# Ontology Modeling for Digital Twin Development in Maritime Logistics

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This paper develops a domain ontology to enhance the digital twin for maritime logistics at the Twente canal. The research aims to improve operational efficiency, resilience, and stakeholder collaboration through a comprehensive ontological framework. The study employed a literature review and iterative model development using OntoUML. The main models created include the Domain Model, which maps the primary relationships within the Twente canal's logistics operations, and the Disruption and Digital Twin Models, which focus on contingency planning and technological integration, respectively. The outcomes demonstrate that the ontology can significantly enhance semantic interoperability and support proactive management strategies, promoting a robust digital twin implementation. Future work could focus on validating the ontology and working on the effective integration to ensure its practical applicability and scalability.

Additional Keywords and Phrases: Digital Twin, Ontology, OntoUML, Domain Modelling.

## 1 INTRODUCTION

In today's digital era, the concept of a digital twin has emerged as a powerful tool for enhancing operational efficiency and resilience in various domains [13]. A digital twin is commonly described as a virtual emulation of an object or system, persisting throughout its lifecycle, continuously updated with real-time data, and leveraging simulation, machine learning, and reasoning techniques to support decision-making processes [10].

The Port of Twente has initiated a project to develop a digital twin for the Twente canal, motivated by recent problems caused by disruptive events (drought, floods, and infrastructure breakdown/failure) that have negatively impacted logistics operations, stakeholder satisfaction, and environment along the canal [16]. Altering ecological systems and physical infrastructure is a costly and time-consuming endeavor. However, proactive steps can be taken to redesign the logistics system, utilizing innovative strategies such as digital twins, to establish resilient and adaptable corridors in response to changing environmental conditions. The aim of this digital twin is to create a resilient toolbox for multimodal transportation, enabling proactive decision-making and mitigating the impact of unforeseen events.

It is evident that digital twins can provide various benefits for the maritime logistics domain, including fleet optimization, port management, supply chain efficiency, and stakeholder collaboration [12]. For instance, at the Port of Twente, a digital twin could be utilized to optimize vessel traffic during adverse weather conditions. By simulating various scenarios and testing out hypothetical situations, the digital twin can predict potential disruptions and recommend proactive measures to mitigate their impact. Stakeholders, including port authorities, shipping companies, and logistics partners, could receive real-time information and alerts from the digital twin, enabling timely decision-making and resource allocation. Similarly, the digital twin could be employed to predict the impact of infrastructure maintenance on logistics operations, allowing stakeholders to plan and schedule maintenance activities to minimize disruptions. However, the implementation of digital twins also entails complex tasks that need to be addressed to realize their full potential.

## 2 PROBLEM STATEMENT

The complexities of digital twin systems in maritime logistics arise from diverse data sources, dynamic operations, and interoperability challenges. Managing large volumes of heterogeneous data, adapting to changing conditions, and integrating disparate systems pose significant hurdles. Additionally, scalability and adaptability are crucial for accommodating evolving operations. These challenges underscore the necessity of developing a comprehensive domain ontology model. Such a model plays a pivotal role in ensuring seamless communication, effective data integration, and semantic interoperability within the digital twin ecosystem [14].

In the context of the Port of Twente, the development of a digital twin for the Twente canal presents a significant opportunity to improve the resilience and efficiency of maritime logistics operations. Furthermore, the utilization of ontology-based models is increasingly recognized as a crucial component in the development of digital twins [2]. Ontology in the field of metaphysics explores various forms of existence through the delineation of categories, properties, and relationships [6]. In the context of digital twins, ontologies provide a formal representation of domain knowledge, facilitating interoperability, data integration, and conceptual understanding [2].

Therefore, understanding the importance of developing an ontology and its role in enhancing the interoperability of information is crucial for the success of the Port of Twente's digital twin project. The complexities associated with the digital twin emerge into the following research question:

*"What are the fundamental components and strategic implications of constructing a domain ontology to facilitate the development of a Digital Twin in Maritime Logistics?"*

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The main goal of the research question is to develop an ontology-based model that is directly applicable to the Port of Twente project and captures all relevant aspects in detail.

To effectively answer the research question, the following sub-questions were formulated:

- What are the key concepts and relationships that need to be represented in the ontological model for a Digital Twin in Maritime Logistics?

- How can stakeholder requirements and domain knowledge be effectively integrated into the ontological model for the Twente canal project?

By addressing these questions, the research aims to contribute to the development of more resilient and efficient maritime logistics systems, leveraging the full potential of digital twin technology.

