EUROPEAN UNION AGENCY FOR RAILWAYS

Making the railway system
work better for society.

Telematics ontology

Telematics TSI - Technical document - Ontology

Version 4.0

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Contents

A. Document management

A.1. Document properties

- File name: ERA_TD_Ontology.docx
- Subject and document type: Telematics TSI - Technical document - Ontology
- Author: European Railway Agency
- Version: 4.0

A.2. Change management

Updates to this technical document shall be subject to Change Control Management procedure managed by the Agency pursuant:

- the applicable requirements in the reference TSI
- Art. 23(2) of the Agency Regulation

If necessary, working groups are created in line with Art. 5 of the Agency Regulation.

A.3. Configuration management

A new version of the document will be created if new changes are considered following the Change Control Management Process led by ERA.

More specifically:

- if there is a change in the requirements which influences the implementation
- if information is added to or deleted from the technical document
- adding test cases to the field checking in messages or databases.

Modifications will have to be highlighted, so they can be easily identified.

Disclaimer:

Specific legal references to technical documents and legal acts shall be revised after the enter into force of the Telematics TSI. In some sections this text can be highlighted.

A.4. Availability

The version in force of this document is available on Agency's Gitlab repository. Any printed copy is uncontrolled.

A.5. Application and actors in the scope

Date of entry into force of reference TSI.

This document applies to all the actors in the scope of the reference TSI.

A.6. Document history

Version	Date	Comments
0.1	29/04/2025	Initial version

0.2	14/05/2025	Version for consultation
0.3	26/05/2025	Version updated based on first comments received from the stakeholders.
0.4	02/06/2025	Version updated based on the meeting with stakeholders on the 27th May 2025
4.0	10/06/2025	Initial version for Telematics TSI

B. Acronyms, definitions and external references

B.1. Acronyms

Abbreviation	*Description*
CR	Change Request
CCM	Change Control Management
ERA	European Union Agency for Railways also called “the Agency”
IRI	Internationalized Resource Identifier
OWL	Web Ontology Language – A W3C recommendation to formal language for the Semantic Web. OWL 2 Web Ontology Language Document Overview (Second Edition)
RDF	Resource Description Framework
RDF/XML	RDF serialization in XML
SHACL	Shapes Constraint Language
SKOS	Simple Knowledge Organisation System – A recommendation of the W3C as common data model for sharing and linking knowledge organization systems via the Web. http://www.w3.org/TR/skos-reference
Turtle	RDF serialization format with extension .ttl
TSI	Technical Specification for Interoperability
YARRRML	YARRRML is a human readable text-based representation for declarative Linked Data generation rules.
XSD	XML Schema Definition
XSLT	Extensible Stylesheet Language Transformations

B.2. Definitions

Terms contained in this document are defined in the ERA Ontology.

Terms	*Definition*
ERA Ontology	This is the human and machine-readable Vocabulary/Ontology governed by the Union Agency for Railways . It represents the concepts and relationships linked to the sectorial legal framework and the use cases under the Agency´s remit, as described in the Telematics TSI.

B.3. External references

The referenced documents listed in **Error! Reference source not found.** are indispensable for the application of this document:

- For dated references, only the edition cited applies;
- For undated references, if any, the latest edition of the referenced document (including any amendments) applies.

Id	*Title*	*Doc ID, Edition*	*Date*	*Author/ Publisher*
[1]	Directive 2012/34/EU of The European Parliament and of The Council establishing a single European railway area.	Directive 2012/34/EU	21/11/2012	EC
[2]	Directive (EU) 2016/797 of the European Parliament and of the council of 11 May 2016 on the interoperability of the rail system within the European Union (Recast)	Directive (EU) 2016/797	11/06/2016	EC
[3]	Commission implementing regulation (EU) 2019/773of 16 May 2019 on the technical specification for interoperability relating to the operation and traffic management subsystem of the rail system within the European Union and repealing Decision 2012/757/EU	Commission implementing regulation (EU) 2019/773	08/09/2023	EC
[4]	Commission Implementing Regulation - TSI Telematics	XXX	XXX	EU
[5]	ERA-TD-105	ERA_Technical_Document_ TAF-TD-105_D_2_Appendix_F.pdf	XXX	ERA
[6]	ERA Ontology	https://data-interop.era.europa.eu/era-vocabulary/	31/03/2025	ERA
[7]	RINF Regulation	Commission Implementing Regulation (EU) 2023/1694 of 10 August 2023 amending Regulations (EU) No 321/2013, (EU) No 1299/2014, (EU) No 1300/2014, (EU) No 1301/2014, (EU) No 1302/2014, (EU) No 1304/2014 and Implementing Regulation (EU) 2019/777	August 2023	EU

1 Introduction

ERA Ontology means a technical document issued by the Agency pursuant to Article 4(8) of Directive (EU) 2016/797, setting out human-readable and machine-readable data definitions and presentations and the associated quality and accuracy requirements for data elements of the Union rail system [7].

The Agency shall ensure that the ERA Ontology and associated specific data catalogue elements reflect regulatory and technical developments affecting the Union rail system.

Where a telematics stakeholder shares and grants access to data pursuant to this Regulation, it shall comply with the semantics specified in the data catalogue elements referred to in point 1.4 of the Annex [4] as subsets of the ERA Ontology.

In telematics domain, there are different schema (XSD, JSON schema, UML, etc) that need to be harmonized and governed through a single model that is provided by the ERA Ontology.

2 Scope

The Agency shall ensure that the ERA Ontology is compatible with and includes the following data catalogue elements as subsets:

(a) the technical specifications referenced in Appendix C, index [105] [5], for the purposes of the processes referred to in Article 2 (1), points (a) and (b);

(b) the technical specifications referenced in Appendix C, index [P.7] [6], for the purposes of the processes referred to in Article 2 (1), point (c).

Data, objects and messages shared pursuant to the Regulation [4] shall be serialised in XML format. Where agreed between involved stakeholders, any other compliant RDF serialisation derived from the ERA Ontology focusing on telematics may be used.

The Agency shall ensure the publication of all above ontology and data elements together with the proof of conversions between them. The ontology shall reflect and contain the different XSD in use by the sectors, and the corresponding improvements will go through the corresponding CCM process.

3 Reference to ERA Ontology

This section describes the main content of the ERA ontology and how to read it. It also gives a brief overview of the inclusion of the telematics domain in the next release of the ontology.

3.1 Content of the ERA Ontology

An ontology is a formal representation of a shared understanding of a given domain. It is a way to share information that can also be understood and processed by machines because of the logical statements (semantics) that enables reasoning. The language used to implement an ontology is the Web ontology language (OWL). It comprises semantics for representing the knowledge of a given domain.

ERA ontology is composed of a set of classes, attributes, properties, SKOS files and SHACL. The ontology follows a clear versioning covering the different domains that are mandated by the different legal frameworks in the registers such RINF, ERATV or EVR. The RDF serialization used for generating the elements of the ontology is Turtle. There are many open tools available to convert into any other serialization such as RDF/XML, JSON-LD, NQUADS. All those serializations are open standards maintained by the World Wide Web Consortium (W3C).

The ERA ontology is actively maintained on ERA public Gitlab at the following URL: EU Agency for Railways (ERA) / Public / Interoperable data programme / ERA Ontology group / ERA Ontology · GitLab . The structure of the folders in Gitlab is as follows (only the main ones in Figure 1):

- **ontology.ttl: the main file containing ERA ontology[1] .** The serialization used by default for RDF is Turtle. The tool used for the development is Protégé editor combined with Gitlab Continuous Integration (CI) and Continuous Delivery (CD).
- **era-skos:** a folder containing the different SKOS files.
- **era-shacl:** a folder containing the validation rules in SHACL

The human readable version of the ontology based on the Turtle file is available at ERA Ontology. Version 3.1.0 with details of the different classes, properties and annotations. Each domain has a reference to a specific document with a limited scope to the relevant concepts of the domain. . Once published, the telematics specific domain will be available at https://data-interop.era.europa.eu/era-vocabulary/telematics.(The current version to see the content is available at https://uat.ld4rail.fpfis.tech.ec.europa.eu/era-vocabulary/telematics/). In that link, a pdf printout of the telematics related concepts and properties will be available for download and consultation.

Name	Last commit	Last update
.github/workflows	added create release workflow and...	3 months ago
Examples	fixed typos in switch.ttl example	1 month ago
era-kg	update to version-independent DOI	3 months ago
era-shacl	fixed the SHACL shapes that referr...	2 weeks ago
era-skos-deprecated	moved the deprecated TrainProtect...	1 month ago
era-skos-pre-regulation	Migrate SKOS concept schemes to ...	8 months ago
era-skos	Merge branch 'Dev' into 'main'	1 week ago
governance	solved inconsistencies	3 months ago
images	added new images for ontology	1 month ago
public	added readme for HTML output	3 months ago
queries	fixed the URI used in SPARQL queri...	2 weeks ago
requirements	Typo in folder name	1 year ago
.gitignore	updated HTML generated files	3 months ago
.gitlab-ci.yml	added rule to run the file check in e...	2 months ago
LICENSE	updated license to use EUPLv1.2	1 month ago
README.md	updated README.md	1 month ago
ontology.ttl	Merge branch 'Dev' of https://gitlab...	1 week ago

Figure 1 - ERA ontology repository overview in GitLab

[1] https://gitlab.com/era-europa-eu/public/interoperable-data-programme/era-ontology/era-ontology/-/blob/main/ontology.ttl

3.2 How to read and understand ERA Ontology?

3.2.1 RDF Concepts

In this section, we give a short summary of RDF terms, triples, and quads useful to understand and read an ontology file.

