AMSFree

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

Exchange and exploitation of data from Asset Management Systems using vendor free format

Deliverable 5

D5.1: IAMS-oriented Information Delivery Manual

D5.2: IAMS-oriented Application and Extension of the IFC Standard

D5.3: Linking Guide of European Road OTL and National Classifications

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1 IAMS-oriented Information Delivery Manual (IDM)

By introducing Information Containers, the information transfer between a Building Information Model, BIM and Infrastructure Asset Management System, IAMS is established. For the information from the Information Container for linked Document Delivery (ICDD) to be fully utilized, an information exchange between BIM and ICDD on one hand, and between ICDD and IAMS on the other, needs to be enabled. Whereas the former one is enabled by the providing the resource ontologies, the latter one needs to be established by means of Information Delivery Manual (IDM) for the integration of RDF-based data from the information container (i.e., Data structure compliant to the ICDD - ISO 21597) into the existing IAMS (relational database).

In order to precisely depict the scope of information exchange between ICDD and IAMS, and example of a use-case for condition assessment s shown in Figure 1. Here, the focus is on the information flow between an activity “Import ICDD Condition Assessment” and the “AMS" database, both colored orange. The input ICDD for the data transformation colored orange, however, is generated in the blue segment of the process model. The ICDD (ER1_ICDD_Inspection_Assignment) is generated based on the as-built BIM of the infrastructure asset and additional information about the asset, stored in the IAMS database. Once the condition assessment takes place, the ICDD (ER2_ICDD_Condition_Assessment) is generated, by the means of transforming the previous one.