## 3 RESEARCH METHODS

This research seeks to explore and develop an ontological model to facilitate the development of a digital twin for maritime logistics tailored for the Twente canal project at the association of Port of Twente. The methodology includes a literature review, model development using OntoUML, and a reflection on strategic significance of such an ontology for the development of a digital twin.

### 3.1 Research Design

The research employs an iterative design approach for developing the ontological model combined with a more qualitative approach that will help leverage the existing theory to develop and validate the ontological model. The focus is on creating a detailed and accurate ontology-based model that can be utilized for the development of a digital twin in maritime logistics.

### 3.2 Literature Review

A literature review was conducted to gather information on digital twins, ontology modeling specific to digital twins, and OntoUML specifics. This review helped identify the key concepts, relationships, and challenges associated with the development of digital twins in maritime logistics.

The literature review helped to establish a theoretical foundation for the research by highlighting the benefits of digital twins, the role of ontology in modeling, and the specific challenges in maritime logistics. It also provided insights into the existing methodologies and frameworks used in digital twin studies, thereby informing the development of the OntoUML models. The OntoUML modelling language has been thoroughly studied as well.

### 3.3 Development of OntoUML Models

The development of the ontological model has been carried out using the OntoUML language. OntoUML extends the traditional UML (Unified Modeling Language) through the addition of ontological distinctions, which makes it suitable for representing complex domain knowledge with high accuracy [6].

Through an iterative approach to the design of the ontology, the development process has been divided into three distinct phases: the domain model, the disruption model, and the digital twin model.

The domain model captures essential entities and their relationships within the maritime logistics context of the Twente canal, including components such as vessels, ports, bridges, and locks. The development process involved identifying key entities and their attributes, defining relationships to reflect operational dynamics, and creating an initial OntoUML diagram. The disruption model focuses on identifying and representing various disruptions in maritime logistics. This phase involved identifying the causes of disruptions and modeling their impact on port operations. The digital twin model extends the domain model by incorporating IoT sensor devices on relevant entities to collect real-time data, which is then integrated into a platform for monitoring, simulation, and optimization. This phase involved identifying entities from the domain model to be equipped with IoT devices and developing the digital twin model to represent these devices.

### 3.4 Reflection and Iteration

The research methodology incorporates continuous reflection and iteration. Based on feedback and validation results, the models are constantly updated to improve their accuracy and applicability. This process ensures that the final models are inclusive, comprehensive, and practical for use in developing the digital twin for the project.

## 4 LITERATURE REVIEW

The literature review provides an exploration of the development and application of digital twins and relevance to maritime logistics. It examines the role of ontology in creating comprehensive models by using the OntoUML modelling language and points out the current challenges and research gaps in this field. The review aims to establish a basis for the development of an ontological model for the Twente canal project.

### 4.1 Overview of Digital Twins

The concept of digital twins has evolved significantly over the past decade, driven by advancements in technology and increasing demands for more efficient and resilient systems. A digital twin is a dynamic, virtual representation of a physical object, process, or system, created to simulate, predict, and optimize performance through continuous real-time data integration [3].

Digital twin technology was first utilized in manufacturing and aerospace, where it was used to monitor and maintain complex machinery. Its application has since expanded into various domains, including healthcare, urban planning, and maritime logistics [4]. The integration of Internet of Things (IoT) devices, big data analytics, and artificial intelligence (AI) has been pivotal in the development and deployment of digital twins. These technologies enable the processing and analysis of big amounts of data, which in turn provides a comprehensive understanding of the physical system's state and behavior [15]. In maritime logistics, digital twins are employed to enhance operational efficiency, optimize routes, manage fleets, and maintain port infrastructure. These systems can simulate different operational scenarios, identify potential disruptions, and recommend proactive measures to mitigate risks [9].

The evolution of digital twins has been marked by several key developments:

- The integration of AI and machine learning algorithms has improved the predictive capabilities of digital twins, allowing for more accurate simulations and optimizations [4].
- Recent advancements focus on developing scalable digital twin frameworks that can be applied across different domains and integrated with various systems and platforms, boosting its interoperability [15].
- There has been a push towards standardizing digital twin models to ensure consistency and interoperability across different applications and industries [3].

Overall, the constant evolution and adaptation of digital twin technology showcase its potential to transform maritime logistics by enhancing efficiency, reducing costs, and improving resilience against disruptions.