Terms

Data in the RDF is represented using either an Internationalized Resource Identifier (IRI), a literal, or a blank node. They are known as RDF terms. IRIs are a generalization of URIs that permits a wider range of Unicode characters. For example, http://data.europa.eu/949/functionalInfrastructure/operationalPoints/0003dde9aa5d15d164fbb1aa37fe287a3ae542b7[2] for the station of Quiévrain in RINF. Literals are used for values such as strings, numbers, and dates. A literal consists of two or three elements:

- a lexical form, for example, "Quiévrain"
- a datatype IRI, for example, http://www.w3.org/2001/XMLSchema#string
- a non-empty language tag, for example, "en"

In RDF, Blank nodes can be used and are disjoint from IRIs (known nodes) and literals. Unlike IRIs and literals, blank nodes do not identify specific resources. Statements involving blank nodes say that something with the given relationships exists, without explicitly naming it.

Triples

An RDF triple consists of three main components:

- the subject, which is an IRI or a blank node
- the predicate, which is an IRI
- the object, which is an IRI, a literal or a blank node

A triple is conventionally written in the order subject, predicate, object. It is viewed as graph with nodes and edges.

Example (in Turtle):

This triple represents an operational point (OP) with IRI http://data.europa.eu/949/functionalInfrastructure/operationalPoints/0003dde9aa5d15d164fbb1aa37fe287a3ae542b7 with the name "Quiévrain" using the property in ERA Ontology <http://data.europa.eu/949/opName>.

```
<http://data.europa.eu/949/functionalInfrastructure/operationalPoints/0003dde9aa5d15d164fbb1aa37fe287a3ae542b7> <http://data.europa.eu/949/opName>  "Quiévrain".
```

Quads

An RDF quad consists of four components:

- the subject, which is an IRI or a blank node
- the predicate, which is an IRI
- the object, which is an IRI, a literal or a blank node
- the graph, which is an IRI or a blank node

[2] The user can put the URI on a browser and starts discovering more details under http://data.europa.eu/949/functionalInfrastructure/operationalPoints/0003dde9aa5d15d164fbb1aa37fe287a3ae542b7 (follow-your-nose principal)

A quad is conventionally written in the order subject, predicate, object, graph.

Example (in Turtle):

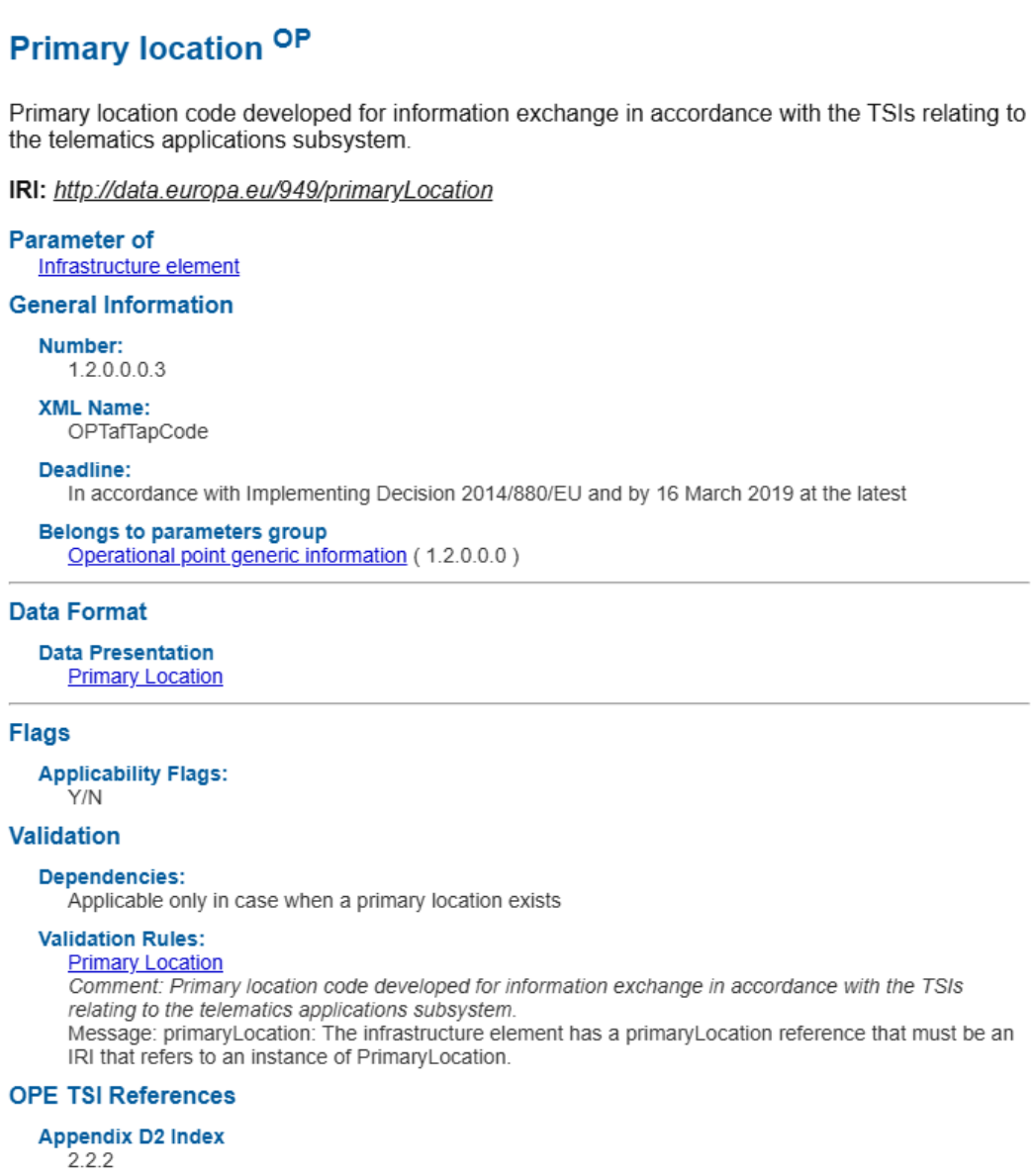
This Quad represents the same station "Quiévrain" in the name graph RINF located in the IRI `<http://data.europa.eu/949/graph/rinf>.`

```
<http://data.europa.eu/949/functionalInfrastructure/operationalPoints/0003dde9aa5d15d164f
bb1aa37fe287a3ae542b7>       <http://data.europa.eu/949/opName>   "Quiévrain"
<http://data.europa.eu/949/graph/rinf>.
```

3.2.2 Understanding the ERA Ontology

The human readable version of the ontology aims at giving all the relevant information regarding the concept defined in the ontology. Let's see the example depicted in Figure 1 below for the concept "Primary Location".

The mention "OP" on top left means it is `owl:ObjectProperty` (a property used to link two classes) followed by a description with possible references. The unique identification (IRI) of the concept in the ontology is <*http://data.europa.eu/949/primaryLocation*>. The namespace for ERA publisher for the ontology and related data is under http://data.europa.eu/949/. All the URIs are dereferenceable using the namespaces of ERA. If that is not the case, the issue is fixed by uploading the relevant artifacts in the graph database management tool.



Primary location OP

Primary location code developed for information exchange in accordance with the TSIs relating to the telematics applications subsystem.

IRI: *http://data.europa.eu/949/primaryLocation*

Parameter of
Infrastructure element

General Information

Number:
1.2.0.0.0.3

XML Name:
OPTafTapCode

Deadline:
In accordance with Implementing Decision 2014/880/EU and by 16 March 2019 at the latest

Belongs to parameters group
Operational point generic information (1.2.0.0.0)

Data Format

Data Presentation
Primary Location

Flags

Applicability Flags:
Y/N

Validation

Dependencies:
Applicable only in case when a primary location exists

Validation Rules:
Primary Location
Comment: Primary location code developed for information exchange in accordance with the TSIs relating to the telematics applications subsystem.
Message: primaryLocation: The infrastructure element has a primaryLocation reference that must be an IRI that refers to an instance of PrimaryLocation.

OPE TSI References

Appendix D2 Index
2.2.2

Figure 2 - A view of a Primary Location object property extracted from ERA ontology v3.1.0 with a "RINF view".

Figure 3 below shows a conceptual view of the telematic related concepts in the current RINF domain the ERA Ontology. The extended version will be fully depicted in the release integration all the elements present in the XSD TAF TAP and according to the relevant technical documents.