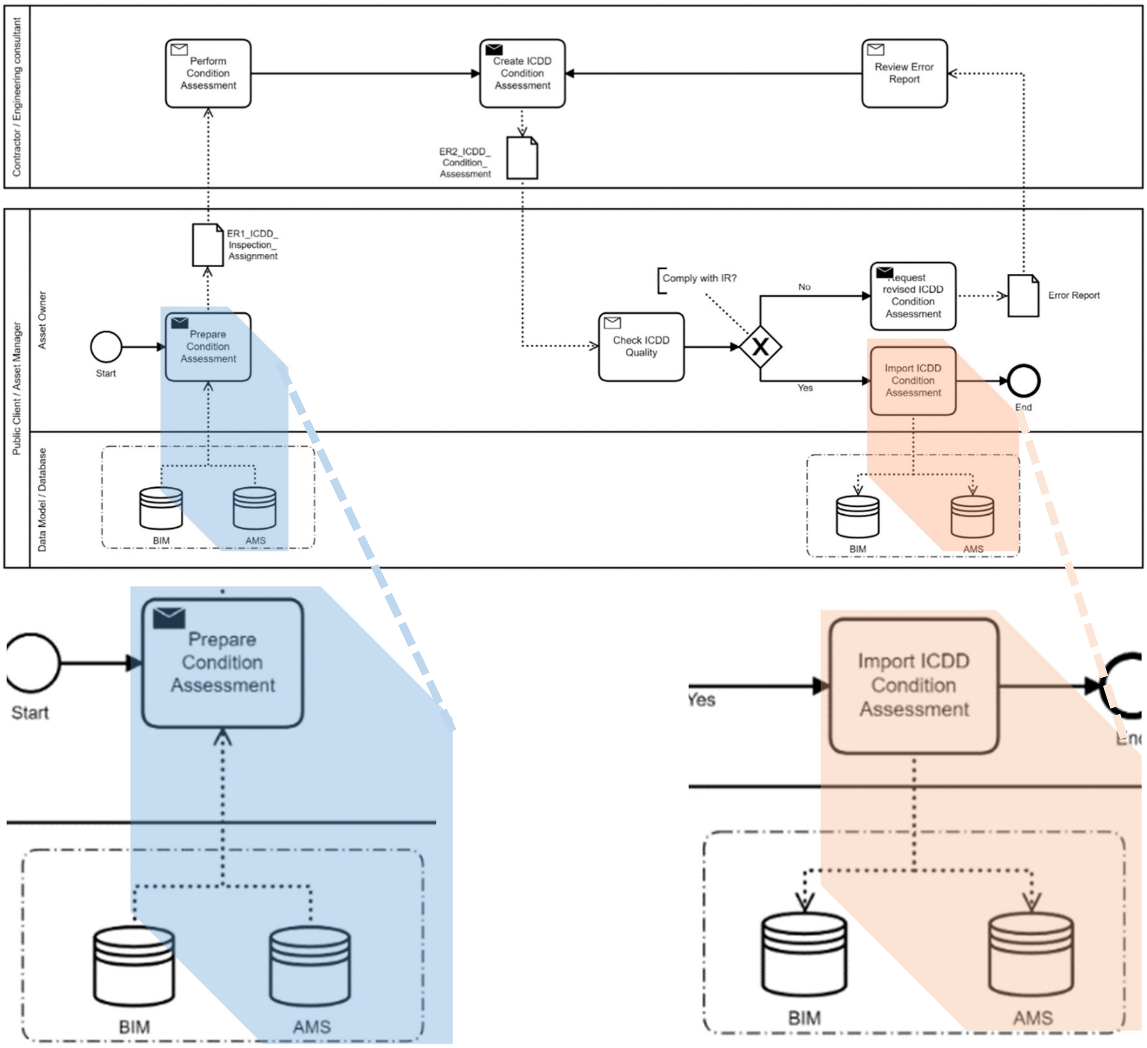


Figure 1. Focused information flow between ICDD and AMS.

The same form of information flow can be applied for use cases on maintenance, considering roads and structural assets. In a simplified form, this information flow is shown in Figure 2. On the left-hand side is the ICDD, whose content depends on the use case. On the right-hand side, the Infrastructure Asset Management (IAMS) database is shown. In between, a sub-process of the data transfer between ICDD and IAMS is shown.

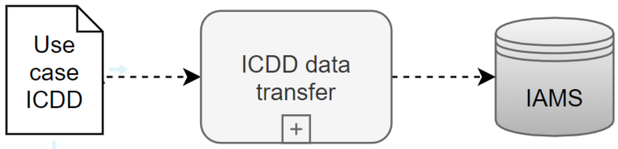


Figure 2. Simplified process model for transferring data from ICDD to the IAMS database.

The sub-process "ICDD data transfer" is described in more detail in an expanded view, shown in Figure 3.

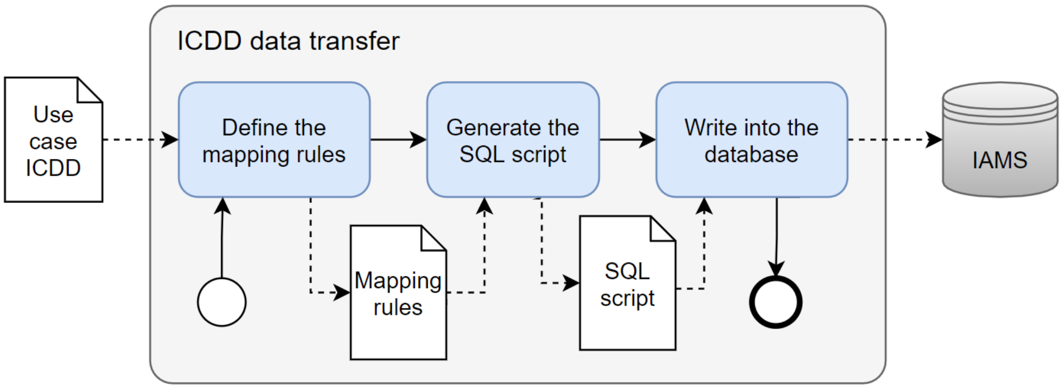


Figure 3. Process model for transferring data from ICDD to the IAMS database (BPMN).

The proposed process model heavily relies on the approach thoroughly described by (Liu, Hagedorn, & König, 2021). The data transfer utilizes the information transformation schemas proposed by (Costa & Sicilia, 2020). The ontology is mapped to the IAMS database following the approach of (Afzal, Waqas, & Naz, 2016).

As opposed to the information exchange between human actors, here all the activities including the data exchange is done automatically. Firstly, the rules for mapping the ontology entities to the database are defined. Here, the ontology type may refer to the multiple object instances in the BIM model, thus needed to be mapped to the multiple database entities. (Costa & Sicilia, 2020) labeled such mapping scenarios as "many to many attributes". Once the mapping rules are defined, the SQL script targeting the correct database entities is generated. This is done by means of SPARQL-Construct queries. A detail working example, including the SPARQL code, is provided by (Liu & Hagedorn, 2021). Finally, the SQL script imports the ICDD data to the IAMS. A thorough specification of this process model is shown in Figure 4.

