Interdisciplinary Journal of Information, Knowledge, and Management

An Official Publication of the Informing Science Institute InformingScience.org

IJIKM.org

Volume 20, 2025

COCP: A MODULAR CORE ONTOLOGY FOR INTELLIGENT MANAGEMENT OF CUSTOMS PROCEDURES

Minh Duc Nguyen — Department of Economic Information Systems, University of Economics, Hue University, Hue, Vietnam — nguyenminhduc@hueuni.edu.vn

ABSTRACT

Aim/Purpose: The paper introduces and develops the Core Ontology for Customs Procedures (COCP), a modular and scalable knowledge model designed to address the complexities of customs operations by formally representing operational, regulatory, security, transport, and financial transaction knowledge in alignment with global standards.

Background: Customs authorities face increasing challenges related to evolving regulations, inconsistent documentation, and the lack of interoperability in existing systems. While some ontologies exist, they are often domain-specific and fail to provide a unified structure capable of supporting the breadth of customs activities and automation needs. COCP responds to this gap by offering a comprehensive and integrative solution.

Methodology: COCP was developed using the NeOn scenario-based methodology, which supports iterative development and resource reuse. The ontology went through multiple phases including requirements specification based on competency questions, structured knowledge acquisition from authoritative sources, formal implementation in OWL using Protégé, axiomatization of semantic rules, and validation through reasoning tools, question-based testing, and SPARQL-based real-world scenarios.

Contribution: The paper contributes a formalized and validated ontology that unifies key customs processes and ensures semantic consistency across modules. It incorporates internationally recognized models such as the World Customs Organization (WCO) Data Model and Harmonized System (HS) Codes, allowing it to function as a foundation for legal compliance, operational efficiency, and AI integration. COCP is structured for modularity, making it adaptable and extendable to changing regulatory and technical environments.

Accepting Editor Narongsak Sukma │ Received: April 9, 2025 │ Revised: June 7, June 19, 2025 │ Accepted: June 11, 2025.

Cite as: Nguyen, M. D. (2025). COCP: A modular core ontology for intelligent management of customs procedures. *Interdisciplinary Journal of Information, Knowledge, and Management, 20,* Article 20. https://doi.org/10.28945/5591

Findings	COCP helps standardize customs procedures by promoting consistent data exchange, goods classification, and declaration handling across borders. It supports legal compliance and risk management through formalized rule definitions and reasoning mechanisms. The ontology also facilitates integration with intelligent technologies by providing machine-readable structures.
Recommendations for Practitioners	Customs authorities and operational stakeholders are advised to adopt COCP to automate customs clearance, ensure uniform regulatory compliance, and integrate intelligent tools for decision support. The ontology's standardized structure can improve coordination among actors and reduce procedural delays.
Recommendations for Researchers	Researchers are encouraged to expand COCP's application to specialized customs domains, such as trade sanctions, bonded zones, or e-commerce-related imports. Opportunities also exist to explore its integration with machine learning and natural language processing for automated knowledge updates and deeper analytics.
Impact on Society	The implementation of COCP can lead to faster, more transparent, and legally compliant customs processes, reducing friction in global trade and enhancing public trust in customs governance. By supporting streamlined procedures and intelligent automation, the ontology contributes to more effective and secure international commerce.
Future Research	Future directions include extending COCP to region-specific and domain-specific customs contexts, strengthening its interoperability with diverse platforms, and incorporating AI-driven reasoning systems for advanced automation. Ensuring the ontology remains adaptable to continuous legal and procedural changes will be essential for sustaining its value in global customs environments.

Keywords	customs procedures, core ontology, global trade, risk management, compliance

INTRODUCTION

Efficient and transparent customs procedures are crucial for facilitating global trade, ensuring that goods move smoothly across international borders while adhering to regulatory requirements (World Customs Organization, 2008). The introduction of new trade agreements, such as the Regional Comprehensive Economic Partnership (RCEP), has further underscored the need for streamlined customs operations. RCEP seeks to harmonize customs procedures across the Asia-Pacific region by promoting predictable, consistent, and transparent practices that align with international standards set by the World Customs Organization (WCO). These requirements emphasize the importance of swift goods clearance and simplified customs processes to support trade facilitation and improve overall efficiency.

However, meeting these requirements presents several challenges for customs authorities. A key difficulty is managing complex, evolving regulatory frameworks across jurisdictions, which require constant updates and compliance (Boer et al., 2003). Another challenge is processing large volumes of diverse documentation efficiently, where ensuring accuracy while handling high transaction volumes can cause delays and errors (Karklina-Admine et al., 2024). Additionally, enforcing strict risk management protocols is essential to secure international trade, requiring customs authorities to balance security and efficiency (World Customs Organization, 2012). The rapid evolution of regulations and new trade agreements further demands adaptable customs systems capable of integrating changes seamlessly (Karklina-Admine et al., 2024). Traditional customs systems, which often rely on manual processes and fragmented data management, are ill-equipped to handle these increasing demands. As a result, inefficiencies, delays, and risks of non-compliance become more common, putting further strain on customs operations (Loukakos & Setchi, 2010).

In order to address these challenges, there is an increasing trend toward utilizing digital technologies like blockchain, AI, and ontologies in customs operations. Of these, ontologies have garnered significant attention for their ability to formalize domain knowledge, ensuring consistent data interpretation and facilitating process automation (Aritonang et al., 2017; Loukakos & Setchi, 2010). Ontologies represent a structured and interoperable model of concepts, relationships, and rules within a domain, making them particularly valuable for managing the complex processes and regulations in customs procedures. However, despite notable efforts, existing customs ontologies remain fragmented and domain-specific and often limited to narrow tasks such as document management, goods classification, or risk analysis (Loukakos & Setchi, 2010). Critically, they lack a unified, modular structure capable of representing the full lifecycle of customs procedures, and they seldom integrate international standards. Moreover, most fail to support intelligent reasoning mechanisms for tasks such as compliance verification, duty exemption assessment, or risk-based inspection.

This paper addresses these gaps by proposing COCP – a comprehensive, modular core ontology for customs procedures that aligns with global standards and enables intelligent customs management. COCP not only models operational, legal, security, logistics, and financial aspects of customs processes but also provides a formal structure that supports automated reasoning, semantic integration, and extensibility across diverse jurisdictions and use cases. Developed using the NeOn methodology (Suárez-Figueroa et al., 2015), COCP follows a scenario-based approach across five key phases: requirements specification, knowledge acquisition and modularization, implementation, axiomatization, and validation. These phases were conducted within an iterative development lifecycle to ensure continuous refinement and alignment with real-world use cases. In the final phase, the ontology underwent validation through reasoning for consistency, competency question-based validation, and scenario-based evaluation, confirming its effectiveness in modeling practical customs procedures. Based on the identified challenges and limitations in existing customs ontologies, this study aims to address the following key research objectives:

1. To design and develop a comprehensive, modular core ontology that captures the full scope of customs procedures, including operational, legal, security, logistical, and financial elements.
2. To ensure semantic consistency and compliance support by integrating international standards such as the WCO Data Model, Harmonized System (HS) Codes, and trade agreements.
3. To enable intelligent applications in customs management such as compliance checks, risk assessments, and duty exemptions, through the use of formal axioms, semantic rules, and reasoning mechanisms.

The rest of the paper is organized as follows. The Background and Related Work section presents a review of customs procedures, existing customs ontologies, and ontology development methodologies. The COCP Ontology: Iterative Development Lifecycle section details the iterative process used to develop the COCP ontology. This is followed by the Discussion section, which explores practical use cases and highlights challenges encountered during development. Finally, the Concluding Remarks section summarizes the key contributions and limitations, and outlines directions for future work.

BACKGROUND AND RELATED WORK

Customs procedures vary across jurisdictions, creating challenges for global trade. International efforts, such as the WCO data model, aim to standardize these processes. At the same time, ontology-based approaches have been developed to model complex customs operations and support automation. This section reviews the evolution of customs procedures, the role of ontologies in the customs domain, and key methodologies for ontology development, providing the foundation for the COCP ontology.

Customs Procedures

Customs procedures are critical processes that ensure goods moving across borders comply with both national and international laws. They encompass several key activities, including document verification, goods inspection, tariff and duty calculation, and risk assessment (World Customs Organization, 2008). These procedures involve multiple stakeholders, such as suppliers, carriers, customs authorities, and customers, all working together to facilitate the movement of goods while ensuring legal compliance (World Trade Organization, 2014). Customs procedures vary across countries, but they typically follow similar overarching goals, such as facilitating trade, ensuring safety, and enforcing legal regulations (Loukakos & Setchi, 2010; World Customs Organization, 2021a).