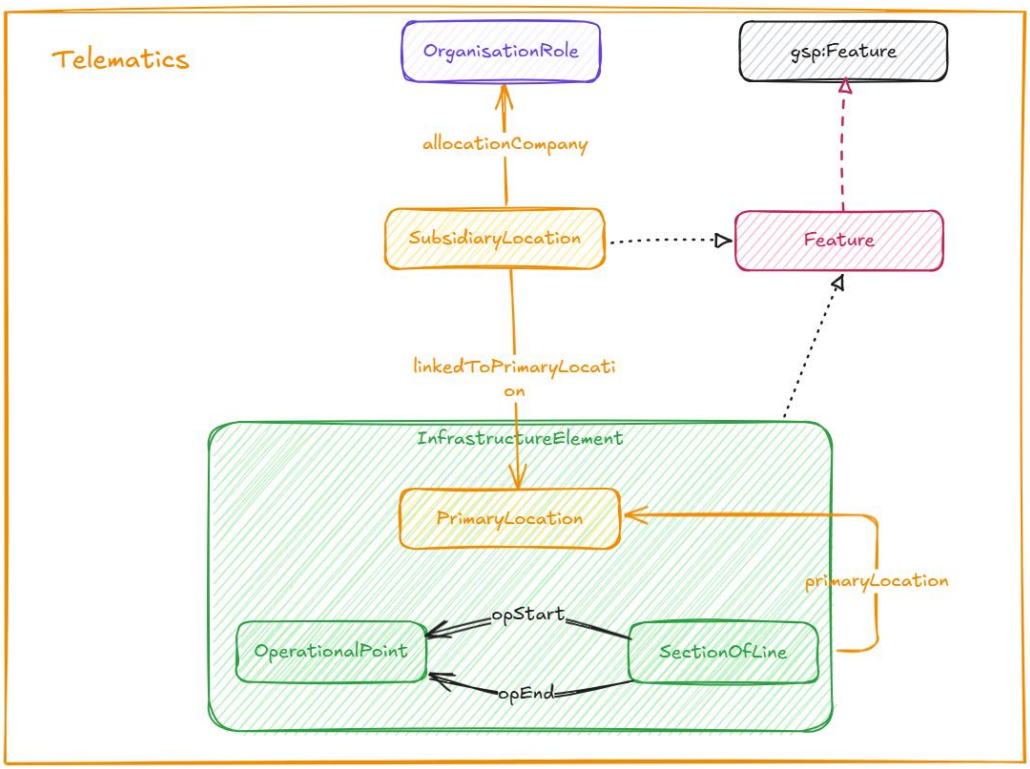


Figure 3

Figure 3: Overview of the interface between railway infrastructure and telematics in ERA ontology v3.1.0 prior integration of full Telematics TSI. The namespace *gsp:* corresponds to GeoSPARQL ontology. The dotted arrow represents rdfs:subClassOf, plain arrow for owl:ObjectProperty while rectangles represent owl:Class. Additionally, a rectangle inside another rectangle represents that the latter is rdfs:subClassOf the former.

The machine-readable version of the definition of the property era:primaryLocation is depicted in Figure 4 below. Those axioms are used to constraint the usage of the property from an instance of era:InfrastructureElement (or subClasses) with the usage of rdfs:domain and to the RDFS range Class `PrimaryLocation`.

The signature of era:primaryLocation is equivalent to a function with two parameters (era:InfrastructureElement, era:PrimaryLocation). Many annotations are used for displaying human readable versions of the ontology such as rdfs:comment, era:rinfIndex, era:shaclShapeValidationRule.

```
###  http://data.europa.eu/949/primaryLocation
era:primaryLocation rdf:type owl:ObjectProperty ;
                    rdfs:subPropertyOf era:opGenericObjParameter ;
                    rdfs:domain era:InfrastructureElement ;
                    rdfs:range era:PrimaryLocation ;
                    era:XMLName "OPTafTapCode" ;
                    era:applicable "Y/N" ;
                    era:dependencyNote "Applicable only in case when a primary
location exists"@en ;
                    era:legalDeadline "In accordance with Implementing Decision
2014/880/EU and by 16 March 2019 at the latest"@en ;
                    era:rinfIndex "1.2.0.0.0.3" ;
                    era:shaclShapeValidationRule
<http://data.europa.eu/949/shapes/PrimaryLocation> ;
                    era:tsiOPEAppendixD2Index "2.2.2" ;
                    dcterms:modified "2024-12-03"^^xsd:date ,
```

```
                                    "2025-01-30"^^xsd:date ;
                    dcterms:replaces era:tafTAPCode ;
                    rdfs:comment "Primary location code developed for information
exchange in accordance with the TSIs relating to the telematics applications
subsystem."@en ;
                    rdfs:isDefinedBy <http://data.europa.eu/949/> ;
                    rdfs:label "primary location"@en .
```

Figure 4 - A snapshot of the axioms in OWL defining the property era:primaryLocation, with the domain of application

3.3 Change Control Management Process of ERA Ontology

The Change Control Management Process of ERA Ontology is bi-directional.

A CR can be on the one hand triggered at the level of the technical specifications referenced in Appendix C, index [105] where elements can be modified which can affect the elements of the ERA Ontology [6]: in such cases the submitter of the telematics CR must be aware of this and coordination between the CCM Boards of both domains is needed.

On the other hand, a CR can be triggered at the level of the ERA Ontology [6] where elements can be modified which can affect the elements of the technical specifications referenced in Appendix C, index [105] [5]: in such cases the submitter of the telematics CR must be aware of this and coordination between the CCM Boards of both domains is needed.

In order to ensure transparency of the dependencies between above domains, such elements will be clearly identified in [5] and [6]. For this purpose, the ERA ontology will use a specific annotation property to tag classes and properties that belong to Telematics.

4 Processes of conversion

4.1 Scope and input

The way we enrich ERA ontology with telematics concepts and relations is using the existing XSD files available on the current TAF-TAP Github, completed with NeTEx related XSD. ERA has designed and implemented a methodology of automatic generation of the ontology, reference data (SKOS files) and validation files (SHACL). The is to generate ONE single ontology containing the classes, relations and properties used by the sector.

The list of the XSD used for the conversion are listed below:

- **Taf_cat_complete.xsd:** https://github.com/EU-Agency-for-Railways/TSI_TAF/blob/master/taf_cat_complete.xsd
- **NeTEx complete.xsd : NeTEx/xsd/NeTEx_publication.xsd at master · NeTEx-CEN/NeTEx**
- **Tap Tsi B.10 XSD, Version 1.2 (https://github.com/EU-Agency-for-Railways/TSI_TAP/blob/master/tap_tsi_b.10.xsd)**
- **B5 schema files (https://github.com/EU-Agency-for-Railways/TSI_TAP/blob/master/B.5%20xml_schema_files.zip)**

The conversion approach begins with the schema definition for messages used by ERA within TAF TSI (e.g., taf_cat_complete.xsd). The elements of this XSD schema file are first converted into SHACL shapes and then transformed into OWL classes and properties. The resulting OWL file has also received some manual curation for the current draft. However, the final version of the ontology will require no curation. The ontology will serve as the backbone of an automated pipeline (see Figure 5 below) for converting ERA's XML-based data into RDF.

4.2 Methodology

The main steps of the conversion are described below. It consists of 5 main steps that are automated to be aligned with XSD source file.

- **Step 1:** XSD to OWL lifting based on mapping rules.
- **Step 2:** XSD to SHACL - structural transformation to SHACL constraints
- **Step 3**: SHACL to OWL to derive ontological constructs via pattern extraction
- **Step 4:** XSD to SKOS to transform XSD code lists to SKOS concepts
- **Step 5**: Integration to existing ontology considering ERA principles in ontology development[3] with the following subprocess:
    - Harmonization of namespaces
    - Metadata generation of the ontology
    - Reuse of existing ERA concepts
    - Annotations of the new concepts and properties
    - Mappings between concepts and properties with same semantics
    - Validation of the artifacts.

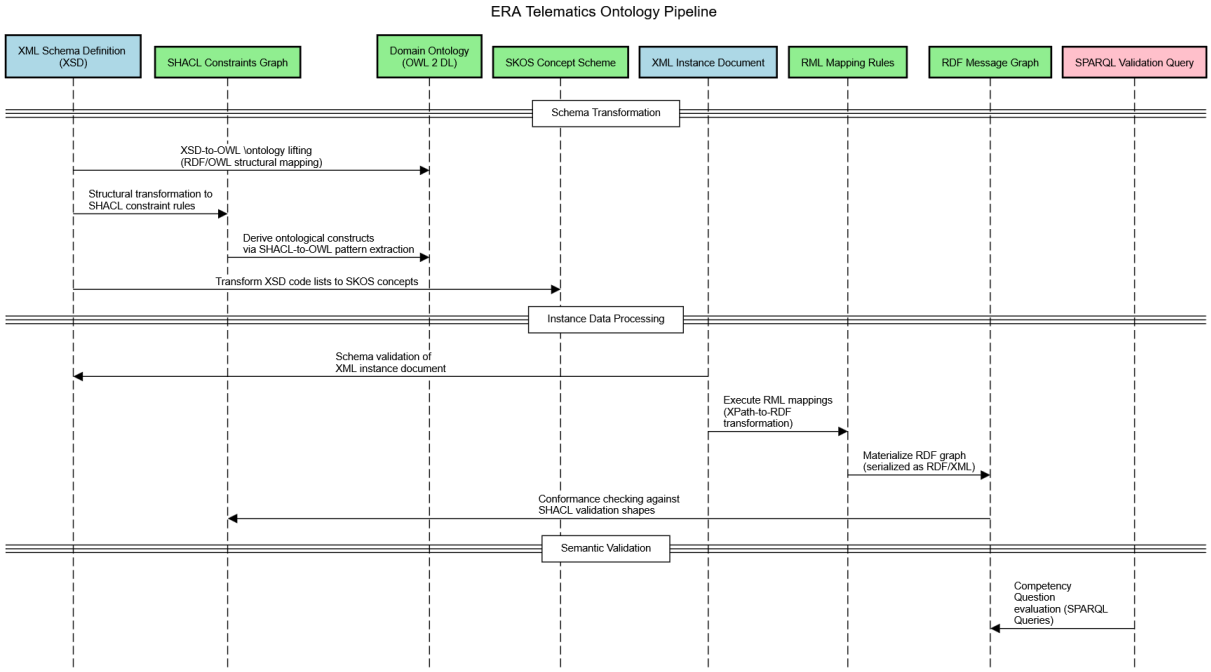


Figure 5 - Overview of the automated pipeline for converting ERA's XML-based data into RDF.

As explained above, the same conversion approach is applied for the TAP related XSD schema (timetables and fares) from NeTEx ("full xsd") based on CEN Transmodel published at NeTEx_publication.xsd.