## 4.2 Ontology of Digital Twins

Ontology plays a crucial role in the development and implementation of digital twins by providing a structured framework to represent domain knowledge. Ontologies help in defining the concepts, properties, and relationships within a particular domain, facilitating data integration and interoperability [6]. In the context of digital twins, ontology models ensure that all relevant aspects of the physical system are accurately represented in the digital twin, enabling more precise simulations and analyses [2].

The use of ontologies in digital twins involves creating a formal representation of the knowledge within the domain. This includes defining the various entities involved, their attributes, and the relationships between them. By using a standardized ontology, different systems and components can communicate more effectively, ensuring that data is accurately shared and interpreted across the digital twin ecosystem [15].

## 4.3 OntoUML Modelling Language

The application of OntoUML in digital twin development involves creating detailed models that capture the essential aspects of the physical system. These models are then used to guide the construction of the digital twin, ensuring that it accurately reflects the real-world system. For example, in maritime logistics, an OntoUML model could represent the various components of a port, such as vessels, cranes, and storage areas, along with their interactions and dependencies [2].

OntoUML's ability to provide a clear and comprehensive representation of domain knowledge makes it an invaluable tool in the development of digital twins. By using OntoUML, developers can create models that are not only accurate but also adaptable, which can help the digital twin to evolve as the underlying physical system changes [6, 7].

The fundamental distinction in OntoUML is between Types and Individuals. Types refer to general categories or classes of entities, which define the common properties and behaviors that their instances (individuals) share [7]. Individuals are the specific instances of these types. For example, "Vessel" is a type, while "Vessel A" and "Vessel B" are individuals that fall under the type "Vessel".

OntoUML introduces several class stereotypes that help distinguish between different kinds of entities and their roles within a domain [6, 7]. These stereotypes include:

- Kind: Represents a fundamental category of entities that are essential and immutable. For example, a Vessel in maritime logistics.
- Role: Represents entities based on their roles or functions in specific contexts, which can change over time. For instance, a Skipper is a role that a Person may assume.
- Phase: Represents temporal states that an entity can go through during its existence. For example, different operational states of a Lock.

Furthermore, important concepts include the classifications of Rigids and Sortals [6, 7]:

- Rigids: Categories that an instance cannot cease to belong to without ceasing to exist. For instance, a Person is a rigid category because a person cannot stop being a person without ceasing to exist.
- Sortals: Provide criteria for identity and classification for their instances. For example, Vessel is a sortal because it defines what constitutes a vessel and how vessels are differentiated from one another.

To showcase and establish the intermediaries of relationships among the entities, concepts of Mediations and Relators are introduced [6, 7]:

- Relators: Represent relationships that provide a context in which entities participate. Relators are crucial for modeling complex interactions and dependencies. An example could the Ownership relationship between a Person and a Vessel, indicating responsibility and control.
- Mediations: Mediations are specialized types of relationships that involve relators. They provide a structured way to represent interactions between entities. For example, the Employment relationship mediates between a Person and a Canal Authority or

Port Organization, indicating the person's role and responsibilities within these entities.

Moreover, OntoUML uses a specific coloring to differentiate among various class stereotypes. Objects are red (specific instances or entities); Relators are green; Intrinsic moments are in blue (properties or qualities related to other entities) [6]. Other stereotypes are also color-coded for clear differentiation and readability.

Last, but not the least are the different types of relationship stereotypes that exist in OntoUML. The three relationships that were used the most in the models are: Mediation (connects a relator to the entities, showing dependency), Characterization (links an entity to an intrinsic moment, indicating properties or qualities), and Generalization (establishes a hierarchy where a subclass inherits properties from a superclass). Cardinalities and multiplicities specify the number of instances involved in a relationship. Cardinality indicates the exact number of instances, while multiplicity indicates a range of possible instances. For example, "0..1" means zero or one instance, "1" means exactly one instance, "1.." means at least one instance with no upper limit, and "0.." means zero or more instances.
Other important concepts needed for the understanding of the models will be discussed in further sections of their respective models.

### 4.4 Challenges and Gaps

Despite the potential benefits, the implementation of digital twins in maritime logistics presents several challenges. These include the management of large volumes of heterogeneous data, the need for high computational power, and the integration of disparate systems [18]. Additionally, there are significant gaps in the literature concerning the standardization and scalability of digital twin models across different maritime environments [11].

Even though the development and knowledge base for ontologies of digital twins have gained a lot of popularity recently, the research in constructing an ontology for the maritime sector of digital twins is still underdeveloped. Current efforts have primarily focused on general frameworks and applications in other industries, leading to a lack of standardized methodologies and frameworks that can be universally applied in maritime contexts [8].