Process Model			
Name:	PM_ICDD-IAMS_data_transfer		
Identifier:			
Authors:			
Create Date:			
Document Owner:			
Task	**Name**		**Description of Task**
	Define the mapping rules		Pairing of ontology types from ICDD with corresponding IAMS database entries
	Generate the SQL script		Automatic generation of the code for the SPARQL-Construct query which singles out the entities to be written into the IAMS database
	Write into the database		Automatic fill of the IAMS database table with the selected data from the ICDD
Exchange Requirements	**Name**	**Type**	**Description of documentation**
	Use case ICDD	ICDD	Information Container for linked Documentation Delivery whose content depends on the use case.
Object Data	**Name**	**Type**	**Description of Object Data**
	IAMS		Infrastructure Asset Management System

Figure 4. Process model for transferring data from ICDD to the IAMS database (table specification).

The data transformation described applies to all the use cases considered in AMS Free deliverables D3.2, D4.2 and D4.3. The exchange requirements models which correspond to each specific use case are thoroughly described in the previous reports and are shown in Figures 5 – 8.

Exchange Requirements Model		
Name:	Visual Bridge Inspection Results	
Identifier:	ER2_ICDD_Condition_Assessement	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology Resources:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
	DamageClassification.rdf	rdf
	ConditionClassification.rdf	rdf
	BridgeClassification.rdf	rdf
Payload Documents:		
	BridgeModel.ifc	ifc
	LocalPlacement.ifc	ifc
	Report.xml	xml
	ImageDamage.png	jpg/png/gif
Payload Triples:		
	DamagePlacement.rdf	rdf
	ReportLinking.rdf	rdf
	ReportVisualDetails.rdf	rdf

Figure 5. ICDD for the bridge inspection use case.

Exchange Requirements Model		
Name:	Dynamic response analysis for bridges	
Identifier:	ER2_ICDD_Condition_Assessement	
Description:	**Name**	**Type**
	Index.rdf	rdf
Ontology:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
Payload Documents:		
	BdrigeSensorModel.ifc	ifc
	SensorData.xml	xml
	Report.xml	xml
Payload Triples:		
	SensorLinking.rdf	rdf
	ReportLinking.rdf	rdf

Figure 6. ICDD for the non-destructive bridge testing use case.

Exchange Requirements Model		
Name:	Ground Penetrating Radar for roads	
Identifier:	ER2_ICDD_Condition_Assessement	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
	PavementClassification.rdf	rdf
Payload Documents:		
	RoadModel.ifc	ifc
	RoadSections.ifc	ifc
	Report.xml	xml
	DrillCores.ifc	ifc
	GPRData.xml	xml
Payload Triples:		
	ReportLinking.rdf	rdf
	DrillCoreLinking.rdf	rdf
	GPRLinking.rdf	rdf

Figure 7. ICDD for the non-destructive road testing use case.

Exchange Requirements Model		
Name:	Road Maintenance Program	
Identifier:	ER2_ICDD_Maintenance_Program	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology Resources:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	AsphaltCondition.rdf	rdf
	MaintenanceProgram.rdf	rdf
Payload Documents:		
	RoadModel.ifc	ifc
	RoadSections.ifc	ifc
	Condition.xml	xml
	MaintenanceProgram.xml	xml
Payload Triples:	RoadSectionCondition.rdf	rdf
	RoadSectionMaintenance.rdf	rdf

Figure 8. ICDD for the road maintenance use case.

2 IAMS-oriented Application and Extension of the IFC Standard

2.1 Introduction

In the previous work packages, the requirements for the use of digital models in operation, e.g. inspection and maintenance plan, were developed. The associated information containers for bridge inspection and pavement maintenance planning have been defined in terms of content and linkage between the different data source. The necessary ontologies for these activities have also been developed according to the national guidelines and standards from three of the project funding countries (Germany, Netherlands and Denmark).