4.3 XSD to SHACL Conversion

The first process consists of generating SHACL constraints from the original XSD, using clear mappings during the conversion. The figure 6 below lists some of the rules for mapping XSD construct to the equivalent version of SHACL. XSD2RDF is the tool used to generate various RDF artefacts based on XSD publicly available at https://gitlab.com/era-europa-eu/public/interoperable-data-programme/era-ontology/xsd2rdf.

[3] governance/era-principles.md · main · EU Agency for Railways (ERA) / Public / Interoperable data programme / ERA Ontology group / ERA Ontology · GitLab

XSD Construct	SHACL Construct	*Rationale*	Example Input (XSD)	Example Output (SHACL)
attribute				
boolean				
byte				
choice	sh:xone	*Choose exactly one of several options*	<xs:**choice**> <xs:element ref="PrepaidCodeCustomer"/> <xs:element ref="IncotermCode"/> </xs:**choice**>	sh:**xone** (<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/ConsignmentOrderMessage/COMS/COM/ChargingSections/AdditionalCharges/Prepaid> <http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/ConsignmentOrderMessage/COMS/COM/ChargingSec
choice				
complexContent				
complexType	sh:NodeShape	*Complex types define structure, mapped to node shapes*	<xs:complexType name="**CompositIdentifierOperationalType**">	<http://www.era.europa.eu/schemes/TAFTSI/3.5/NodeShape/**CompositIdentifierOperationalType**> a sh:NodeShape ;
date				
dateTime				
decimal				
default attribute	sh:defaultValue	*Default value for element or attribute*	<xs:element name="RollingRoadUnitType" **default="HGZ"** minOccurs="0">	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/RollingRoadUnit/RollingRoadUnitDetails/RollingRoadUnitType> a sh:PropertyShape ; **sh:defaultValue "HGZ" ;**
documentation	sh:description	*Human-readable descriptions*	<xs:documentation>**Date and Time when the check was performed**</xs:documentation>	sh:description "**Date and Time when the check was performed**" ;
element				
element (global)	sh:NodeShape	*Top-level elements are represented as shapes*	<xs:element name="RollingRoadUnit">	<http://www.era.europa.eu/schemes/TAFTSI/3.5/NodeShape/**RollingRoadUnit**> a sh:NodeShape ; sh:targetClass ex:RollingRoadUnit .
element (local)	sh:property	*Child elements become properties of the shape*	<xs:element name="**AssociatedAttachedTrainServiceNumber**" type="String1-8">	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/**AssociatedAttachedTrainServiceNumber**> a sh:PropertyShape ; sh:datatype xsd:**string** ;
enumeration				
extension				
float				
fractionDigits				
import	owl:imports	*Include external definitions*	<xs:import namespace="http://example.org/other"/>	owl:imports <http://example.org/other>;
import				
include	Processing of included schema	*Including another schema*	<xs:include schemaLocation="taf_cat_codelists.xsd"/>	N/A
int				
integer				
length	sh:minLength + sh:maxLength	*Fixed string length*	<xs:length value="19"/>	sh:minLength 19; sh:maxLength 19;
maxExclusive	sh:maxExclusive	*Maximum numeric value (exclusive)*	<xs:maxExclusive value="100"/>	sh:maxExclusive 100;
maxInclusive	sh:maxInclusive	*Maximum numeric value (inclusive)*	<xs:maxInclusive value="10"/>	sh:maxInclusive 10;
maxLength	sh:maxLength	*Maximum string length*	<xs:maxLength value="10"/>	sh:maxLength 10;
maxOccurs	sh:maxCount	*Maximum occurrence constraint*	<xs:element name="CustomerReference" minOccurs="0" **maxOccurs="5"**>	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/Wagons/WagonDetails/CustomerReference> a sh:PropertyShape ; **sh:maxCount 5 ;**
minExclusive	sh:minExclusive	*Minimum numeric value (exclusive)*	<xs:minExclusive value="0"/>	sh:minExclusive 0;
minInclusive	sh:minInclusive	*Minimum numeric value (inclusive)*	<xs:minInclusive value="1"/>	sh:minInclusive 1;
minLength	sh:minLength	*Minimum string length*	<xs:minLength value="3"/>	sh:minLength 3;
minOccurs	sh:minCount	*Minimum occurrence constraint*	<xs:element ref="JourneyLocationTypeCode" **minOccurs="1"** maxOccurs="unbounded"/>	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/JourneyLocationTypeCode> a sh:PropertyShape ; **sh:minCount 1 ;**
pattern	sh:pattern	*Regular expression pattern*	<xs:pattern value="[0-1]{1,740}"/>	sh:pattern "[0-1]{1,740}"
positiveInteger				
restriction	Various constraints	*Value restrictions*	<xs:restriction base="xs:string">...</xs:restriction>	sh:datatype xsd:string; + constraints
restriction				
schema	sh:NodeShape collection	*The entire schema is represented as a collection of shapes*	<xs:schema>...</xs:schema>	Multiple sh:NodeShape declarations

Figure 6 - Sample mappings from XSD to SHACL

SHACL to OWL Conversion

An excerpt below shows the conversion rules from SHACL to OWL.

For example, any sh:NodeShape are converted into an owl:Class in the Ontology. The last two columns of the figure show examples of both input and output result.

SHACL	OWL	Rationale	Example Input (SHACL)	Example Output (OWL)
sh:class	rdfs:range	*SHACL sh:class defines the range of OWL ObjectProperties.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/WagonTelematics/TelematicsDevice/MountedPosition> **sh:class** ex:MountedPosition .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPosition> **rdfs:range** <http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPosition> .
sh:datatype	rdfs:range	*SHACL sh:datatype defines the range of OWL DatatypeProperties.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/WagonTelematics/TelematicsDevice/ATEXCertified> **sh:datatype** xsd:boolean .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/ATEXCertified> **rdfs:range** xsd:boolean .
sh:description	rdfs:comment	*SHACL sh:description is mapped to OWL rdfs:comment.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/NodeShape/WagonTelematics> **sh:description** "Groups telematics capabilities for wagons." .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/TelematicsDevice> **rdfs:comment** "Groups telematics capabilities for wagons." .
sh:name	rdfs:label	*SHACL sh:name is mapped to OWL rdfs:label.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/NodeShape/WagonTelematics> **sh:name** "WagonTelematics" .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/TelematicsDevice> **rdfs:label** "Telematics Device" .
sh:NodeShape	owl:Class	*SHACL NodeShapes are mapped to OWL Classes.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/NodeShape/WagonTelematics> a **sh:NodeShape** ; sh:targetClass ex:TelematicsDevice .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/TelematicsDevice> a **owl:Class** ; rdfs:label "Telematics Device" .
sh:PropertyShape	owl:DatatypeProperty	*SHACL PropertyShapes with sh:datatype are mapped to OWL DatatypeProperties.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/WagonTelematics/TelematicsDevice/ATEXCertified> a **sh:PropertyShape** ; sh:path ex:ATEXCertified ; sh:datatype xsd:boolean .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/ATEXCertified> a **owl:DatatypeProperty** ; rdfs:label "ATEX Certified" ; rdfs:range xsd:boolean .
sh:PropertyShape	owl:ObjectProperty	*SHACL PropertyShapes with sh:nodeKind sh:IRI are mapped to OWL ObjectProperties.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/WagonTelematics/TelematicsDevice/MountedPosition> a **sh:PropertyShape** ; sh:path ex:MountedPosition ; sh:nodeKind sh:IRI .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPosition> a **owl:ObjectProperty** ; rdfs:label "Mounted Position" .
sh:targetClass	rdfs:domain	*SHACL sh:targetClass defines the domain of OWL properties.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/WagonTelematics/TelematicsDevice/ATEXCertified> **sh:targetClass** ex:TelematicsDevice .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/ATEXCertified> **rdfs:domain** <http://www.era.europa.eu/schemes/TAFTSI/3.5/TelematicsDevice> .
sh:targetClass + sh:property	rdfs:domain + rdfs:range	*SHACL sh:targetClass and sh:property define OWL domain and range.*	<http://www.era.europa.eu/schemes/TAFTSI/3.5/NodeShape/WagonTelematics> **sh:targetClass** ex:TelematicsDevice ; **sh:property** <http://www.era.europa.eu/schemes/TAFTSI/3.5/PropertyShape/WagonTelematics/TelematicsDevice/ATEXCertified> .	<http://www.era.europa.eu/schemes/TAFTSI/3.5/ATEXCertified> **rdfs:domain** <http://www.era.europa.eu/schemes/TAFTSI/3.5/TelematicsDevice> ; **rdfs:range** xsd:boolean .

Figure 7 - Excerpt of sample rules transformation from SHACL to OWL axioms.

4.4 XSD to SKOS Conversion

The following table shows some generic constructions from XSD that are used to generate the list of SKOS concepts.