The WCO has played a key role in the global standardization of customs procedures through initiatives such as the WCO data model (World Customs Organization, 2022c). This model aims to streamline customs procedures by establishing uniform standards for documentation and data exchange, thereby enhancing coordination between customs authorities and traders. As a global framework, the WCO data model harmonizes the exchange of information across customs systems, ensuring that data from different jurisdictions can be processed seamlessly. By providing a consistent format for customs declarations, regulatory documents, and other relevant data, the model helps reduce delays and discrepancies in the clearance process. Its adoption enables countries to simplify the submission and handling of documentation, facilitating smoother trade operations while ensuring compliance with international standards. To provide a clearer understanding of the cross-border regulatory global model in the WCO data model, Figure 1 presents a high-level use case diagram that highlights two key business processes: Transport and Report/Declare. These two business processes represent the primary stages of customs operations, where the movement of goods and the submission of required documentation take place (World Customs Organization, 2022a).

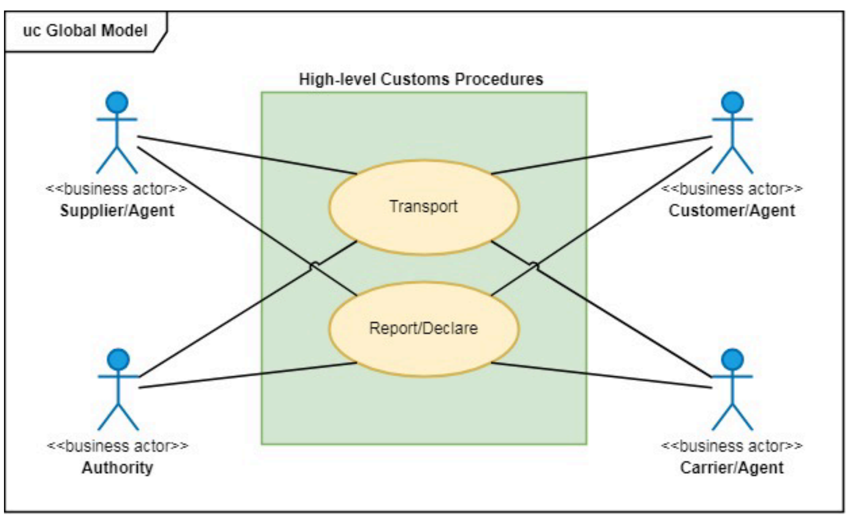

Figure 1. High-level use case diagram of customs procedures
(World Customs Organization, 2022a)

The *Transport* process covers the movement of goods from suppliers to customers, managed by carriers, with customs authorities ensuring legal compliance along the route. This process involves various steps, such as shipping, cargo handling, and transit procedures, depending on national and international regulations. Similarly, the *Report/Declare* process focuses on the submission of documents to customs authorities, which typically includes customs declarations, invoices, and certificates of origin. Customs officials verify the accuracy of these documents to determine applicable duties and ensure compliance with regulations. This process may also include steps such as duty calculation, risk assessment, and inspection.

Customs operations face several key challenges, particularly due to the complexity and variability of procedures across countries. One of the main challenges is data inconsistencies, as documents submitted by various actors often contain discrepancies, leading to delays (Polner, 2011). Additionally, lack of interoperability between customs systems complicates the exchange of information, especially in cross-border trade, where differing national regulations apply (Lane, 1998). Many customs authorities still rely on manual processes, which are prone to human error and slow down the clearance process. Traders also struggle to stay compliant with ever-evolving national and international regulations, which adds further complexity to the customs processes (McLinden et al., 2010).

These challenges have emphasized the need for more efficient management of customs procedures. The COCP ontology addresses this by building on the WCO data model, providing a robust framework to simplify and modernize the management of customs procedures, ultimately enhancing global trade efficiency.

Customs Ontology

Ontology is a foundational tool for organizing domain knowledge, offering a formal representation of concepts and their relationships, which facilitates data interoperability, automation, and consistent understanding across various systems (Guarino et al., 2009). This technology has been extensively applied across various fields, such as finance (Bennett, 2013), knowledge management (Garbacz et al., 2012), e-commerce (Hepp, 2008), and even entertainment (Kim, 2017). In the customs domain, ontologies have been used to model complex processes, regulatory frameworks, and relationships among various actors, allowing for more efficient decision-making and improved compliance management (Loukakos & Setchi, 2010).

One significant application of ontological model in the customs domain focuses on risk assessment and the automation of customs inspections. For instance, Zang et al. (2008) developed an ontology that automates the identification of HS Codes for products during customs inspections. This ontology enables customs authorities to automate policy matching for goods by using HS Codes, thereby improving the accuracy and efficiency of customs operations. The reasoning mechanism embedded in this ontology allows for dynamic product classification, thereby automating inspection and quarantine procedures. Similarly, Loukakos and Setchi (2010) presented an ontology designed for the European Union customs domain, focusing on risk analysis. This ontology enables the sharing of customs knowledge between various stakeholders, including national customs administrations and economic operators. It facilitates the representation of complex customs relationships and supports risk assessment activities within the customs domain. The ontology, expressed in OWL-DL, offers robust semantic reasoning capabilities that can be extended for future applications in compliance automation and risk management. In another study, Aritonang et al. (2017) modeled a semantic network of regulations for customs and excise using an ontology-based approach. This network, implemented using a Neo4j graph database, provides customs authorities with tools to manage, track, and understand the evolving relationships between various regulations and customs processes.

In addition to these foundational efforts, more recent studies have expanded the use of ontologies in customs-related domains. Lamharhar et al. (2014) proposed an e-government knowledge model specifically for e-Customs, where layered ontologies enable semantic interoperability across administrative services. Ouchetto et al. (2012) further applied ontologies for multilingual service retrieval in e-government, constructing a customs-specific ontology to improve user access to relevant services. Another relevant contribution is the study on tracking relationships in e-Customs, which applied ontology-based relationship reasoning to identify hidden trade risk factors (Seo et al., 2013). While some of these works incorporate intelligent reasoning (e.g., graph traversal or rule-based matching), others present semantic structures suitable for future integration into AI-driven or blockchain-based systems. However, these ontologies typically target narrow functionalities, such as document retrieval, classification, or risk identification, and lack a unified, modular architecture that covers the full spectrum of customs operations. Moreover, existing customs ontologies often face interoperability challenges. These include inconsistent concept definitions, limited use of international standards such as the WCO Data Model, and structural designs that hinder modular reuse. As a result, integrating these ontologies with external systems or extending them across jurisdictions becomes difficult.

To address this gap, the COCP ontology is developed as a comprehensive, modular framework that spans the entire customs process lifecycle, from pre-clearance to post-clearance. This ontology-driven approach not only facilitates seamless cross-border trade but also addresses the evolving needs of customs authorities in an increasingly complex regulatory environment, offering a scalable and adaptable solution to modern customs challenges.

ONTOLOGY DEVELOPMENT

Ontology development is a structured process aimed at creating formal representations of domain knowledge (Noy & Mcguinness, 2001). These representations enable systems to perform complex tasks such as data integration, decision support, and compliance automation (Khadir et al., 2021). In the customs domain, ontology development involves modeling the intricate relationships between regulations, processes, and stakeholders to improve the automation and efficiency of customs operations (Aritonang et al., 2017; Loukakos & Setchi, 2010).

The field of ontology development has evolved significantly over the past two decades, particularly with the rise of the Semantic Web, introduced by (Berners-Lee et al., 2001). Various standards and languages, such as Resource Description Framework (RDF), RDF Schema (RDFS), Web Ontology Language (OWL), and OWL-2, have laid the technical foundation for building ontologies. Despite the growing number of ontologies, the methodologies for ontology development remain limited. These methodologies can broadly be categorized into three types: traditional methods, collaborative methods, and customized methods (Noy & Mcguinness, 2001; Suárez-Figueroa et al., 2012).

Traditional methods of ontology development are characterized by their structured, manual approach to constructing ontologies. Methontology (Fernández-López et al., 1997) is a foundational methodology for ontology development, guiding users through phases such as specification, conceptualization, and formalization. While it remains widely used for its structured approach, it faces limitations in adapting to dynamic domains and reusing existing knowledge resources (Noy & Mcguinness, 2001; Suárez-Figueroa et al., 2015).

To address these limitations, collaborative methods focus on the reuse and reengineering of existing knowledge resources while allowing for greater flexibility and adaptability. A notable collaborative method is the On-To-Knowledge methodology (Sure et al., 2004), which emphasizes the integration of knowledge management and ontology development. On-To-Knowledge follows an iterative process where domain experts and knowledge engineers collaborate to refine and evolve the ontology over time. The NeOn methodology (Suárez-Figueroa et al., 2012, 2015) extends earlier approaches by enabling the reuse of both ontological and non-ontological resources and supporting the continuous evolution of ontologies. Its scenario-based, iterative development is well-suited for complex, multi-stakeholder domains like customs, where legal and procedural compliance is critical.