Moreover, the complexity involved in modelling dynamic and interconnected maritime logistics environments exacerbates these challenges. The creation of robust ontologies that can accurately capture the intricacies of these systems requires extensive domain knowledge and interdisciplinary collaboration, which are currently insufficiently addressed in existing studies [6]. This gap highlights the need for further research focused on developing and validating comprehensive ontology models that can be seamlessly integrated into digital twin frameworks.

## 5 ONTOUML MODELS

### 5.1 Domain Model

The Domain Model serves as the foundational framework for visualizing daily operations and interactions among physical objects within the maritime logistics context (Fig.1, model can also be accessed through a link in Appendix A1). This model includes essential entities, attributes, and relationships that capture the dynamic operational environment of the port. The model is designed to support the development of a digital twin,

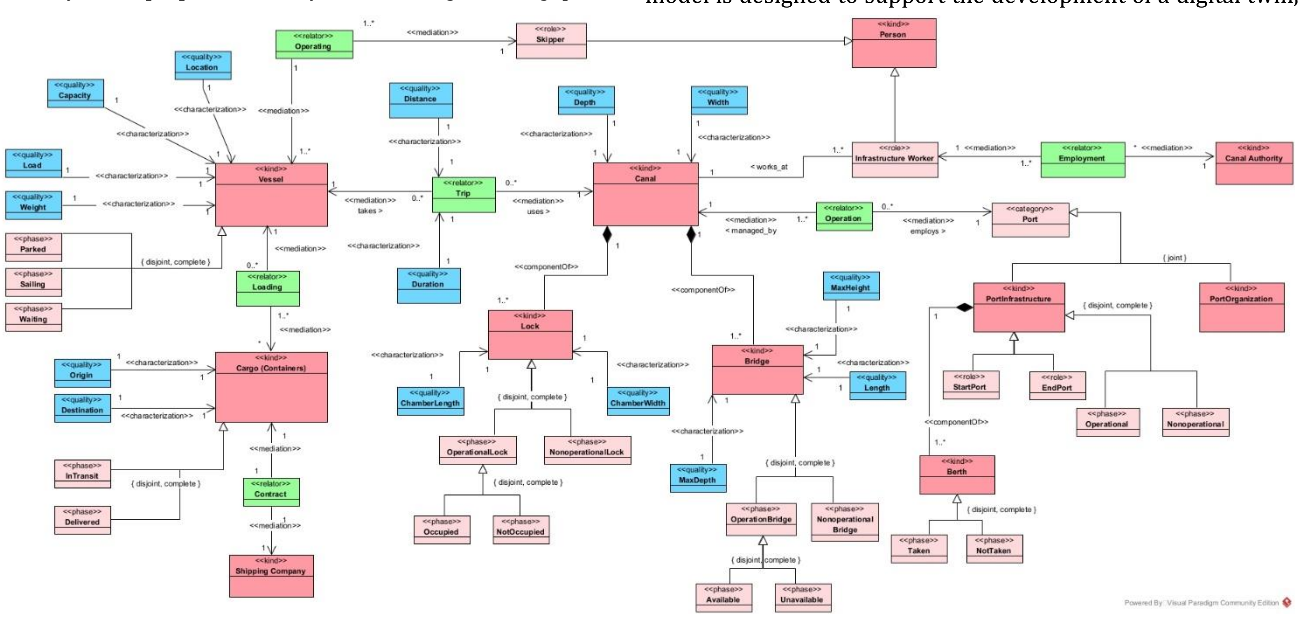


Figure 1. OntoUML Domain Model

enabling accurate simulations and optimizations of port operations.

At the center of the model is the "Canal" kind, which represents the Twente canal. It is characterized by qualities, which refer to specific attributes or properties such as depth and width that are essential for determining operational constraints [6, 7]. The Canal includes several critical components such as "Locks" and "Bridges" (shown with a "componentOf" relationship), which have their own specific attributes and phases. Locks are characterized by chamber length and width and can be operational or non-operational phases. If the "Lock" is operational, it is generalized by two more phases "Occupied" and "NotOccupied" which reflect the case where the lock might be in use by the ship. Similarly, bridges have qualities like length, maximum depth, and maximum height and can also be in operational or non-operational phases. The operational phase is generalized by "Available" and "Unavailable" phases which mirror the functioning of the bridge. These details are crucial for the digital twin to simulate and optimize infrastructure usage.
"Vessel" navigates through the canal and interacts with its components. They are characterized by qualities such as capacity, load, and weight, which reflect their vital operational attributes. The inclusion of phases like parked, sailing, and waiting allows the model to capture the different states a vessel can be in during its use. This detailed representation of vessels is crucial for the digital twin to accurately simulate and manage maritime traffic. "Cargo (Containers)", is another vital entity, characterized by qualities such as origin, destination, and phases like in transit or delivered. The relationship between vessels and cargo is represented by the "Loading" relator, which illustrates the process of loading cargo, a critical operation within the port. The category "Port" represents .... and is generalized by "Port organization" and "Port Infrastructure". The infrastructure includes the kind "Berth", which has phases indicating the availability and occupancy status. This helps in managing the allocation of docking spaces for vessels. The port organization oversees overall operations. It was important to represent the Port as a combination of two kinds for an accurate distinction between the physical infrastructure and organization.