XSD Construct	SKOS	Rationale	Example Input (XSD)	Example Output (SKOS)
documentation	skos:definition	*Maps documentation to a concept or scheme definition.*	<xsd:**documentation** xml:lang="en">Indication of where the telematics unit is located on the component.</xsd:documentation>	skos:**definition** "Indication of where the telematics unit is located on the component." .
enumeration value	skos:prefLabel	*Provides a human-readable label for a concept or scheme.*	<xsd:**enumeration value**="Top"/>	skos:**prefLabel** "Top" ;
enumeration value	skos:Concept	*Represents individual enumeration values as concepts.*	<**xsd:enumeration value**="Top"/>	<http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPosition_Top> a **skos:Concept** ; skos:prefLabel "Top" .
enumeration value	skos:inScheme	*Links a concept to its parent concept scheme.*	<**xsd:enumeration value**="Top"/>	<http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPosition_Top> skos:**inScheme** <http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPositionScheme> .
enumeration value	skos:topConceptOf	*Marks a concept as a top-level concept in a scheme.*	<**xsd:enumeration value**="Top"/>	<http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPosition_Top> skos:**topConceptOf** <http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPositionScheme> .
simpleType	skos:ConceptScheme	*Represents a concept scheme for enumerations.*	<xs:**simpleType** name="MountedPosition"> <xs:enumeration value="Top"/> </xs:simpleType>	<http://www.era.europa.eu/schemes/TAFTSI/3.5/MountedPositionScheme> a skos:**ConceptScheme** ; skos:prefLabel "Concept Scheme for Mounted Position" .

simpleType	dct:title	*Adds a title to the concept scheme.*	<xs:**simpleType** name="MountedPosition">	dct:**title** "Concept Scheme for Mounted Position" .
simpleType	dct:issued	*Adds the creation date of the concept scheme.*	<xs:**simpleType** name="MountedPosition">	dct:**issued** "2025-04-29"^^xsd:date .
simpleType	dct:modified	*Adds the last modification date of the concept scheme.*	<xs:**simpleType** name="MountedPosition">	dct:**modified** "2025-04-29"^^xsd:date .

Table 1 - mapping rules used to generate SKOS concepts from XSD constructs

We provide below two snippets derived from the conversion process, using TAF and NeTEx XSD files

1 – Example snippet for connecting reservations type code list –

```
@prefix cc: <http://creativecommons.org/ns#> .
@prefix dct: <http://purl.org/dc/terms/> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
_00> a skos:Concept ;
    skos:definition "no free connecting reservation" ;
    skos:inScheme
<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
Scheme> ;
    skos:prefLabel "00" ;
    skos:topConceptOf
<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
Scheme> .

<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
_01_-_98> a skos:Concept ;
    skos:definition "number of free connecting reservations" ;
    skos:inScheme
<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
Scheme> ;
    skos:prefLabel "01 - 98" ;
    skos:topConceptOf
<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
Scheme> .

<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
_99> a skos:Concept ;
    skos:definition "all connecting reservation are free" ;
    skos:inScheme
<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
Scheme> ;
    skos:prefLabel "99" ;
```

```
    skos:topConceptOf
<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
Scheme> .

<http://data.europa.eu/949/concepts/ConnectingReservationsTypeCodeList
Scheme> a skos:ConceptScheme ;
    rdfs:label "Concept Scheme for Connecting Reservations Type Code
List" ;
    cc:license <http://data.europa.eu/eli/dec_impl/2017/863/oj> ;
    dct:issued "2025-05-12"^^xsd:date ;
    dct:modified "2025-05-12"^^xsd:date ;
    dct:title "Concept Scheme for Connecting Reservations Type Code
List" ;
    skos:definition "Code list for connecting reservations (B.3.7)" .
```

2- Example snippet for passenger information facilities derived from NeTEx

```
@prefix : <http://www.netex.org.uk/netex/> .
@prefix cc: <http://creativecommons.org/ns#> .
@prefix dct: <http://purl.org/dc/terms/> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .


:PassengerInformationFacilityEnumerationScheme a skos:ConceptScheme ;
    rdfs:label "Concept Scheme for Passenger Information Facility
Enumeration" ;
    cc:license <http://data.europa.eu/eli/dec_impl/2017/863/oj> ;
    dct:issued "2025-05-08"^^xsd:date ;
    dct:modified "2025-05-08"^^xsd:date ;
    dct:title "Concept Scheme for Passenger Information Facility
Enumeration" ;
    skos:definition "Allowed values for Passenger information
facility." .


:PassengerInformationFacilityEnumeration_nextStopIndicator a
skos:Concept ;
    skos:inScheme :PassengerInformationFacilityEnumerationScheme ;
    skos:prefLabel "Next Stop Indicator" ;
    skos:topConceptOf :PassengerInformationFacilityEnumerationScheme .
```

```
:PassengerInformationFacilityEnumeration_other a skos:Concept ;
    skos:inScheme :PassengerInformationFacilityEnumerationScheme ;
    skos:prefLabel "Other" ;
    skos:topConceptOf :PassengerInformationFacilityEnumerationScheme .

:PassengerInformationFacilityEnumeration_passengerInformationDisplay a
skos:Concept ;
    skos:inScheme :PassengerInformationFacilityEnumerationScheme ;
    skos:prefLabel "Passenger Information Display" ;
    skos:topConceptOf :PassengerInformationFacilityEnumerationScheme .

:PassengerInformationFacilityEnumeration_realTimeConnections          a
skos:Concept ;
    skos:inScheme :PassengerInformationFacilityEnumerationScheme ;
    skos:prefLabel "Real Time Connections" ;
    skos:topConceptOf :PassengerInformationFacilityEnumerationScheme .

:PassengerInformationFacilityEnumeration_stopAnnouncements            a
skos:Concept ;
    skos:inScheme :PassengerInformationFacilityEnumerationScheme ;
    skos:prefLabel "Stop Announcements" ;
    skos:topConceptOf :PassengerInformationFacilityEnumerationScheme .
```

4.5 Practical usage of the Telematics pipeline

The conversion tool is documented on Gitlab for reuse and test purposes. It covers the generation of relevant XSD files that are later integrated into the ERA Ontology. The link is the following: EU Agency for Railways (ERA) / Public / Interoperable data programme / ERA Ontology group / ERA Telematics Ontology Pipeline · GitLab

The repository provides the automation for the publication of the ERA (European Union Agency for Railways) telematics ontology. It includes:

- **The input XSD source file as well as a fixed version of it (see further)**
- **Scripts for further post-processing the RDF files after output by the `xsd2rdf` tool (XSD2RDF repository)**
- **Several example folders containing both xml and rdf messages as well as several transformation options**
- **A CI/CD pipeline for validation, transformation, documentation generation, and publishing**

Please note that this repository is subject to improvements and updates.

4.5.1 Automation

The telematics ontology is automatically generated in a two steps process with respect to the following steps as implemented in the tooling:

- **conversion from the XSD schema using the `xsd2rdf` tool**

- **post-processing using the scripts defined in this repository**

There is no manual curation performed.

4.5.2 Repository Structure

- **`xsd-source/` — Source XSD files (including `taf_cat_complete.xsd` and `taf_cat_complete_fixed.xsd`).**
- **`post-processing/` — Python scripts for post-processing RDF/OWL files.**
- **`example-xml-messages/` — A wide variety of example XML messages. Their purpose is to serve as test messages to validate the ontology.**
- **`example-rdf-messages/` — Example RDF/Turtle telematics messages, converted from XML messages.**
- **`example-transforming-xml-messages/` — Demonstrates various methods for transforming between XML and RDF representations. Organized into subfolders for different approaches:**
  - **`xml-to-rdf/rml-mapping/`: Uses RML (RDF Mapping Language) to map XML data to RDF.**
  - **`xml-to-rdf/sparql-anything/`: Demonstrates the use of SPARQL Anything for querying and transforming XML to RDF.**
  - **`xml-to-rdf/yarrrml/`: YARRRML (Yet Another RDF Mapping Language) templates for declarative XML-to-RDF transformation.**
  - **`rdf-to-xml/pure-python/`: Scripts and examples for converting RDF to XML using pure Python code.**
  - **`rdf-to-xml/xslt/`: XSLT stylesheets and examples for transforming RDF/XML using XSLT.**
- **`output-rdf-result/` — (Generated) RDF/OWL/SHACL/SKOS files from an intermediate version of the `xsd2rdf` tool and the post-processing, manually added to the repository.**
  - **`taf/`: output RDF/OWL/SHACL/SKOS files for TAF XSD file**
  - **`netex/`: output RDF/OWL/SHACL/SKOS files for NeTEx XSD publication file.**
- **`public-doc/`: contains the human readable documentation generated for the TAF semantic artifacts.**

4.5.3 Source XSD File and Fixes

The main XSD file for this repository is `taf_cat_complete_fixed.xsd` in the `xsd-source/` directory. This file is based on the official TAF TSI schema but includes several important fixes and clarifications:

- **RID_Checking / CheckingResults: Changed from a pattern restriction to an enumeration for better validation and clarity.**
- **Customers / AdditionalInformation: Added explicit datatype and corrected a typo.**
- **RID_Class: Two separate definitions were merged into a single reference to avoid duplication and confusion.**

These changes ensure improved schema validation, data consistency, and easier downstream processing. Besides these mandatory fixes to the schema, suggestions for improvement can also be found in the issues section of this repository.

4.5.4 Post-processing

The `xsd2rdf` tool is a generic tool that aiming at converting every xsd file. In order to make the output more integrated with the ERA's ontology, we perform some post-processing steps on the generated RDF/OWL files. The post-processing is done using a Python script that performs the following tasks:

- Change the namespace to **http://data.europa.eu/949/** (or subdir /concepts for SKOS and /shapes for SHACL)
- Create mapping annotations for the classes and properties that are similar in the ERA ontology (under construction)
- Create property hierarchy (using `owl:subPropertyOf`) for documentation generation. These use the SPARQL CONSTRUCT queries in the `pg_construct_queries` folder.
- Add `era:shaclShapeValidationRule` and `era:inSkosConceptScheme` to classes and properties using the SPARQL CONSTRUCT queries in the `constraint_queries` folder

4.5.5 Message transformation

The repository contains several examples of transforming XML messages to RDF and vice versa. The examples are organized into subfolders, each demonstrating a different approach or tool for the transformation.