In recent years, customized methods have emerged, leveraging the strengths of both traditional and collaborative approaches. For example, the YAGO ontology (Rebele et al., 2016) was developed by reusing multiple data sources such as Wikipedia and WordNet. Similarly, cross-domain ontologies like the MedRed ontology (Calbimonte et al., 2017) combine vocabularies from multiple fields, including healthcare and biomedical sciences, to create comprehensive knowledge bases. Additionally, advances in natural language processing (NLP) and machine learning have contributed to automating some stages of ontology development. For instance, Patel et al. (2023) proposed a semi-automatic NLP-guided framework for extracting all possible relations among objects. Machine learning approaches, such as those presented by Wang et al. (2020), have been used to generate large-scale ontologies by extracting and classifying semantic relationships from multiple data sources. For readers interested in automated ontology construction and evolution, we refer to the comprehensive survey by Khadir et al. (2021), which reviews linguistic, statistical, and machine learning-based approaches, including recent developments in deep learning.

In this study, the NeOn methodology was adopted for the development of the COCP ontology. Section 3 explores the specific application of the NeOn methodology in COCP's development, detailing each phase of the process.

COCP Ontology: Iterative Development Lifecycle

Overview

Ontology engineering methodologies offer structured processes for building ontologies that are scalable, reusable, and tailored to the specific needs of a domain. Common methodologies such as Methontology (Fernández-López et al., 1997) and On-To-Knowledge (Sure et al., 2004) have been widely used in various domains, but the NeOn methodology (Suárez-Figueroa et al., 2015) was selected for the development of the COCP ontology due to its flexibility in reusing resources, supporting modular development, and facilitating the creation of ontology networks. The NeOn methodology's scenario-based approach was particularly suited for the customs domain, which requires a comprehensive and modular approach. NeOn allows for the reuse and reengineering of both ontological and non-ontological resources, a crucial feature given the complex nature of customs operations and their reliance on external regulatory, legal, and logistics data.

For the development of COCP, we selected four scenarios from the NeOn methodology, based on their relevance to the customs domain and their alignment with the project's modular and extensible design goals. Scenario 1 (*from specification to implementation*) was used to guide the entire process, from the initial specification of requirements through to the final implementation of the ontology. This scenario ensures that the development process addresses the specific needs of the customs domain while maintaining a structured and goal-oriented approach. Scenario 2 (*reusing non-ontological resources*) was chosen to incorporate external resources such as international customs regulations, tariff schedules, and logistical standards into the ontology, ensuring that COCP is grounded in real-world customs practices. Additionally, Scenario 6 (*reusing, merging and reengineering ontological resources*) was selected to adapt and modify the non-ontological resources integrated through Scenario 2. Importantly, Scenario 6 inherently includes the aspects of Scenarios 3, 4, and 5, which focus on the reuse of ontological resources, reengineering them, and merging existing resources to fit new requirements. This makes Scenario 6 a powerful, comprehensive approach to ensure that COCP incorporates and adapts both ontological and non-ontological resources, creating a cohesive and tailored ontology for customs operations. Finally, Scenario 8 (*restructuring ontological resources*) was employed to mainly modularize COCP effectively. By restructuring the ontology into distinct modules, Scenario 8 makes COCP scalable, maintainable, and easily extensible for future use cases, ensuring it can be reused and updated as customs procedures evolve. Other NeOn scenarios were not adopted, as they were not directly applicable to our goals or the centralized nature of our development and validation process.

Based on the selected scenarios, the COCP ontology was developed through an iterative development lifecycle (see Figure 2), consisting of five key phases: (i) requirements specification, (ii) knowledge acquisition and modularization, (iii) implementation, (iv) axiomatization, and (v) validation.

As shown in Figure 2, each phase is interconnected, forming a continuous cycle aimed at refining the ontology until it reaches finalization. The process begins with defining the requirements, followed by acquiring and organizing knowledge into modules. The ontology is then implemented, axiomatized for semantic enrichment, and validated. The cycle repeats, with each phase contributing to the continuous improvement of the ontology until it meets all its design objectives. The remainder of this section details each phase in the following subsections.

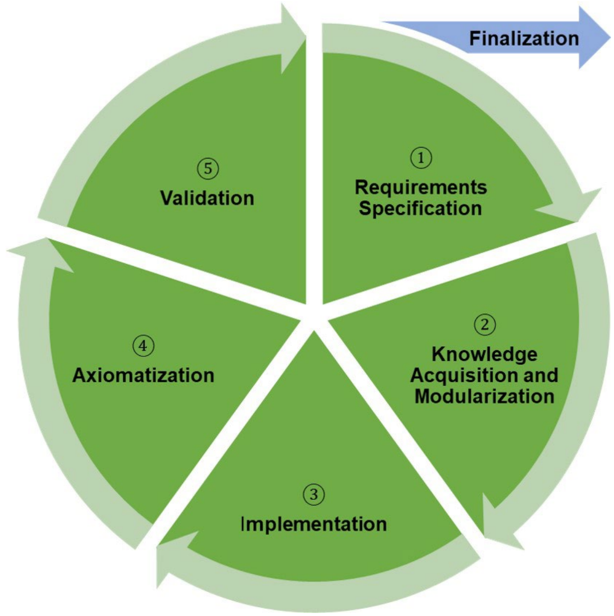

Figure 2. Iterative development lifecycle of the COCP ontology.

REQUIREMENTS SPECIFICATION

The development of the COCP ontology began with the creation of a set of Competency Questions (CQs) designed to capture the core requirements of the ontology. These CQs were instrumental in shaping the initial structure by identifying the primary objectives, functional expectations, and key use cases the ontology needed to address. The CQs were then used to create the Ontology Requirements Specification Document (ORSD), which formalized these requirements into a foundational framework guiding the development of COCP. As the ontology evolved, the CQs were extended and refined during the validation of COCP to ensure it fully met its intended objectives without any gaps or inadequacies. Once the CQs were finalized, adjustments were made to the ORSD to reflect the updated requirements and align with the ontology's structure. A subset of these finalized CQs will be presented in the last phase, validation of COCP, to illustrate how they shaped the CQ-based validation process. The final ORSD, presented in Table 1, provides a comprehensive guide to the design of the COCP ontology.

The ORSD identifies the goals of the ontology, which include automating workflows, ensuring regulatory compliance, integrating customs operations with external systems, facilitating risk-based assessments, and supporting AI-driven decision-making. It also defines the scope of COCP, specifying the critical areas that the ontology must model. These areas include customs declarations, legal compliance, security management, and logistics and financial transactions. This detailed scope ensures that COCP comprehensively represents all major aspects of the customs domain. Furthermore, the ORSD outlines the major use cases that the ontology must support. These use cases correspond to real-world scenarios that COCP will handle, such as verifying customs declarations, calculating duties, and managing risk assessments. The ORSD also identifies the key stakeholders, including customs authorities, suppliers, customers, and carriers, who will interact with COCP.

By mapping out the functional requirements, the ORSD serves as a critical guide for the design and development of COCP, ensuring that it meets the operational needs of stakeholders while maintaining compliance with regulatory standards.

Table 1. The ORSD for developing the COCP ontology

Section	Description
1. Purpose	Core objectives that the COCP ontology aims to achieve: - Assisting in the automation of customs workflows and decision-making. - Ensuring compliance with customs regulations and trade agreements. - Integrating customs operations with external systems. - Facilitating risk-based assessments for high-risk shipments. - Supporting AI applications in customs operations.
2. Scope	The scope of the COCP ontology will cover the following areas: - Customs operations: Key processes such as declarations, inspections, and the release of goods. - Legal compliance: Duty calculations, adherence to trade agreements, and regulatory frameworks. - Security management: Risk assessments, inspections, and security measures in customs operations. - Logistics and financial transactions: Modeling transportation, customs fees, and related financial transactions.
3. Use cases	COCP is designed to handle a variety of practical use cases within the customs domain. The major use cases include: - Verifying the validity and compliance of customs declarations. - Automating tariff and duty calculations based on goods classification. - Conducting risk assessments for incoming shipments. - Tracking the status of customs declarations and associated payments.
4. Stakeholders	This section identifies the key stakeholders who will interact with COCP, including customs authorities, suppliers, customers, and carriers.

Knowledge Acquisition and Modularization

The development of the COCP ontology involved a comprehensive process of knowledge acquisition by gathering existing resources and integrating them with custom elements developed specifically for COCP. The acquisition and reuse of existing resources process involved the integration of both non-ontological and ontological resources that are essential for representing customs procedures. Several non-ontological resources were identified and adapted to form the backbone of the COCP ontology. These resources provide legal, procedural, and classification standards for customs operations. The following are the major non-ontological resources contributing to COCP:

- HS Codes (World Customs Organization, 2022b): The HS classification system, developed by the WCO, serves as the global standard for classifying traded products.
- WCO data model (World Customs Organization, 2022c): The WCO data model provides a standard framework for customs data elements, facilitating interoperability between customs authorities and businesses.