The category "Port" represents a shared set of essential properties for different types of ports and is generalized by "Port organization" and "Port Infrastructure". The infrastructure includes the kind "Berth", which has phases indicating the availability and occupancy status. This helps in managing the allocation of docking spaces for vessels. The port organization oversees overall operations.

Relators play a significant role in the model by representing the truth-makers of material relations. For example, the "Operating" relator connects vessels to the skippers that sail it. The "Trip" relator represents the journey a vessel takes through the canal, using the infrastructure managed by the canal authority. These relators are crucial as they show how different entities interact and are interrelated within the system.

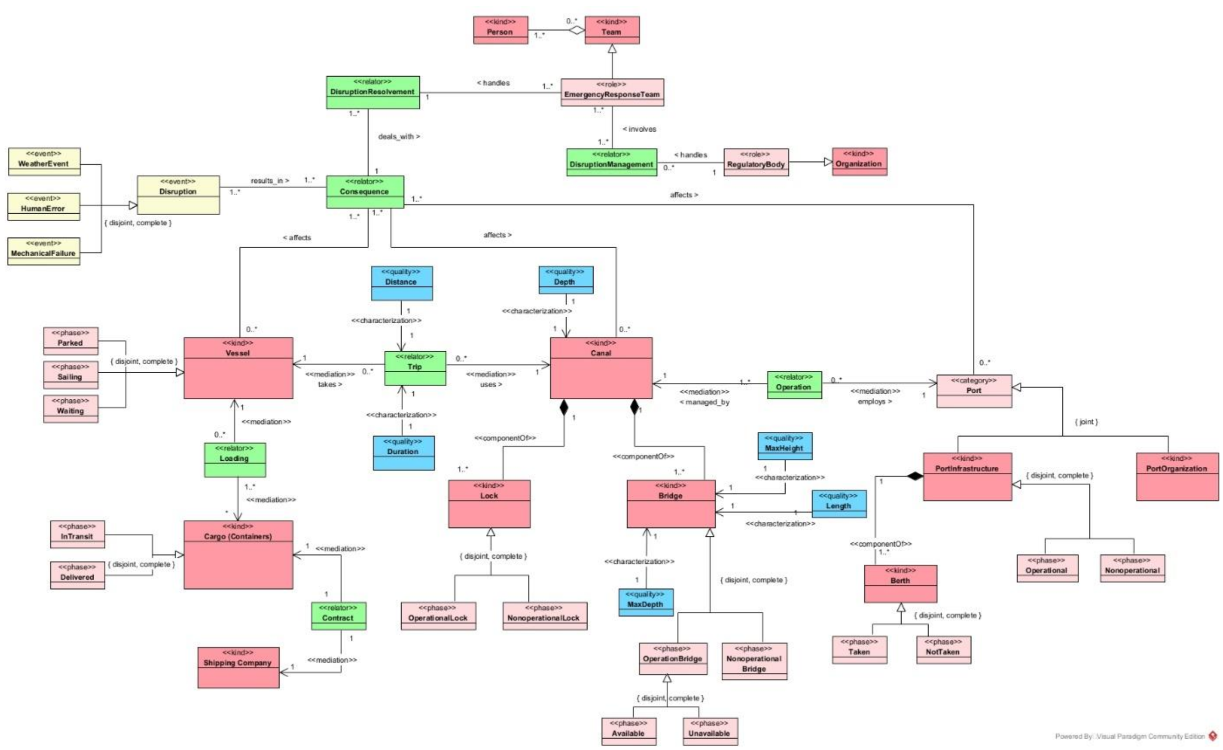


Figure 2. OntoUML Disruption Model

The phases for physical infrastructure of the canal were added to represent their operational and non-operational status, which is a critical feature for a digital twin.