We recommend using the following approaches:

- XML -> RDF: YARRRML mapping (less verbose than RML mapping, easier to write compared to sparql-anything for xml files)
- RDF -> XML: XSLT (easier to maintain and understand than custom Python code)

4.5.6 CI/CD Pipeline

The repository uses GitLab CI/CD to automate the following stages: (NOTE - this CI/CD is NOT yet synchronised with ERA AWS publishing pipeline)

1. validate-input
    a. Validates the main XSD (`taf_cat_complete_fixed.xsd`) for correctness
2. generate-rdf
    a. Converts the XSD to RDF/OWL, SHACL, and SKOS using the `xsd2rdf` Python library
    b. Runs post-processing on the generated OWL file using the provided Python script
3. generate-documentation
    a. Generates ontology HRML documentation (for human readable)
    b. Generates SHACL documentation
    c. Generates combined documentation (dummy for now, to be replaced with actual tool)
4. publish
    a. Publishes the processed ontology and documentation to GitLab Pages

4.5.7 Artifacts and Releases

- The generated `RDF/OWL`, `SHACL`, `SKOS`, and documentation files are available as pipeline artifacts and via GitLab Pages
- On tag creation, outputs are also attached to the release

5 Sample messages in RDF

We display some outputs derived from the Ontology to generate some sample RDF graph messages, as well as the conversion back from RDF/XML to XML compliant with telematics XSD.

5.1 TELEM XSD to RDF (using YARRRML)

The sample used is a path confirmed message. YARRRML ((Yet Another RDF Mapping Language) is a declarative language to convert XML/CSV/JSON files into RDF. The specification is available here https://rml.io/yarrrml/spec/https://rml.io/yarrrml/spec/. A tutorial explaining how to use YARRRML is available at rml.io/yarrrml/tutorial/getting-started/rml.io/yarrrml/tutorial/getting-started/

```
prefixes:
  rr: http://www.w3.org/ns/r2rml#
  rml: http://semweb.mmlab.be/ns/rml#
  ql: http://semweb.mmlab.be/ns/ql#
  xsd: http://www.w3.org/2001/XMLSchema#
  taf: http://www.era.europa.eu/ontologies/taf#
  dc: http://purl.org/dc/elements/1.1/
  dct: http://purl.org/dc/terms/
  foaf: http://xmlns.com/foaf/0.1/
  owl: http://www.w3.org/2002/07/owl#
  rdfs: http://www.w3.org/2000/01/rdf-schema#
  ex: http://example.org/
  base: http://data.europa.eu/949/triplesmap/

mappings:
  PathConfirmedMessage:
    sources:
      - access: ERA_legacy/data/20240123-80865-PathConfirmed-TOI17_OK.xml
        referenceFormulation: xpath
        iterator: /ns1:PathConfirmedMessage
 s:
http://data.europa.eu/949/telematicsMessage_$(ns1:MessageHeader/ns1:MessageR
eference/MessageIdentifier)
    po:
      - [a, taf:PathConfirmedMessage]
      - [taf:hasMessageStatus, $(ns1:MessageStatus), xsd:string]
      - [taf:hasTypeOfRequest, $(ns1:TypeOfRequest), xsd:string]
      - [taf:hasTypeOfInformation, $(ns1:TypeOfInformation), xsd:string]
      - [taf:hasCoordinatingIM, $(ns1:CoordinatingIM)]
      - [taf:hasLeadRU, $(ns1:LeadRU)]
      - predicates: taf:hasMessageHeader
        objects:
        -  mapping: MessageHeader
      - predicates: taf:hasIdentifiers
        objects:
        -  mapping: Identifiers
      - predicates: taf:hasAdministrativeContactInformation
```

```
        objects:
        -  mapping: AdminContact

  MessageHeader:
    sources:
      - access: ERA_legacy/data/20240123-80865-PathConfirmed-TOI17_OK.xml
        referenceFormulation: xpath
        iterator: /ns1:PathConfirmedMessage/ns1:MessageHeader
    s:
http://data.europa.eu/949/telematicsMessage_$(ns1:MessageReference/MessageId
entifier)_header
    po:
      - [a, taf:MessageHeader]
      - [taf:hasSender, $(ns1:Sender)]
      - [taf:hasRecipient, $(ns1:Recipient)]
      -    [taf:hasMessageDateTimeCreated,    $(ns1:MessageDateTimeCreated),
xsd:dateTime]
      - [taf:hasMessageReference, MessageReference]

  MessageReference:
    sources:
      - access: ERA_legacy/data/20240123-80865-PathConfirmed-TOI17_OK.xml
        referenceFormulation: xpath
        iterator:
/ns1:PathConfirmedMessage/ns1:MessageHeader/ns1:MessageReference
    s:
http://data.europa.eu/949/telematicsMessage_$(MessageIdentifier)_reference
    po:
      - [a, taf:MessageReference]
      - [taf:hasMessageType, $(ns1:MessageType)]
      - [taf:hasMessageTypeVersion, $(ns1:MessageTypeVersion)]
      - [taf:hasMessageIdentifier, $(MessageIdentifier)]
      - [taf:hasMessageDateTime, $(MessageDateTime), xsd:dateTime]

  AdminContact:
    sources:
      - access: ERA_legacy/data/20240123-80865-PathConfirmed-TOI17_OK.xml
        referenceFormulation: xpath
        iterator:
/ns1:PathConfirmedMessage/ns1:AdministrativeContactInformation
    s:
http://data.europa.eu/949/telematicsMessage_$(../ns1:MessageHeader/ns1:Messa
geReference/MessageIdentifier)_contact
    po:
      - [a, taf:AdministrativeContactInformation]
      - [foaf:name, $(ns1:Name)]

  Identifiers:
```

```
    sources:
      - access: ERA_legacy/data/20240123-80865-PathConfirmed-TOI17_OK.xml
        referenceFormulation: xpath
        iterator: /ns1:PathConfirmedMessage/ns1:Identifiers
    s:
http://data.europa.eu/949/telematicsMessage_$(../ns1:MessageHeader/ns1:MessageReference/MessageIdentifier)_identifiers
    po:
      - [a, taf:Identifiers]
      - predicates: taf:hasPlannedTransportIdentifiers
        objects:
        -  mapping: PlannedTransportIdentifiers

  PlannedTransportIdentifiers:
    sources:
      - access: ERA_legacy/data/20240123-80865-PathConfirmed-TOI17_OK.xml
        referenceFormulation: xpath
        iterator:
/ns1:PathConfirmedMessage/ns1:Identifiers/ns1:PlannedTransportIdentifiers
    s:
http://data.europa.eu/949/telematicsMessage_$(../../ns1:MessageHeader/ns1:MessageReference/MessageIdentifier)_identifier_$(substring-before\(substring-after\(path\(.\),'PlannedTransportIdentifiers['\),']'\))
    po:
      - [a, taf:PlannedTransportIdentifiers]
      - [taf:hasObjectType, $(ns1:ObjectType)]
      - [taf:hasCompany, $(ns1:Company)]
      - [taf:hasCore, $(ns1:Core)]
      - [taf:hasVariant, $(ns1:Variant)]
      - [taf:hasTimetableYear, $(ns1:TimetableYear), xsd:integer]
```

The source of the script is also available in ERA Gitlab in the subfolder xml-to-rdf/yarrrml for generating XML messages and rdf-to-xml to convert RDF/XML from the ontology into telematics XML. Link: [example-transforming-xml-messages/rdf-to-xml · main · EU Agency for Railways (ERA) / Public / Interoperable data programme / ERA Ontology group / ERA Telematics Ontology Pipeline · GitLab]

transform_yarrrml.bat 590 B

```
@echo off
REM Batch script to transform YARRRML mappings to RML using Docker

echo Converting YARRRML to RML format...

REM Set file variables
set YARRRML_FILE=pathconfirmed.yarrrml.yml
set OUTPUT_FILE=pathconfirmed.rml.ttl

REM Run Docker container to convert YARRRML to RML
docker run --rm -v %cd%:/data rmlio/yarrrml-parser:latest -i /data/%YARRRML_FILE% -o /data/%OUTPUT_FILE%

IF %ERRORLEVEL% EQU 0 (
    echo Conversion successful! RML file created at: %OUTPUT_FILE%
) ELSE (
    echo Error during conversion. Please check your YARRRML syntax.
    exit /b 1
)

echo Process completed.
```

Figure 8: Sample bash runner to convert XML to RDF available in Gitlab.