- Global trade agreements and customs regulations: International documents and agreements accepted by multiple nations have been incorporated to ensure that COCP complies with global legal frameworks. Key agreements include the Agreement on Trade Facilitation (TFA) (World Trade Organization, 2014) and the General Agreement on Tariffs and Trade (GATT) (World Trade Organization, 1947), along with its subsequent modifications.
- Risk management guidelines: Best practices for risk management in customs, as outlined in the WCO Risk Management Compendium (World Customs Organization, 2012), were used to model risk assessments and inspections for high-risk goods.

Apart from non-ontological sources, several existing ontologies were reused and adapted to structure COCP effectively. These ontologies provide the foundational elements for the formal representation of knowledge in customs processes. The major ontological resources include:

- Legal Knowledge Interchange Format (LKIF) ontology (Hoekstra et al., 2007): LKIF was used to model legal rules and regulations within the customs domain, particularly for compliance with international trade laws.
- GoodRelations ontology (Hepp, 2008): The GoodRelations ontology was used for modeling product and service information, providing support for goods classification and transactions in customs.

In addition to these major ontological resources, event ontology was incorporated to represent the various events (e.g., customs declaration, inspections, payments) involved in the customs process (Raimond & Abdallah, 2007). Furthermore, time and location ontologies were used to handle temporal and spatial data relevant to customs operations, including the timelines for processing customs declarations and the geographic locations of ports and warehouses (Battle & Kolas, 2012; Hobbs & Pan, 2006).

By combining these key non-ontological and ontological resources, COCP achieves a comprehensive representation of the customs procedures, ensuring compliance with legal standards while supporting efficient workflows and risk assessments.

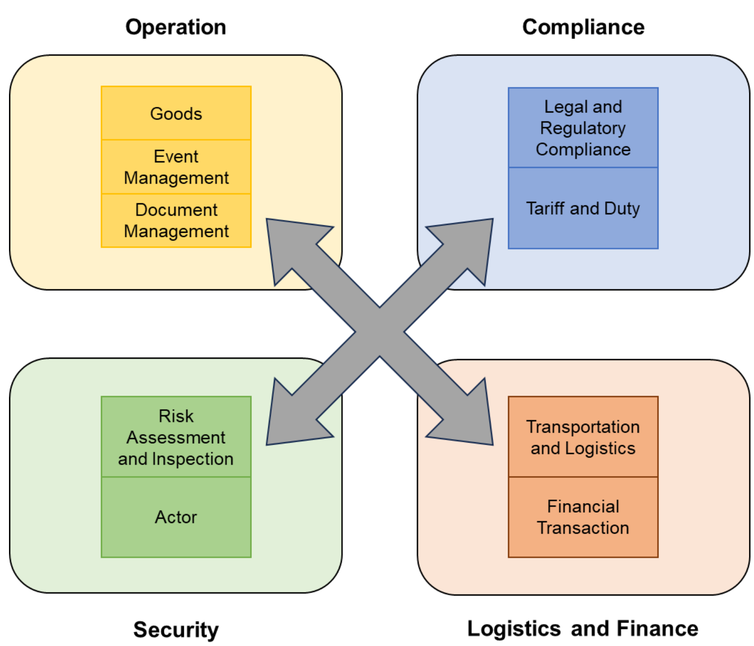

Figure 3. Overview of the core modules categorized into groups within the COCP ontology

After gathering and integrating both non-ontological and ontological resources, the next step was to organize the ontology into distinct modules. This modularization involved structuring COCP into key modules, each representing specific types of information managed throughout the customs procedures. Figure 3 illustrates the four key groups in the COCP ontology: *Operation*, *Compliance*, *Security*, and *Logistics and Finance*. Each group consists of modules that handle specific aspects of their respective areas.

Specifically, the modules were developed to reflect distinct functions within customs operations, allowing the COCP ontology to manage each aspect independently while ensuring seamless interaction across the modules. This modular design offers key advantages, such as scalability – allowing for the expansion of modules as new customs regulations emerge without impacting others – and maintainability, making updates and fixes more manageable. Additionally, it enhances interoperability by facilitating integration with external systems such as legal or logistics ontologies, while providing the flexibility to adapt to changes in technology and regulations. Although each module operates autonomously, the groups of modules are designed to collaborate seamlessly. For example, the *Operation* group works closely with the *Compliance* group to ensure customs declarations comply with relevant trade agreements and regulations, while the *Security* group interacts with the *Logistics and Finance* group to flag high-risk shipments, ensuring that inspections are completed before goods are cleared. This integrated approach ensures that the COCP ontology delivers a unified and efficient model for managing end-to-end customs operations.

IMPLEMENTATION

The implementation of the COCP ontology was carried out using the Protégé (https://protege.stanford.edu/) 5.6.1 ontology editor, a widely adopted tool for building and maintaining ontologies. Protégé allows for the creation, editing, and visualization of ontologies, supporting the OWL format, which was selected for COCP due to its compatibility with reasoning engines and its flexibility in representing complex relationships between customs entities. The implementation process consists of two key steps: (i) developing classes and class hierarchy, and (ii) defining object properties. Once the required classes were identified, the focus shifted to building the class hierarchy, organizing domain concepts into a structured model. To define object properties, relationships were established between classes, accurately reflecting interactions within the customs procedures. As a result, Figure 4 presents an excerpt of the COCP ontology, visualized using the OntoGraf plugin in Protégé.

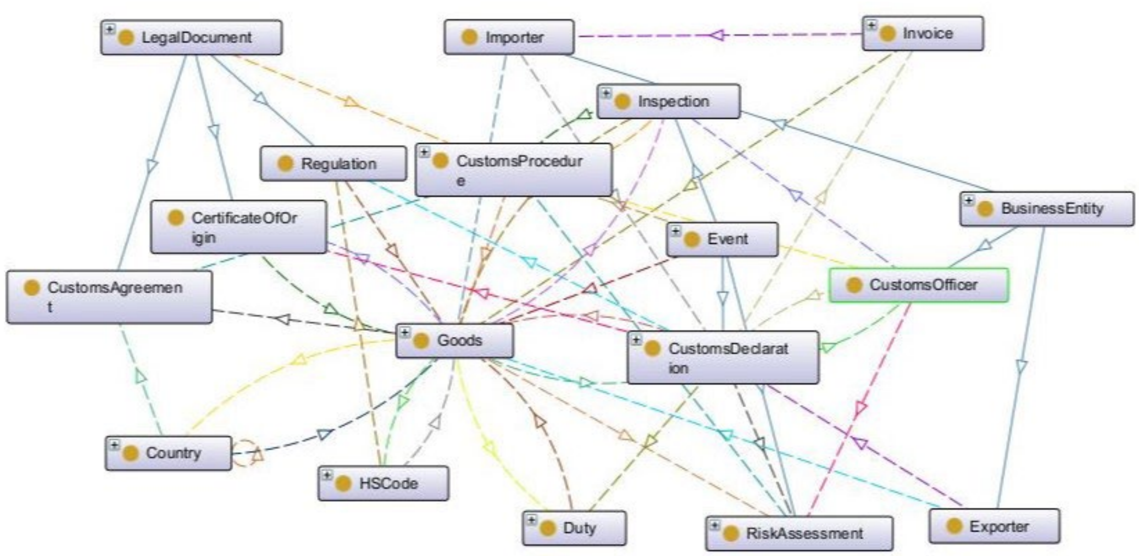

Figure 4. An excerpt of the COCP ontology

In Figure 4, the links between a class and its subclasses are represented by light blue arcs. OntoGraf uses different colors to depict all other types of relationships between the various classes in the ontology. To specify the outcome of defining object properties, Table 2 presents a set of typical properties implemented in the COCP ontology. The domain refers to the class from which the property originates, while the range represents the class to which the property is linked.

Table 2 illustrates how properties semantically connect entities across modules, enabling the ontology to accurately model diverse relationships and workflows. These semantic connections ensure that the COCP ontology remains logically structured and meaningful. In total, the COCP ontology comprises 82 classes, 213 object properties, reflecting its scope and coverage across legal, operational, secure, financial, and logistical dimensions of customs procedures.

