/
[6] https://github.com/iofoundry/ontology/tree/master/supplychain

ontologies address inter-organizational logistics in the context of supply chain applications. However, only a small subset of these ontologies (five of them) incorporates internal logistics aspects. The authors also noted that the representation of physical resources across all ontologies was insufficient and lacking in detail.

In their survey [7] focused on robotic systems, the authors identified only 3 ontologies addressing warehousing applications in this domain. They also mentioned the ADACOR ontology [8], which was developed as part of a multi-agent manufacturing system control, but has not been tested in a real environment. The authors noted that cognitive capabilities have been designed most of the time in a prototypical way. Another study by [9] highlighted that previous work did not adequately consider internal logistics aspects, and the developed ontologies were not intended for use in other contexts due to their lack of interchangeability and heterogeneous structure.

Domain specific ontologies

On one hand, general ontologies offer a high-level perspective on logistics, encompassing a wide range of concepts. On the other hand, domain specific ontologies focus on given aspects within the logistics ecosystem. By targeting specific needs and requirements, domain specific ontologies provide a detailed understanding of processes enabling customized approaches to improve operational efficiency.

City Logistics

In the survey conducted by [10], the authors provide a comprehensive review of city logistics modelizations. They observed that most existing work focused on an administrator's perspective and neglected the contributions of other important stakeholders. To this end, the authors compared 31 ontologies and evaluated them based on the stakeholders represented, objectives, descriptors, and solutions. Their findings highlight the need for additional descriptors, such as modal transfer and vehicle loading, to enhance the modeling of urban freight and gain a deeper understanding of the underlying causes involved in this process. The authors noted the scarcity of representations that consider infrastructural impacts, such as congestion charging for goods delivery vehicles.

Construction

The digital construction ontologies (DiCoN) [11] represents logistics management in the construction domain, they aim to handle quality management data and workflows of AI-based information. T In the future, the authors hope to develop extensions of these ontologies to support image-based AI applications. Nevertheless, one of DiCoN's limitations lies in its lack of alignment with pre-existing initiatives, despite the consideration of obvious conceptual overlaps.

Packaging

Little attention was given to the design of ontologies about packaging, one of the first studies investigating this topic was conducted by [12] where they used database schemas as a foundation to generate the initial draft of an ontology. This foundational draft was further refined by domain experts, who also contributed with valuable business rules specific to the packaging domain. Seeking to bridge the knowledge gap regarding packaging, particularly for perishable goods, the authors of [13] took on the task of developing an ontology focused on food packaging. For this purpose, they established relationships with entities in the field of fresh logistics. However, it is important to recognize that this ontology has certain limitations. Notably, it falls short in considering sustainable packaging approaches such as batch binding, expiration management, and reverse logistics.

Conclusion

Ontologies hold a crucial role in the logistics domain by serving as formal knowledge representations that facilitate data standardization and foster data interoperability among stakeholders. The review of current ontologies landscape in logistics reveals that both general and domain-specific ontologies fail to address aspects related to internal logistics and sustainability in logistics. While general logistics aspects tend to be well represented, domain-specific ontologies are often unlikely to be viable in real-world scenarios due to their lack of development with practicality in mind. Additionally, they often fail to prioritize the reuse of existing work, hampering progress and efficiency in this domain.

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