RDF output in Turtle

```
@prefix            dc:            <http://purl.org/dc/elements/1.1/>            .
@prefix              dct:              <http://purl.org/dc/terms/>              .
@prefix                ex:                <http://example.org/>                .
@prefix              foaf:              <http://xmlns.com/foaf/0.1/>             .
@prefix             owl:              <http://www.w3.org/2002/07/owl#>           .
@prefix msg: <http://data.europa.eu/949/telematics/messages/> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix taf: <http://www.era.europa.eu/ontologies/taf#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a a taf:PathConfirmedMessage;
  taf:hasAdministrativeContactInformation          msg:_55552e54-b9e1-11ee-a64d-
00505691ec1a_contact;
  taf:hasCoordinatingIM "0071";
  taf:hasIdentifiers msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_identifiers;
  taf:hasLeadRU "2171";
  taf:hasMessageHeader msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_header;
  taf:hasMessageStatus "1";
  taf:hasTypeOfInformation "17";
  taf:hasTypeOfRequest "2" .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_reference a taf:MessageReference;
  taf:hasMessageDateTime "2024-01-23T12:19:54.565+01:00"^^xsd:dateTime;
  taf:hasMessageIdentifier "55552e54-b9e1-11ee-a64d-00505691ec1a";
  taf:hasMessageType "2002";
  taf:hasMessageTypeVersion "3.4.0" .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_contact                              a
taf:AdministrativeContactInformation;
  foaf:name "RENFE MERCANCIAS S.A.,S.M.E." .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_header a taf:MessageHeader;
  taf:hasMessageDateTimeCreated "2024-01-23T12:19:54.558+01:00"^^xsd:dateTime;
  taf:hasMessageReference "MessageReference";
```

```
  taf:hasRecipient "0071";
  taf:hasSender "2171" .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_identifier_1                    a
taf:PlannedTransportIdentifiers;
  taf:hasCompany "0071";
  taf:hasCore "----OMRM0026";
  taf:hasObjectType "CR";
  taf:hasTimetableYear 2024;
  taf:hasVariant "01" .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_identifier_2                    a
taf:PlannedTransportIdentifiers;
  taf:hasCompany "2171";
  taf:hasCore "----80803003";
  taf:hasObjectType "TR";
  taf:hasTimetableYear 2024;
  taf:hasVariant "00" .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_identifier_3                    a
taf:PlannedTransportIdentifiers;
  taf:hasCompany "0071";
  taf:hasCore "-----2041753";
  taf:hasObjectType "PA";
  taf:hasTimetableYear 2024;
  taf:hasVariant "01" .

msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_identifiers a taf:Identifiers;
  taf:hasPlannedTransportIdentifiers              msg:_55552e54-b9e1-11ee-a64d-
00505691ec1a_identifier_1,
    msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_identifier_2,
    msg:_55552e54-b9e1-11ee-a64d-00505691ec1a_identifier_3 .
```

5.1.1 Visualization of PathConfirmed Message

It is possible to RDF graph by using open-source tools or visualizations integrated into the graph data management tool. For the pathConfirmed message, we use two different visualizations:

- Visualization using graph-explorer

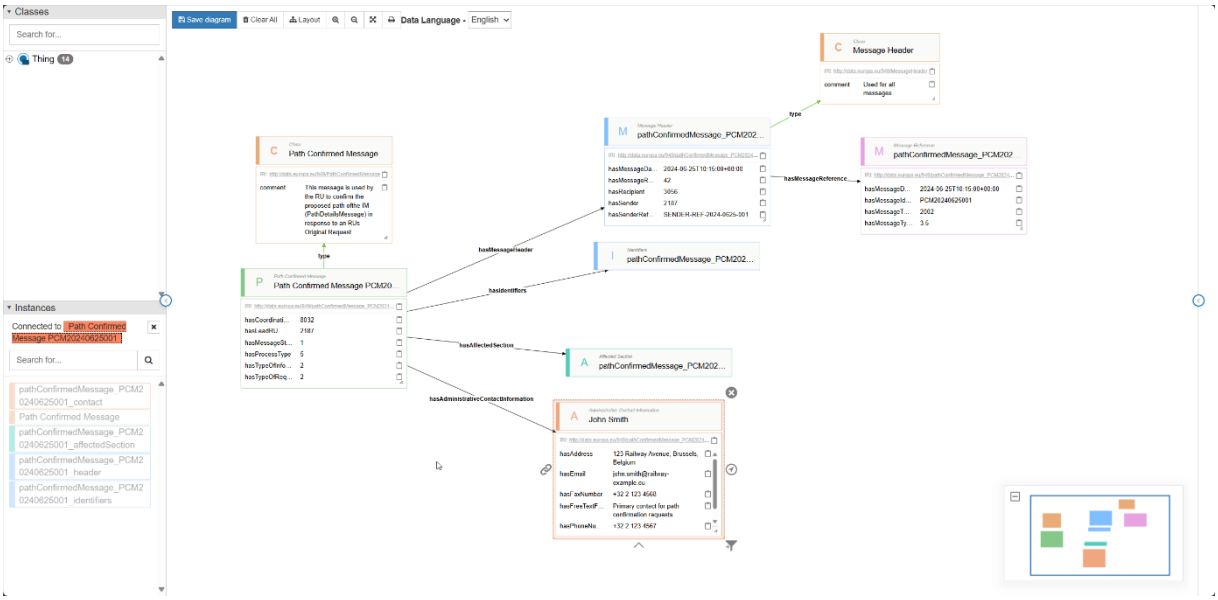


Figure 9a: PathConfirmed Message visualization with graph-explorer (https://github.com/DataTreehouse/graph-explorer)

5.1.2 Visualization using graph "bubbles"

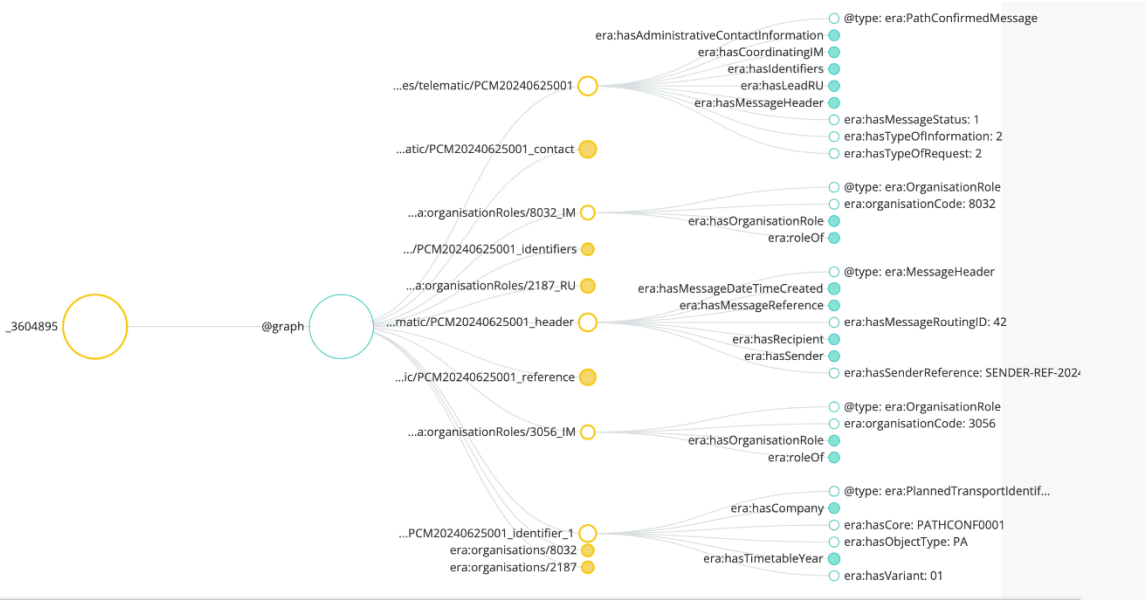


Figure 9b: PathConfirmed Message visualization using JSON-LD playground (https://json-ld.org/playground/). Note here that the input serialization is JSON-LD.

5.2 RDF to TELEM XSD (with XSLT with intermediary "RDF/XML")

Use of XSLT template to convert from RDF/XML to telematics XML. The intermediate RDF/XML is generated using the Python language library RDFLib, one of the most used libraries for managing RDF. Almost all main programming languages have an implementation of RDF.

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF
   xmlns:foaf="http://xmlns.com/foaf/0.1/"
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:taf="http://www.era.europa.eu/ontologies/taf#">
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a_identifiers">
    <rdf:type
```

```
rdf:resource="http://www.era.europa.eu/ontologies/taf#Identifiers"/>
    <taf:hasPlannedTransportIdentifiers
rdf:resource="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-
a64d-00505691ec1a_identifier_1"/>
    <taf:hasPlannedTransportIdentifiers
rdf:resource="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-
a64d-00505691ec1a_identifier_2"/>
    <taf:hasPlannedTransportIdentifiers
rdf:resource="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-
a64d-00505691ec1a_identifier_3"/>
  </rdf:Description>
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a_reference">
    <rdf:type
rdf:resource="http://www.era.europa.eu/ontologies/taf#MessageReference"/>
    <taf:hasMessageDateTime
rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2024-01-
23T12:19:54.565000+01:00</taf:hasMessageDateTime>
    <taf:hasMessageIdentifier>55552e54-b9e1-11ee-a64d-
00505691ec1a</taf:hasMessageIdentifier>
    <taf:hasMessageType>2002</taf:hasMessageType>
    <taf:hasMessageTypeVersion>3.4.0</taf:hasMessageTypeVersion>
  </rdf:Description>
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a_contact">
    <rdf:type
rdf:resource="http://www.era.europa.eu/ontologies/taf#AdministrativeContactInfor
mation"/>
    <foaf:name>RENFE MERCANCIAS S.A.,S.M.E.</foaf:name>
  </rdf:Description>
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a">
    <rdf:type
rdf:resource="http://www.era.europa.eu/ontologies/taf#PathConfirmedMessage"/>
    <taf:hasAdministrativeContactInformation
rdf:resource="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-
a64d-00505691ec1a_contact"/>
    <taf:hasCoordinatingIM>0071</taf:hasCoordinatingIM>
    <taf:hasIdentifiers
rdf:resource="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-
a64d-00505691ec1a_identifiers"/>
    <taf:hasLeadRU>2171</taf:hasLeadRU>
    <taf:hasMessageHeader
rdf:resource="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-
a64d-00505691ec1a_header"/>
    <taf:hasMessageStatus>1</taf:hasMessageStatus>
    <taf:hasTypeOfInformation>17</taf:hasTypeOfInformation>
    <taf:hasTypeOfRequest>2</taf:hasTypeOfRequest>
  </rdf:Description>
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a_identifier_1">
    <rdf:type
rdf:resource="http://www.era.europa.eu/ontologies/taf#PlannedTransportIdentifier
s"/>
    <taf:hasCompany>0071</taf:hasCompany>
    <taf:hasCore>----OMRM0026</taf:hasCore>
```