Table 2. Typical properties of COCP

Property	Domain	Range
belongsToCountry	Goods	Country
isOwnedBy	Goods	Importer
isReleasedBy	CustomsDeclaration	CustomsOfficer
isDeclaredBy	CustomsDeclaration	Importer
hasInvoice	CustomsDeclaration	Invoice
includesItem	Invoice	Goods
hasCertificateOfOrigin	Goods	CertificateOfOrigin
hasMutualAgreement	Country	Country
compliesWithRegulation	CustomsDeclaration	Regulation
hasTariff	Goods	Tariff
hasDutyAmount	CustomsDeclaration	Duty
isSubjectToInspection	Shipment	Inspection
assessedRiskLevel	Shipment	RiskLevel
flaggedForInspection	Goods	RiskLevel
representedBy	CustomsOfficer	Organization
hasPortOfEntry	Shipment	Port
isTransportedBy	Goods	TransportVehicle
hasShippingMethod	Shipment	ShippingMethod
hasTransactionFee	Invoice	TransactionFee
paidBy	Invoice	Importer

Table 3. Key areas of axiomatization with examples

No.	Area	Utilization and example
1	Class axioms	Define constraints for specific classes.
		Every instance of the `Goods` class must have exactly one `HSCode`: `SubClassOf(cocp:Goods ObjectExactCardinality(1 cocp:hasHSCode cocp:HSCode))`
2	Disjointness and completeness axioms	Ensure that certain classes do not overlap and that all necessary relationships are captured.
		`Importer` and `Customs Officer` are disjoint, meaning no individual can be both: `DisjointClasses(cocp:Importer cocp:CustomsOfficer)`
3	Cardinality constraints	Limit the number of relationships between classes (e.g., a class can have at most one property).
		Each `Customs Declaration` can be linked to at most one `Transport Vehicle`: `SubClassOf(cocp:CustomsDeclaration ObjectMaxCardinality(1 cocp:hasTransportVehicle cocp:TransportVehicle))`
4	Domain and range axioms	Define the valid domain and range for object properties.
		The *hasInvoice* property links `Customs Declaration` (domain) to `Invoice` (range): `ObjectPropertyDomain(cocp:hasInvoice cocp:CustomsDeclaration)` and `ObjectPropertyRange(cocp:hasInvoice cocp:Invoice)`
5	Transitivity axioms	Ensure that a property is transitive, meaning if A is linked to B and B is linked to C, then A is linked to C.
		If a `Goods` item is linked to a `Country`, all related components of that goods inherit the country link: `TransitiveObjectProperty(cocp:isFromCountry)`
6	Properties and relationships definition	Define object properties and their relationships between classes.
		The *hasInvoice* object property links `Customs Declaration` to `Invoice`: `ObjectProperty(cocp:hasInvoice)`
7	Inverse properties	Define inverse relationships, ensuring that if A is related to B, then B is related to A.
		If a `Customs Declaration` is inspected by a `Customs Officer`, the inverse is that the `Customs Officer` inspects the `Customs Declaration`: `InverseObjectProperties(cocp:isInspectedBy cocp:inspects)`
8	Symmetry axioms	Ensure that if A is related to B, then B is also related to A (e.g., mutual agreements).
		If Country A has a mutual agreement with Country B, then Country B also has a mutual agreement with Country A: `SymmetricObjectProperty(cocp:hasMutualAgreement)`

AXIOMATIZATION

Axiomatization is a critical step in the development of the COCP ontology, as it establishes the rules, constraints, and logical relationships between entities. By defining axioms, we enhance the semantic structure, enabling automated reasoning and maintaining logical consistency. When the ontology is sufficiently enriched with axioms that formalize and define its structure, it becomes expressive (Khadir et al., 2021), allowing it to model complex customs processes with precision. Table 3 illustrates the key areas of axiomatization within COCP, detailing their purpose and providing examples of how they were implemented using OWL 2 Functional Syntax (https://www.w3.org/TR/owl2-syntax/). These axioms serve as the backbone of the ontology's reasoning capabilities, ensuring compliance with customs regulations, facilitating efficient processes, and supporting complex queries related to customs operations.

In summary, the axiomatization work has enriched the COCP ontology by defining formal rules, constraints, and logical relationships between concepts, ensuring consistency and supporting automated reasoning. This foundational step strengthens the ontology's ability to represent real-world customs processes accurately.

VALIDATION

The validation of the COCP ontology ensures that the ontology meets its design objectives and accurately models the customs procedures. To achieve comprehensive validation, we employed three key methods: Ontology reasoning for consistency, competency question-based validation, and practical scenario-based testing. These methods collectively validated the consistency, correctness, and practical applicability of the COCP ontology.

Ontology reasoning for consistency

To ensure the COCP is consistent and logically valid, we utilized the HermiT (http://www.hermit-reasoner.com/) 1.3.8 reasoner within the Protégé environment. HermiT provides automated reasoning capabilities to verify the ontology's logical structure, detect inconsistencies, and infer additional relationships that may not be explicitly defined. These steps are crucial for ensuring that COCP accurately models customs procedures.

Specifically, HermiT performs consistency checks to prevent conflicts, such as classifying a `Goods` as both low-risk and high-risk. It infers subclass relationships, like confirming that `Regulation` is a subclass of `Legal Document`, ensuring the class hierarchy reflects customs concepts. It also validates properties, ensuring relationships like *hasTariff* and *hasRiskAssessment* correctly link `Goods` to `Tariff` and `Shipment` to `Risk Assessment`. HermiT further checks for logical consistency in inverse relationships, such as *hasTariff* and *isTariffFor*.

In our evaluation, HermiT successfully classified the entire ontology and completed consistency checking in approximately 5.3 seconds on a standard machine (Intel i7, 16 GB RAM). This reasoning process ensures that COCP maintains logical consistency, structural soundness, and regulatory compliance, thereby reinforcing its robustness and reliability for deployment in real-world customs applications.

Competency question-based validation

CQ-based validation is a central method for evaluating the completeness and accuracy of the COCP ontology. CQs are crafted to test whether the ontology can address critical queries within the customs domain. They serve as essential guidelines for defining both the content and structure of the ontology. If COCP can correctly answer the formulated CQs, it demonstrates that the ontology encompasses the necessary knowledge to support customs operations, ensuring its competency in modeling customs processes.

Throughout the development of COCP, the list of CQs was continuously refined and expanded. Initially, a core set of CQs guided the construction of the ontology. However, as new insights into the customs domain emerged, both the CQs and the ontology were modified and extended to cover additional aspects. This process was strongly supported by expert consultations, involving customs officers, legal professionals, and logistics stakeholders. Experts reviewed whether the ontology could provide meaningful and accurate answers to realistic queries reflecting day-to-day customs activities. Their comments prompted the reformulation of existing CQs, clarification of question scope, and the addition of new CQs targeting scenarios. These changes ensured that the CQs remained aligned with practical needs and that the ontology evolved to comprehensively support them.

Moreover, expert feedback was instrumental in highlighting areas where the ontology lacked coverage or needed refinement. For example, handling duty exemptions based on trade agreements was identified as a gap in the original ontology. To address this, the introduction of the *hasExemption* relationship between `Goods` and `Trade Agreement` allowed COCP to accurately model queries related to exemptions for specific goods.

This expert feedback during validation was instrumental in identifying conceptual gaps, terminological inconsistencies, and coverage issues. When COCP was unable to provide correct answers to certain CQs, the underlying concepts and relationships were revisited and refined to close those gaps. This iterative approach, informed by stakeholder validation, allowed COCP to evolve into a robust and comprehensive model that reflects real-world customs procedures and meets the information needs of customs authorities.

In total, 51 CQs were developed to comprehensively test COCP's capability to model the customs processes. For illustrative purposes, 21 key CQs are presented in Table 4, each mapped to specific modules within COCP.

Table 4. Typical CQs for validating COCP

Group/Module	CQ
Operation	
Goods	CQ1: What tariff and duty rates are applied to specific goods based on their classification (e.g., HS Code)?
	CQ2: Which goods are classified under high-risk categories and require special clearance procedures?
Event Management	CQ3: Which customs declarations have been processed within a specific time interval, and what were the key events?
	CQ4: Which customs officers are responsible for handling specific events (e.g., inspections or releases) in the customs process?
Document Management	CQ5: Which customs declarations are linked to specific certificates of origin or other required documents?
	CQ6: What documents (invoices, certificates of origin) are required for the clearance of particular goods or shipments?
Compliance	
Legal and Regulatory Compliance	CQ7: Which shipments are subject to specific legal frameworks (e.g., trade agreements) and require compliance checks?
	CQ8: Which countries have bilateral or multilateral trade agreements that affect the clearance process for certain goods?