## 5.2 Disruption Model

The Disruption Model is an extension of the Domain Model used for the Twente canal project, designed to address the complexities of disruptions within the maritime logistics operations. This model excludes entities from the Domain Model that are not relevant to understanding disruptions, focusing instead on how disruptions can be ontologically modeled to reflect their impact on the canal's operation and associated infrastructure (Fig. 2, model can also be accessed through a link in Appendix A1).

Central to this model are entities like "WeatherEvent", "HumanError", and "MechanicalFailure", which are types of events that most commonly lead to disruptions. These disruptions are fundamental in understanding how various unforeseen events affect the canal system, vessels, and the port infrastructure. In the context of OntoUML, events are considered fundamental entities that represent occurrences affecting endurants, such as physical objects and systems [1]. This model encapsulates how such a disruption may occur caused by a disruptive event, which then leads to consequences that impact the operation and management of the logistics system. The model illustrates the relationships between disruptions and their consequences, where each disruption leads to one or more consequences affecting various aspects of the maritime system (Vessels, Ports, Canal, and its components Lock and Bridge). This relationship is crucial as it helps in identifying the ripple effects of disruptions on the logistics chain and infrastructure.

The model also includes entities like the "EmergencyResponseTeam" and "RegulatoryBody", which play critical roles in managing these disruptions. The "EmergencyResponseTeam" is responsible for immediate response actions during disruptions, while the "RegulatoryBody" oversees and ensures compliance with safety and operational standards. Moreover, the model introduces the resolution of disruption as a key process handled by teams and involves several entities including the EmergencyResponseTeam. This resolution process is crucial for mitigating the effects of disruptions and restoring normal operations as efficiently as possible.

In constructing this model, the focus was on accurately representing the cause-effect relationships and management responses to disruptions in a maritime logistics context. The model aids in visualizing and planning for potential disruptions, ensuring that stakeholders can develop more resilient strategies and responses. It highlights the critical pathways through which disruptions impact operations, and the collaborative efforts required to manage and mitigate their effects.

## 5.3 Digital Twin Model

The Digital Twin Model builds upon the foundational entities and relationships established in the Domain model, integrating real-time data collection and processing to enable dynamic simulation, monitoring, and optimization of the Twente canal's operations. This model represents the base of digital infrastructure necessary to create a comprehensive digital representation of the canal, focusing on the installation and interaction of IoT devices and the flow of data (Fig. 3, model can also be accessed through a link in Appendix A1).

Central to the model is the "IOTDevice" kind, which is a generalization for various types of sensors installed on key entities within the system. These sensors include "VesselSensor," "ContainerSensor," "LockSensor,"