```
    <taf:hasObjectType>CR</taf:hasObjectType>
    <taf:hasTimetableYear
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">2024</taf:hasTimetableYe
ar>
    <taf:hasVariant>01</taf:hasVariant>
  </rdf:Description>
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a_identifier_3">
    <rdf:type
rdf:resource="http://www.era.europa.eu/ontologies/taf#PlannedTransportIdentifier
s"/>
    <taf:hasCompany>0071</taf:hasCompany>
    <taf:hasCore>-----2041753</taf:hasCore>
    <taf:hasObjectType>PA</taf:hasObjectType>
    <taf:hasTimetableYear
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">2024</taf:hasTimetableYe
ar>
    <taf:hasVariant>01</taf:hasVariant>
  </rdf:Description>
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a_identifier_2">
    <rdf:type
rdf:resource="http://www.era.europa.eu/ontologies/taf#PlannedTransportIdentifier
s"/>
    <taf:hasCompany>2171</taf:hasCompany>
    <taf:hasCore>----80803003</taf:hasCore>
    <taf:hasObjectType>TR</taf:hasObjectType>
    <taf:hasTimetableYear
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">2024</taf:hasTimetableYe
ar>
    <taf:hasVariant>00</taf:hasVariant>
  </rdf:Description>
  <rdf:Description
rdf:about="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-a64d-
00505691ec1a_header">
    <rdf:type
rdf:resource="http://www.era.europa.eu/ontologies/taf#MessageHeader"/>
    <taf:hasMessageDateTimeCreated
rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2024-01-
23T12:19:54.558000+01:00</taf:hasMessageDateTimeCreated>
    <taf:hasMessageReference
rdf:resource="http://data.europa.eu/949/telematicsMessage_55552e54-b9e1-11ee-
a64d-00505691ec1a_reference"/>
    <taf:hasRecipient>0071</taf:hasRecipient>
    <taf:hasSender>2171</taf:hasSender>
  </rdf:Description>
</rdf:RDF>
```

Final output from the RDF to XML generator

```
<?xml version='1.0' encoding='utf-8'?>
<ns1:PathConfirmedMessage
xmlns:ns1="http://www.era.europa.eu/schemes/TAFTSI/3.5"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
```

```
xmlns:taf="http://www.era.europa.eu/ontologies/taf#"
xmlns:foaf="http://xmlns.com/foaf/0.1/"
xsi:schemaLocation="http://www.era.europa.eu/schemes/TAFTSI/3.5
../../xsd/taf_cat_complete.xsd">
  <ns1:MessageHeader>
    <ns1:MessageReference>
      <ns1:MessageType>2002</ns1:MessageType>
      <ns1:MessageTypeVersion>3.4.0</ns1:MessageTypeVersion>
  <ns1:MessageIdentifier>55552e54-b9e1-11ee-a64d-
00505691ec1a</ns1:MessageIdentifier>
      <ns1:MessageDateTime>2024-01-
23T12:19:54.565000+01:00</ns1:MessageDateTime>
    </ns1:MessageReference>
    <ns1:Sender>2171</ns1:Sender>
    <ns1:MessageDateTimeCreated>2024-01-
23T12:19:54.558000+01:00</ns1:MessageDateTimeCreated>
    <ns1:Recipient>0071</ns1:Recipient>
  </ns1:MessageHeader>
  <ns1:AdministrativeContactInformation>
    <ns1:Name>RENFE MERCANCIAS S.A.,S.M.E.</ns1:Name>
  </ns1:AdministrativeContactInformation>
  <ns1:Identifiers>
    <ns1:PlannedTransportIdentifiers>
      <ns1:ObjectType>CR</ns1:ObjectType>
      <ns1:Company>0071</ns1:Company>
      <ns1:Core>----OMRM0026</ns1:Core>
      <ns1:Variant>01</ns1:Variant>
      <ns1:TimetableYear>2024</ns1:TimetableYear>
    </ns1:PlannedTransportIdentifiers>
    <ns1:PlannedTransportIdentifiers>
      <ns1:ObjectType>TR</ns1:ObjectType>
      <ns1:Company>2171</ns1:Company>
      <ns1:Core>----80803003</ns1:Core>
      <ns1:Variant>00</ns1:Variant>
      <ns1:TimetableYear>2024</ns1:TimetableYear>
    </ns1:PlannedTransportIdentifiers>
    <ns1:PlannedTransportIdentifiers>
      <ns1:ObjectType>PA</ns1:ObjectType>
      <ns1:Company>0071</ns1:Company>
      <ns1:Core>-----2041753</ns1:Core>
      <ns1:Variant>01</ns1:Variant>
      <ns1:TimetableYear>2024</ns1:TimetableYear>
    </ns1:PlannedTransportIdentifiers>
  </ns1:Identifiers>
  <ns1:MessageStatus>1</ns1:MessageStatus>
  <ns1:TypeOfRequest>2</ns1:TypeOfRequest>
  <ns1:TypeOfInformation>17</ns1:TypeOfInformation>
  <ns1:CoordinatingIM>0071</ns1:CoordinatingIM>
  <ns1:LeadRU>2171</ns1:LeadRU>
</ns1:PathConfirmedMessage>
```

5.3 Other RDF serializations

Sample Alert Message in RDF, Turtle serialization

```
@prefix msg: <http://data.europa.eu/949/alertMessages/> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
```

```
@prefix taf: <http://data.era.europa.eu/949/taf/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

msg:_d4f9c334-8e45-11ee-b9d1-0242ac120002 a taf:AlertMessage;
  taf:hasActualETA "2023-12-23T10:15:00+01:00"^^xsd:dateTime;
  taf:hasCommitmentETA "2023-12-21T18:30:00+01:00"^^xsd:dateTime;
  taf:hasMessageHeader <http://data.europa.eu/949/telematics/messages/_d4f9c334-
8e45-11ee-b9d1-0242ac120002_header>;
  taf:hasWagonNumberFreight "247816903542" .

<http://data.europa.eu/949/telematics/messages/_d4f9c334-8e45-11ee-b9d1-
0242ac120002_header> a taf:MessageHeader;
  taf:hasMessageReference <http://data.europa.eu/949/telematics/messages/_d4f9c334-
8e45-11ee-b9d1-0242ac120002_reference>;
  taf:hasMessageRoutingID "04";
  taf:hasRecipient "0071";
  taf:hasSender "0084";
  taf:hasSenderReference "ALERT-REF-20231220-0003" .

<http://data.europa.eu/949/telematics/messages/_d4f9c334-8e45-11ee-b9d1-
0242ac120002_reference> a taf:MessageReference;
  taf:hasMessageDateTime "2023-12-20T14:05:38.220+01:00"^^xsd:dateTime;
  taf:hasMessageIdentifier "d4f9c334-8e45-11ee-b9d1-0242ac120002";
  taf:hasMessageType "5001";
  taf:hasMessageTypeVersion "2.5.0.0" .
```

Sample Alert Message in RDF, JSON-LD serialization

```
{
  "@context": {
    "base": "http://data.europa.eu/949/triplesmap/",
    "dc": "http://purl.org/dc/elements/1.1/",
    "dct": "http://purl.org/dc/terms/",
    "ex": "http://example.org/",
    "foaf": "http://xmlns.com/foaf/0.1/",
    "owl": "http://www.w3.org/2002/07/owl#",
    "rdf": "http://www.w3.org/1999/02/22-rdf-syntax-ns#",
    "rdfs": "http://www.w3.org/2000/01/rdf-schema#",
    "rml": "http://w3id.org/rml/",
    "taf": "http://data.era.europa.eu/949/taf/",
    "void": "http://rdfs.org/ns/void#",
    "xsd": "http://www.w3.org/2001/XMLSchema#",
    "msg": "http://data.europa.eu/949/alertMessages/"
  },
  "@graph": [
    {
      "@id": "msg:_d4f9c334-8e45-11ee-b9d1-0242ac120002",
      "@type": "taf:AlertMessage",
      "taf:hasActualETA": {
        "@type": "xsd:dateTime",
        "@value": "2023-12-23T10:15:00+01:00"
      },
      "taf:hasCommitmentETA": {
        "@type": "xsd:dateTime",
        "@value": "2023-12-21T18:30:00+01:00"
      },
      "taf:hasMessageHeader": {
        "@id": "http://data.europa.eu/949/telematics/messages/_d4f9c334-8e45-11ee-
b9d1-0242ac120002_header"
      },
      "taf:hasWagonNumberFreight": "247816903542"
    },
```

```
    {
      "@id": "http://data.europa.eu/949/telematics/messages/_d4f9c334-8e45-11ee-
b9d1-0242ac120002_header",
      "@type": "taf:MessageHeader",
      "taf:hasMessageReference": {
        "@id": "http://data.europa.eu/949/telematics/messages/_d4f9c334-8e45-11ee-
b9d1-0242ac120002_reference"
      },
      "taf:hasMessageRoutingID": "04",
      "taf:hasRecipient": "0071",
      "taf:hasSender": "0084",
      "taf:hasSenderReference": "ALERT-REF-20231220-0003"
    },
    {
      "@id": "http://data.europa.eu/949/telematics/messages/_d4f9c334-8e45-11ee-
b9d1-0242ac120002_reference",
      "@type": "taf:MessageReference",
      "taf:hasMessageDateTime": {
        "@type": "xsd:dateTime",
        "@value": "2023-12-20T14:05:38.220+01:00"
      },
      "taf:hasMessageIdentifier": "d4f9c334-8e45-11ee-b9d1-0242ac120002",
      "taf:hasMessageType": "5001",
      "taf:hasMessageTypeVersion": "2.5.0.0"
    }
  ]
}
```