Group/Module	CQ
Tariff and Duty	CQ9: What tariff rates are applied to specific goods, and how are duties calculated based on shipment value?
	CQ10: Which shipments are subject to specific duties, and what is the corresponding duty amount for each?
Security	
Risk Assessment and Inspection	CQ11: Which shipments have been flagged for high-risk assessment, and what are the corresponding risk levels?
	CQ12: Which goods have undergone inspection due to high-risk classification, and what were the results of those inspections?
Actor	CQ13: Which customs officers or inspectors are responsible for overseeing the clearance of high-risk shipments?
	CQ14: Which importer or exporter is responsible for the shipment of a specific set of goods, and how are they involved in the clearance process?
Logistics and Finance	
Transportation and Logistics	CQ15: Which shipments were transported through a specific port within a given time period, and what were the associated logistics?
	CQ16: Which goods have been cleared at multiple ports, and what were the associated duties and logistical details for each port?
Financial Transaction	CQ17: Which payment records are linked to customs declarations with duties exceeding a specific threshold?
	CQ18: What duties and tariffs have been paid for a specific shipment, and how were the payments processed?
Cross-module	
Goods / Legal and Regulatory Compliance	CQ19: How are goods classified and linked to specific legal requirements (e.g., trade agreements, certificates of origin) in the clearance process?
Goods / Risk Assessment and Inspection	CQ20: Which goods are classified as high-risk and subject to both compliance checks and risk assessments?
Risk Assessment and Inspection / Financial Transaction	CQ21: How are risk assessments linked to specific financial transactions (e.g., duties or tariffs) for high-risk shipments?

The representative CQs in Table 4 covers essential customs operations, demonstrating that COCP fulfils key functional requirements such as automating procedural workflows, ensuring regulatory compliance, and enabling knowledge-driven decision support for customs authorities.

Practical scenario-based testing

In addition to competency question-based validation, practical scenario-based testing provides an additional layer of testing to ensure the COCP ontology accurately models real-world customs processes. This method focuses on validating COCP by simulating real-life scenarios that represent complex workflows and interactions within customs operations. For this purpose, synthetic individuals were created to populate key classes, reflecting realistic customs cases. These instances were designed based on regulatory requirements and typical operational patterns observed in customs procedures. Scenario queries were executed using the Apache Jena Fuseki 4.7.0 SPARQL endpoint, allowing controlled testing of semantic queries against the ontology in a reproducible local environment.

Scenario 1: High-risk goods requiring multi-port clearance. In this scenario, a shipment of high-risk goods is flagged during the customs clearance process. The goods are classified as high-risk based on their origin and category, triggering actions such as multi-port clearance, enhanced inspection protocols, and compliance checks. The goods first arrive at an initial port, where they undergo a preliminary inspection and risk assessment. Given the high-risk classification, the shipment is flagged for additional inspections at a secondary port. Upon arrival at the second port, further compliance checks are conducted, including verifying trade agreements and calculating applicable tariffs. Once all inspections and checks are completed, and provided there are no violations, the goods are cleared for entry. A SPARQL query and its output (shown in Figure 5) were used to validate how COCP manages these dynamic interactions in real-time decision-making for high-risk goods.

```
PREFIX cocp: <https://w3id.org/CustomsProcedures/COCP#>


SELECT ?goods ?riskLevel ?port ?inspection ?complianceCheck
WHERE {
      ?goods cocp:hasRiskAssessment ?riskAssessment.
      ?riskAssessment cocp:hasRiskLevel "high-risk".
      ?inspection cocp:inspectsGoods ?goods.
      ?inspection cocp:takesPlaceAt ?port.
      ?goods cocp:undergoesComplianceCheck ?complianceCheck.
      ?complianceCheck cocp:relatesToTradeAgreement ?tradeAgreement.
}
```

goods	riskLevel	port	inspection	complianceCheck
cocp:G143	"high-risk"	cocp:Port01	cocp:Ins17	cocp:CCheck9
cocp:G441	"high-risk"	cocp:Port02	cocp:Ins39	cocp:CCheck4
cocp:G191	"high-risk"	cocp:Port01	cocp:Ins53	cocp:CCheck5

Figure 5. SPARQL query and its output for validating high-risk goods requiring multi-port clearance

In Figure 5, the SPARQL query evaluates the ontology's ability to handle multiple inspections, risk assessments, and compliance checks across various ports, ensuring that the relationships between `Goods`, `Risk Assessment`, `Port`, `Inspection`, and `Compliance Check` are accurately modelled.

Scenario 2: Duty exemption for goods under a Free Trade Agreement (FTA). In this scenario, a shipment of goods qualifies for a duty exemption under a specific FTA. The shipment consists of electronics that are eligible for duty exemptions based on the trade agreement between the exporting and importing countries. Upon arrival at the customs port, the customs officer retrieves the relevant trade agreement to verify whether the shipment meets the exemption criteria outlined in the trade agreement. The system checks the origin of the goods, their classification (HSCode), and the applicable tariff schedule to determine whether the duty exemption applies. If all conditions are satisfied, the goods are cleared, and the associated duties and tariffs are waived. To verify this process, a SPARQL query was used, as shown in Figure 6.

```
PREFIX cocp: <https://w3id.org/CustomsProcedures/COCP#>

SELECT ?goods ?origin ?hsCode ?tariff ?customsAgreement ?tradeAgreement
WHERE {
    ?goods cocp:hasOrigin ?origin.
    ?goods cocp:hasHSCode ?hsCode.
    ?goods cocp:isSubjectToCustomsAgreement ?customsAgreement.
    ?customsAgreement cocp:relatesToTradeAgreement ?tradeAgreement.
    ?goods cocp:hasTariff ?tariff.
    FILTER EXISTS {
        ?tradeAgreement cocp:providesDutyExemption ?goods.
    }
}
```

goods	**origin**	**hsCode**	**tariff**	**customsAgreement**	**tradeAgreement**
cocp:G789	cocp:AU	"8471.30"	cocp:Electronics_2024	cocp:ImportElectronics	cocp:FTA_AU_VN
cocp:G812	cocp:CA	"8528.72"	cocp:Displays_2024	cocp:ImportDisplays	cocp:FTA_CA_BG

Figure 6. SPARQL query and its output for validating duty exemption under an FTA

The SPARQL query and its result presented in Figure 6 tests the COCP ontology's ability to model the complex relationships between `Goods`, `Country`, `HSCode`, `Tariff`, `CustomsAgreement`, and `TradeAgreement`. It validates whether the ontology can accurately determine eligibility for duty exemptions based on the origin of the goods, their classification, and the relevant trade agreements.

Scenario-based testing confirms that the COCP ontology can handle complex customs processes, such as multi-port clearance for high-risk goods and duty exemptions under trade agreements. A total of 45 SPARQL-based tests were conducted, without distinguishing between simple or complex scenarios, with a resulting success rate of 97.2%. The use of SPARQL queries in scenario-based testing demonstrated COCP's ability to support decision-making, manage dynamic interactions, and ensure compliance with trade agreements and risk-based procedures, thereby validating its effectiveness in real-world customs operations.

There were three iterations that took place during the development of COCP. In the first iteration, we revised the initial ontology after identifying missing or misrepresented concepts based on reasoning limitations. Specific issues related to customs procedures, such as procedural stages and document dependencies, required structural adjustments and clarification of class definitions. In the second iteration, we added new concepts and relationships to enhance coverage of operational, financial, and logistical aspects. This included introducing classes such as *TransportMode*, *Warehouse*, and *PaymentMethod*, as well as improving inter-module links. In the third iteration, we incorporated expert feedback to refine terminology, improve semantic clarity, and strengthen support for legal compliance. These iterations allowed us to systematically refine the ontology's structure and semantics while maintaining a complete and consistent core model throughout the development process.

Discussion

Practical Applications and Impact of COCP

This section delves into the practical significance of the COCP ontology, highlighting its potential to address real-world challenges within customs operations. It explores the contributions of COCP across three key areas: standardization of customs procedures, enhanced legal compliance and risk management, and AI-driven innovation. Each application demonstrates how COCP can support the resolution of current challenges in customs procedures, contributing to more streamlined, secure, and flexible trade facilitation.

Standardization of customs procedures: Standardizing customs procedures is essential for reducing delays and improving the efficiency of global trade. The Revised Kyoto Convention (World Customs Organization, 2008) emphasizes the need for uniform customs operations worldwide, ensuring that processes are predictable and simplified. In line with Objective 1 and Objective 2 of this study, the COCP ontology was designed using a modular structure and grounded in international standards set by organizations such as the WCO and WTO. This ensures that customs processes comply with globally recognized procedures while maintaining flexibility for future extensions. By adopting these standards, COCP standardizes document management, goods classification, and customs declarations, leading to more consistent practices. This standardization benefits a wide range of stakeholders by streamlining communication and collaboration, as all parties operate under unified procedures. Ultimately, this contributes to the global harmonization of customs processes, supporting broader trade facilitation efforts (World Customs Organization, 2022c). While previous customs ontologies, such as those by Zang et al. (2008) and Loukakos and Setchi (2010), offered valuable domain-specific insights, they lacked a modular structure and did not explicitly support interoperability with external systems. In contrast, COCP was designed with modularity as a core principle, enabling each subdomain (e.g., legal compliance, risk assessment, and logistics) to be developed, maintained, and extended independently. This modular design enhances both reusability and scalability. Furthermore, COCP prioritizes interoperability by integrating international standards (e.g., the WCO Data Model) and aligning with widely accepted semantic technologies. As a result, COCP can interact with diverse customs systems and adapt to evolving regulatory frameworks, overcoming the rigidity observed in earlier models.