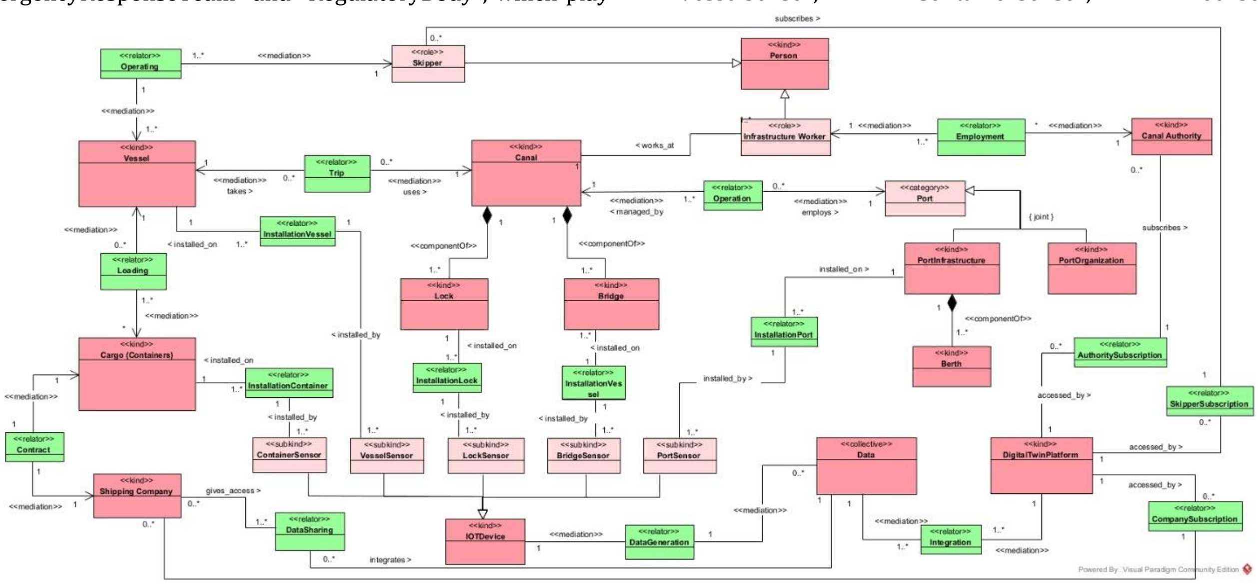


Figure 3. OntoUML Digital Twin Model

"BridgeSensor," and "PortSensor," each representing the specific devices used to monitor different components like vessels, cargo containers, locks, bridges, and port infrastructure. The installation of these sensors is managed through "Installation" relators such as "InstallationVessel," "InstallationContainer," "InstallationLock," "InstallationBridge," and "InstallationPort," indicating the specific process of equipping these entities with IoT devices. Entities such as "Vessel," "Cargo (Containers)," "Lock," "Bridge," and "PortInfrastructure" are equipped with these IoT devices, allowing the digital twin to monitor and manage their real-time statuses. For example, a "VesselSensor" installed on a vessel collects data on its capacity, load, and location, while a "LockSensor" on a lock gathers information on its operational status and physical attributes.

The data generated by these sensors and shared by companies (through “DataSharing” relator) is collected and aggregated into a "Data" collective entity, which serves as a repository for all real-time operational data. A collective refers to a set with a consistent internal structure, where every part is seen in the same way by the whole [6, 7]. This data is crucial for the functionality of the "DigitalTwinPlatform," which accesses and utilizes the data for various simulations and optimizations. The Digital Twin Platform relies on "DataGeneration" and "Integration" relators to ensure continuous data flow and interoperability between different data sources and the digital twin system.

The model also includes different types of "Subscription” relators, representing the mechanisms through which different stakeholders can access and interact with the digital twin. This ensures that relevant data and insights are available to canal authorities, shipping companies, and other involved parties, facilitating informed decision-making and efficient management of maritime operations.

## 6 RESULTS

The two research sub-questions were: “What are the key concepts and relationships that need to be represented in the ontological model for a Digital Twin in Maritime Logistics?” and “How can stakeholder requirements and domain knowledge be effectively integrated into the ontological model for the Twente canal project?” Through an extensive process of modeling and analysis, several critical components and strategic implications have been identified. This section summarizes the key findings of the design process by addressing the research questions.

The Domain Model identified several key entities within the Twente canal’s operational environment (Fig. 1). These entities include vessels, cargo containers, the canal itself, locks, bridges, and port infrastructure. Each entity was characterized by specific attributes, and their interrelationships were defined to capture the operational dynamics of the port. This model highlights the key concepts and relationships in the maritime logistics domain.

The Disruption Model focused on identifying various types of disruptions that can occur in maritime logistics, such as weather events, human errors, and mechanical failures (Fig. 2). The model documented how these disruptions affect the critical infrastructure of the canal, port, and vessels. It also highlighted the roles of emergency response teams and regulatory bodies in managing these disruptions. These findings make an attempt to answer the sub-question about integrating stakeholder requirements and domain knowledge into the ontological model by showing how different disruptions and their management need to be considered, facilitating a creation of resilient toolbox.

The Digital Twin Model aimed to further answer the sub-questions on the key entities of the model and how they can be visualized. It facilitates the path to the digitalization of the logistics operations. The model integrated IoT devices with the previously identified entities to facilitate real-time data collection and monitoring. The model documented the installation of sensors on vessels, containers, locks, bridges, and port infrastructure. The data collected from these sensors can then be aggregated into a central repository and used by the digital twin platform for simulations and optimizations.

Furthermore, the models highlight the necessity of collaboration among various stakeholders, including port authorities, shipping companies, and regulatory bodies. Effective disruption management and operational coordination depend on the seamless interaction between these parties. The technological integration demonstrated by the digital twin model supports continuous monitoring, simulation, and optimization of operations, leading to enhanced overall performance.

## 7 DISCUSSION

The ontology developed in this study plays a pivotal role in the advancement of a digital twin for the Twente canal's maritime logistics domain. Through comprehensive identification and modeling of the key entities and their relationships, the ontology provides a robust framework that supports several critical functions necessary for the effective implementation of a digital twin.