Enhanced legal compliance and risk management: Ensuring legal compliance and managing risks are fundamental to international trade. The WCO SAFE Framework of Standards (World Customs Organization, 2021b) emphasizes the importance of risk-based assessments and automated compliance checks to enhance security and streamline trade operations. In accordance with Objective 2 and Objective 3 of this study, the COCP ontology integrates international legal frameworks and formal compliance rules to support semantic consistency and intelligent automation. It provides a structured foundation for automating compliance checks and enabling risk-based assessments. Given the complexity of customs procedures, the use of formal axioms and semantic rules is essential for adapting to evolving trade laws and handling jurisdiction-specific constraints. This approach helps protect the integrity of global trade by enabling more reliable, scalable, and legally compliant customs operations.

Supporting future AI applications: As customs operations become increasingly complex, the role of AI in automating and optimizing these processes is growing. In line with Objective 3, which focuses on enabling intelligent customs applications, COCP is designed to support the integration of AI-driven tools such as reasoning engines, rule-based automation, and predictive analytics. Recent advances in ontology-based AI systems demonstrate their capacity to support intelligent decision-making in domains such as logistics, compliance monitoring, and trade facilitation (Asim et al., 2018; Khadir et al., 2021). COCP provides the necessary foundation for such AI applications by structuring customs-related data in a machine-readable and semantically rich format, enabling integration with AI techniques like reasoning engines, rule-based automation, and predictive analytics. For example, with COCP's modular structure and standardized relationships, AI tools can dynamically calculate tariffs, assess shipment risks, and automate compliance checks. These capabilities reduce the need for human intervention in routine evaluations, freeing up resources for more strategic oversight. This not only improves operational efficiency but also allows customs authorities to focus on more complex, high-level decision-making (Karklina-Admine et al., 2024). This design also aligns with recent research on ontology-enabled intelligent systems (e.g., Burov et al. (2021)), positioning COCP as a forward-compatible semantic layer for next-generation customs technologies. The potential for AI integration within COCP highlights its readiness to support adaptive, efficient, and legally compliant customs operations in the era of digital transformation.

These three practical applications of the COCP ontology represent some of its most significant and readily apparent contributions to modern customs operations. However, the potential of COCP extends far beyond these areas. As the ontology evolves, additional applications can be explored, unlocking further opportunities to enhance efficiency, adaptability, and innovation in customs management and international trade.

Challenges in the Development and Application of COCP

This section explores the challenges faced by the COCP ontology in addressing real-world issues within customs operations. Specifically, it focuses on three key challenges: Specificity vs. generalizability, scalability and interoperability, and legal adaptability and maintenance. These challenges highlight the complexity of managing evolving customs processes and regulations while ensuring smooth integration with external systems.

Specificity vs. generalizability: While COCP provides broad coverage of core customs procedures, it may lack the specificity required for domain- or country-specific scenarios. Customs regulations often vary significantly across regions, including unique legal constraints, trade sanctions, or bilateral agreements. Although COCP offers a foundational model, tailoring it to capture such nuanced regulatory environments remains a challenge. This trade-off between general applicability and detailed coverage must be addressed in future extensions.

Scalability and interoperability: Scalability is essential for COCP’s use in international and multi-system environments. However, integrating COCP with external systems, especially those using divergent data models or localized formats, presents difficulties. While COCP aligns with international standards like the WCO Data Model, not all jurisdictions or legacy systems adhere to these standards. This limits seamless interoperability and hinders broader adoption without additional mapping or customization.

Legal adaptability and maintenance: The dynamic nature of customs regulations and trade laws necessitates ongoing maintenance of the ontology. Continuous updates are required to reflect changes in national and international policies. However, automating legal reasoning remains difficult due to the ambiguous or conflicting nature of some regulations. Ensuring backward compatibility while integrating new rules and procedures is both technically and legally complex. Human oversight is often required to ensure that COCP's legal inferences remain accurate and compliant.

Despite these challenges, COCP’s modular architecture provides a promising foundation for adaptation. Each module can be individually updated or extended without disrupting the overall structure. This modularization supports the scalable integration of new standards and facilitates interoperability, offering a flexible response to evolving legal and procedural demands.

Conclusion

This paper presents the COCP ontology, a core knowledge model designed to address the complexities of modern customs procedures. The COCP ontology was developed using the NeOn methodology, which employs a scenario-based approach to guide the development process. This methodology supports a modular, scalable design by enabling the reuse of existing resources and ensuring adaptability to evolving real-world requirements. COCP incorporates knowledge of operations, regulations, security, transport, and financial transactions, based on international standards, into a structured model. The development of COCP followed an iterative development lifecycle, consisting of five key phases: requirements specification, knowledge acquisition and modularization, implementation, axiomatization, and validation. This iterative approach allowed for continuous refinement and alignment with real-world customs procedures. Validation results demonstrate the ontology's robustness and applicability. The HermiT reasoner successfully classified the entire ontology and completed consistency checking in approximately 5.3 seconds. A total of 51 competency questions were developed and successfully answered to evaluate the ontology's coverage. Furthermore, 45 SPARQL-based tests were conducted to assess real-world query handling, with a resulting success rate of 97.2 percent. Among these, two representative scenario-based queries were presented to illustrate COCP's ability to support automated decision-making and compliance validation in dynamic customs contexts.

Contributions

The COCP ontology offers several key benefits, including improved standardization of customs procedures, enhanced legal compliance and risk management, and innovative AI-driven applications. Unlike earlier fragmented customs ontologies that were often limited in scope and rigid in structure, COCP was designed with a modular architecture that allows each subdomain (e.g., legal compliance, logistics, and risk assessment) to be developed and maintained independently. This modularity supports better scalability, facilitates integration with diverse systems, and enables targeted updates without disrupting the entire framework.

Challenges

However, COCP also faces challenges, such as addressing domain-specific regulatory nuances, ensuring interoperability with diverse systems across different jurisdictions, and managing the ongoing maintenance required to keep pace with evolving legal frameworks. In terms of validation, while COCP has been rigorously evaluated through ontology reasoning, competency questions, and scenario-based testing, these methods were conducted in controlled environments. As such, practical impacts (such as reductions in declaration errors or improvements in operational performance) have not yet been measured in real-world customs settings. These limitations are acknowledged, and future work will include deployment-oriented evaluations to address this gap.

Future Directions

Looking ahead, future work will proceed in a phased manner, with clear priorities. The first priority is to expand the scope of COCP to encompass more complex and region-specific scenarios, such as trade sanctions and e-commerce-related customs processes. The second priority is to enhance interoperability with international customs systems by aligning with localized standards and developing tools for cross-system integration. Finally, the third priority is to explore the integration of AI-driven technologies, such as machine learning for compliance prediction and natural language processing for automated updates, to further support intelligent automation and decision-making. These developments are planned over the near to medium term and aim to position COCP as a critical tool for modernizing customs operations and meeting the dynamic demands of global trade.

Customs authorities are encouraged to adopt COCP to streamline clearance, ensure regulatory consistency, and support intelligent decision-making. Researchers may explore its application in specialized domains (e.g., e-commerce or trade sanctions) and enhance it with machine learning and natural language processing for automated updates and analytics. These efforts will help establish COCP as a foundational component of modern, intelligent customs management.

ACKNOWLEDGMENTS

We sincerely acknowledge the invaluable feedback and insights provided by domain experts, whose comments greatly contributed to refining the COCP ontology and ensuring its accuracy in modeling real-world customs procedures.

REFERENCES

Aritonang, E. M., Seminar, K. B., Wahjuni, S., & Purbo, O. W. (2017). Modeling ontology and semantic network of regulations in customs and excise. *Telkomnika (Telecommunication Computing Electronics and Control)*, *15*(4), 1929–1937. https://doi.org/10.12928/telkomnika.v15i4.6590

Asim, M. N., Wasim, M., Khan, M. U. G., Mahmood, W., & Abbasi, H. M. (2018). A survey of ontology learning techniques and applications. *Database*, 2018, bay101. https://doi.org/10.1093/database/bay101

Battle, R., & Kolas, D. (2012). Enabling the geospatial Semantic Web with Parliament and GeoSPARQL. *Semantic Web, 3*(4), 355–370. https://doi.org/10.3233/sw-2012-0065

Bennett, M. (2013). The financial industry business ontology: Best practice for big data. *Journal of Banking Regulation*, 14(3), 255–268. https://doi.org/10.1057/jbr.2013.13

Berners-Lee, T., Hendler, J., & Lassila, O. (2001). The semantic web. *Scientific American, 284*(5), 34–43.

Boer, A., van Engers, T., & Winkels, R. (2003). Using ontologies for comparing and harmonizing legislation. *Proceedings of the 9th International Conference on Artificial Intelligence and Law*, 60–69. https://doi.org/10.1145/1047788.1047798

Burov, Y., Mykich, K., & Karpov, I. (2021). Intelligent systems based on ontology representation transformations. In N. Shakhovska & M. O. Medykovskyy (Eds.), *Advances in intelligent systems and computing V* (pp. 263–275). Springer International Publishing. https://doi.org/10.1007/978-3-030-63270-0_18

Calbimonte, J. P., Dubosson, F., Hilfiker, R., Cotting, A., & Schumacher, M. (2017). The MedRed ontology for representing clinical data acquisition metadata. In C. d'Amato, M. Fernandez, V. Tamma, F. Lecue, P. Cudré-Mauroux, J. Sequeda, C. Lange, & J. Heflin (Eds.), *The Semantic Web – ISWC 2017. ISWC 2017. Lecture Notes in Computer Science, vol 10588*. Springer, Cham. https://doi.org/10.1007/978-3-319-68204-4_4

Fernández-López, M., Gómez-Pérez, A., & Juristo, N. (1997). Methontology: from ontological art towards ontological engineering. American Association for Artificial Intelligence.

Garbacz, P., Kulicki, P., & Trypuz, R. (2012). A formal ontology of knowing and knowledge. *Knowledge Management Research & Practice, 10*(3), 206–226. https://doi.org/10.1057/kmrp.2012.16

Guarino, N., Oberle, D., & Staab, S. (2009). What is an ontology? In S. Staab & R. Studer (Eds.), *Handbook on ontologies. International handbooks on information systems* (pp. 1-17). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-92673-3_0

Hepp, M. (2008). GoodRelations: An ontology for describing products and services offers on the web. In A. Gangemi & J. Euzenat (Eds.), *Knowledge engineering: practice and patterns* (pp. 329–346). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-87696-0_29

Hobbs, J. R., & Pan, F. (2006). *Time ontology in OWL*. http://www.w3.org/2001/sw/BestPractices/OEP/Time-Ontology

Hoekstra, R., Breuker, J., Di Bello, M., & Boer, A. (2007). The LKIF core ontology of basic legal concepts. *LOAIT, 321*, 43–63.

Karklina-Admine, S., Cevers, A., Kovalenko, A., & Auzins, A. (2024). Challenges for customs risk management today: A literature review. *Journal of Risk and Financial Management, 17*(8). https://doi.org/10.3390/jrfm17080321

Khadir, A. C., Aliane, H., & Guessoum, A. (2021). Ontology learning: Grand tour and challenges. Computer Science Review, 39, 100339. https://doi.org/10.1016/j.cosrev.2020.100339

Kim, H. (2017). Building a K-Pop knowledge graph using an entertainment ontology. *Knowledge Management Research & Practice, 15*(2), 305–315. https://doi.org/10.1057/s41275-017-0056-8

Lamharhar, H., Kabbaj, A., Chiadmi, D., & Benhlima, L. (2014). An e-government knowledge model: 'e-customs' case study. *Electronic Government, An International Journal, 11*(1/2), 59–82. https://doi.org/10.1504/eg.2014.063314

Lane, M. (1998). *Customs modernization and the international trade superhighway*. Bloomsbury Publishing USA.

Loukakos, P., & Setchi, R. (2010). Application of ontological engineering in customs domain. In R. Setchi, I. Jordanov, R. J. Howlett, & L.C. Jain (Eds.), *Knowledge-based and intelligent information and engineering systems* (pp. 481–490). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-15387-7_52

McLinden, G., Fanta, E., Widdowson, D., & Doyle, T. (2010). *Border management modernization*. World Bank Publications.

Noy, N. F., & Mcguinness, D. L. (2001). *Ontology development 101: A guide to creating your first ontology*. Stanford University.

Ouchetto, H., Ouchetto, O., & Roudiès, O. (2012). Ontology-oriented e-gov services retrieval. *International Journal of Computer Science Issues (IJCSI), 9*(2, No 3). http://www.ijcsi.org

Patel, A. S., Merlino, G., Puliafito, A., Vyas, R., Vyas, O. P., Ojha, M., & Tiwari, V. (2023). An NLP-guided ontology development and refinement approach to represent and query visual information. *Expert Systems with Applications, 213*. 118998. https://doi.org/https://doi.org/10.1016/j.eswa.2022.118998

Polner, M. (2011). Coordinated border management: from theory to practice. *World Customs Journal, 5*(2), 49–64. https://doi.org/10.55596/001c.92724

Raimond, Y., & Abdallah, S. (2007). *The event ontology*. Citeseer. https://motools.sourceforge.net/event/event.html

Rebele, T., Suchanek, F., Hoffart, J., Biega, J., Kuzey, E., & Weikum, G. (2016). YAGO: A multilingual knowledge base from Wikipedia, Wordnet, and Geonames. *Lecture Notes in Computer Science, 9982*. 177–185. https://doi.org/10.1007/978-3-319-46547-0_19

Seo, D., Kim, P., Jung, H., & Lee, S. (2013). Tracking relationships on ontology for revealing potential trade risk factors in e-customs. International Information Institute (Tokyo). *Information, 16*(8), 5453.

Suárez-Figueroa, M. C., Gómez-Pérez, A., & Fernández-López, M. (2012). The NeOn methodology for ontology engineering. In M. C. Suárez-Figueroa, A. Gómez-Pérez, E. Motta, & A. Gangemi (Eds.), *Ontology engineering in a networked world* (pp. 9–34). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-24794-1_2

Suárez-Figueroa, M. C., Gómez-Pérez, A., & Fernandez-Lopez, M. (2015). The NeOn methodology framework: A scenario-based methodology for ontology development. *Applied Ontology, 10*(2), 107–145. https://doi.org/10.3233/ao-150145

Sure, Y., Staab, S., & Studer, R. (2004). On-To-Knowledge Methodology (OTKM). In S. Staab & R. Studer (Eds.), *Handbook on ontologies* (pp. 117–132). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-24750-0_6

Wang, T., Gu, H., Wu, Z., & Gao, J. (2020). Multi-source knowledge integration based on machine learning algorithms for domain ontology. *Neural Computing and Applications, 32*(1), 235–245. https://doi.org/10.1007/s00521-018-3806-5

World Customs Organization. (2008). *Text of the revised Kyoto Convention*. https://www.wcoomd.org/Topics/Facilitation/Instrument%20and%20Tools/Conventions/pf_revised_kyoto_conv/Kyoto_New

World Customs Organization. (2012). *WCO customs risk management compendium*. https://www.wcoomd.org/en/topics/facilitation/instrument-and-tools/tools/risk-management-compendium.aspx

World Customs Organization. (2021a). *Global adoption of the WCO data model*. https://www.wcoomd.org/-/media/wco/public/global/pdf/topics/facilitation/instruments-and-tools/tools/data-model/global-adoption-of-the-wco-data-model_en.pdf?la=en

World Customs Organization. (2021b). *SAFE framework of standards.* https://www.wcoomd.org/-/media/wco/public/global/pdf/topics/facilitation/instruments-and-tools/tools/safe-package/safe-framework-of-standards.pdf

World Customs Organization. (2022a). *Business process model for WCO data model.* https://www.wcoomd.org/-/media/wco/public/global/pdf/topics/facilitation/instruments-and-tools/tools/data-model/wco-dm-3_9_0/business-process-model/wco-dm-v3_9_0_business-process-model.pdf

World Customs Organization. (2022b). *HS nomenclature 2022 edition.* https://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs-nomenclature-2022-edition.aspx

World Customs Organization. (2022c). *Making digital collaboration possible: the WCO data model – latest developments and implementation guidance.* https://mag.wcoomd.org/magazine/wco-news-97-issue-1-2022/making-digital-collaboration-possible-the-wco-data-model-latest-developments-and-implementation-guidance/

World Trade Organization. (1947). *General agreement on tariffs and trade.* https://www.wto.org/english/docs_e/legal_e/gatt47_01_e.htm

World Trade Organization. (2014). *Trade facilitation agreement.* https://www.wto.org/english/docs_e/legal_e/tfa-nov14_e.htm

Zang, B., Li, Y., Xie, W., Chen, Z., Tsai, C.-F., & Laing, C. (2008). An ontological engineering approach for automating inspection and quarantine at airports. *Journal of Computer and System Sciences, 74*(2), 196–210. https://doi.org/https://doi.org/10.1016/j.jcss.2007.04.020

AUTHOR

Minh Duc Nguyen is a lecturer at the Department of Economic Information Systems, University of Economics, Hue University, Hue, Vietnam. He received his M.Eng. and Ph.D. degrees in Information Systems from Inje University, Korea, in 2017 and 2021, respectively. His research interests include data mining, ontology engineering, semantic technologies, knowledge management, and blockchain systems.