First of all, considering the numerous stakeholders involved in the Twente canal operations the ontology facilitates semantic interoperability across multiple data sources. These stakeholders rely on diverse repositories, files, and systems, each potentially using different data formats and terminologies. The Domain Model, with its detailed representation of entities like vessels, cargo containers, locks, and port infrastructure, ensures that information from these varied sources can be integrated and understood consistently. This integration is crucial for creating a uniformed view of the canal's operations, enabling seamless communication and data exchange among stakeholders.

Secondly, the Disruption Model enhances the system's ability to handle and mitigate disruptions effectively. By modeling potential disruptions and their impacts on the canal's infrastructure, the ontology provides a clear framework for predicting and managing these events. This proactive approach is essential for maintaining operational resilience and ensuring that the canal's operations can continue smoothly despite unforeseen incidents. The roles of emergency response teams and regulatory bodies, as highlighted in the disruption model, emphasize the importance of coordinated efforts in managing these disruptions. This coordination is driven by the shared understanding and common language provided by the ontology.

The Digital Twin Model further extends the applicability of the ontology by outlining the necessary technology and infrastructure required for the digital twin. By integrating IoT devices on critical entities and capturing real-time data, the digital twin provides continuous monitoring and optimization of the canal's operations. The model documents the installation of sensors, the collection and aggregation of data, and its utilization in simulations and decision-making processes. This comprehensive representation guides the implementation of the digital twin, ensuring that all technological and infrastructural components are accurately included.

Additionally, the digital twin model's real-time data integration supports enhanced decision-making and operational efficiency. By providing accurate and up-to-date information, stakeholders can make informed decisions quickly, responding effectively to changing conditions. This capability is vital for optimizing operations and ensuring the canal's smooth functioning.

In summary, the ontology developed in this research serves as a foundational framework for the digital twin of the Twente canal's maritime logistics domain. It supports data harmonization among diverse data sources, enhances the management of disruptions, and guides the implementation of the necessary technology and infrastructure for the digital twin. By supporting seamless data integration, contingency planning, and operational optimization, the ontology contributes to the resilience and efficiency of the canal's operations.

### 7.1 Limitations

This research has several limitations. First of all, the validation of the ontology with stakeholders was limited. While the models were developed based on extensive literature review and theoretical foundations, practical validation through stakeholder engagement was constrained. Secondly, time constraints impacted the development of more comprehensive models. The iterative process of refining and validating the ontology requires time to incorporate feedback and make necessary adjustments. Additionally, the process of learning ontology and OntoUML was time-consuming as well.

## 8 CONCLUSION

The aim of this research was to explore the fundamental components and strategic implications of constructing a domain ontology to facilitate the development of a digital twin in maritime logistics for the Twente canal project. Through an extensive literature review, iterative model development using OntoUML, and reflection on the strategic significance of such an ontology, several key findings and contributions have emerged.

The development of the Domain Model captured the essential relationships and interactions within the system, offering a comprehensive framework for understanding the dynamics of maritime logistics. The Disruption Model highlighted the critical pathways through which disruptions influence the logistics chain and the necessary measures for effective management by documenting the effects of these disruptions and the roles of emergency response teams and regulatory bodies. The Digital Twin Model outlined the installation and interaction of sensors, data aggregation, and the utilization of data for decision-making, providing a blueprint for implementing the digital twin. The role of the developed ontology in enhancing semantic interoperability among diverse data sources, supporting proactive disruption management, and guiding the implementation of necessary technology and infrastructure for the digital twin can be seen.

Future work may involve comprehensive validation of the ontology with the project stakeholders to gather feedback and further enhance the model. After the ontology is finalized, it has to be integrated in the digital twin, which can be done through the use of ontology implementation language.

In conclusion, this paper argues about the essential role of a well-constructed ontology in developing a digital twin that can significantly enhance the resilience and efficiency of maritime logistics. The ontology serves not only as a base for the digital twin's development but also as a strategic tool that enhances the resilience and adaptability of maritime logistics operations at Twente canal. By addressing both technical and operational challenges, the models present a foundation for future innovations in digital twin technology, especially within the maritime logistics sector.

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## APPENDIX A

A.1 Link to access the models in higher resolution can be found here: https://drive.google.com/drive/folders/1Y0ZbJ1RgKvVJZWORznzWLptFPQN5G2m5?usp=sharing

## AI STATEMENT

During the preparation of this work the author used:

- Scopus in order to search for relevant literature.
- Google Scholar in order to search for relevant literature.
- ChatGPT in order to brainstorm ideas for the research proposal.
- Chat.PDF in order to interact with big documents.
- Grammarly in order to check grammar and spelling of the text.
- Thesaurus in order to paraphrase references.
- Visual Paradigm in order to design models.

After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the work.