In this work package, the first part presents the Information Delivery Manual for the integration of RDF-based data from the Information Container into existing AMS, based on a relational database structure. The Model View Definition (MVD) for the exchange of the IFC model according to the defined use case is created. As described in the other work packages, the semantic information of the inspection and maintenance plan is captured using ontologies in the information container. The IFC model primarily provides the geometry in sufficient granularity of the structure and the pavement. Nevertheless, it is possible to add semantic information directly within the IFC schema. The different situations where this approach is used are listed below:

- Handover the as-built model from construction phase to operation phase
- Collect existing semantic information from the AMS for an activity in the operation phase
- Collect new semantic information of an activity in the operation phase

Depending on the particular application, it must be investigated whether it makes sense to attach certain information directly as property sets to objects in IFC format. If property sets are added directly to the IFC model, appropriate software must be available and attention must be paid to ensuring that fundamental structures are not changed during the IFC export. Changes to GUIDs are particularly critical, as these identifiers are often used for linking. If information is collected later and fundamental information about IFC objects should not be changed in this case, external linking is recommended. Exactly for this purpose the information containers were developed, which allow an easy linking without changes of the IFC file. In the field of asset management, databases and suitable data models already exist. Therefore, it is recommended that such information be linked externally via ontologies rather than being stored directly in the IFC model. The use of ontologies to collect such information also enables consistent and easy querying based on existing standards.

The necessary semantic information must take into account the information needs of the defined use case. That is, the content must be complete and the data type must be present as an exact type (RDF-based or IFC schema-based). The following sections provide general descriptions of the MVD concept.

2.2 General Description of MVD

By exchanging models via IFC, the exchange requirements of the defined use case must be complied with. These can be defined as rules using the MVD. It provides a technical solution to capture the use case specific rules in a machine-readable format mvdXML (Borrmann, König, Koch, & Beetz, 2015). The organization buildingSMART International (bSI) has delivered a set of MVDs. The official MVDs releases are listed according to IFC version and application purpose in their database (buildingSMART International, 2021). In addition to the released MVDs, the user can define an own MVD on the specific requirement as mvdXML. Although the mvdXML can be defined indeed using any test editor, a free tool IFCDOC.EXE (IfcDoc Tooltik, 2021) provided by the bSI can be used for generation of user-defined mvdXML. Mainly IFC-based software should support to read the mvdXML for data filtering and validation.

As presented in (Chipman, Liebich, & Weise, 2012), the mvdXML must contain two constituents: templates and views. Templates provide reusable concept as templates, which include the applicable schema, the applicable entity, the rules with attribute definitions. The view contains a set of model views, which include the exchange requirements and the referenced concept (see Figure 9).

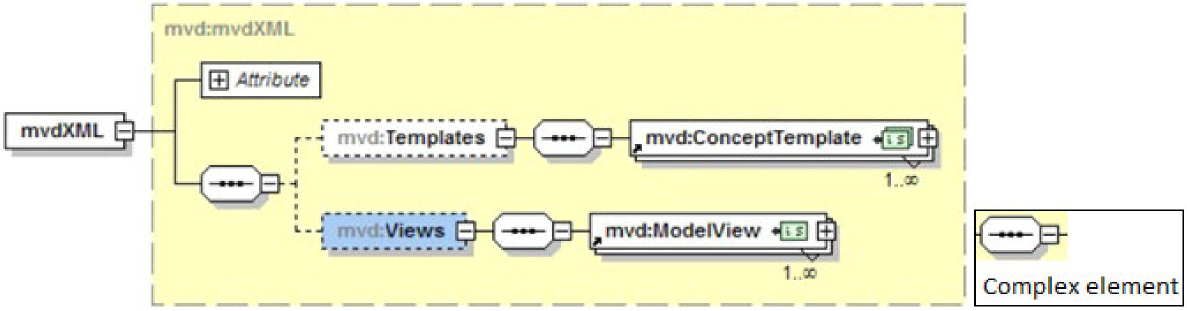


Figure 9: Basic structure of the mvdXML schema (Chipman, Liebich, & Weise, 2012)

The MVD is not only used for the definition of standardized use cases (e.g., by buildingSMART International). With the help of MVD it is also possible to define individual requirements in the form of test rules for special exchange scenarios. An MVD can be defined in such a way that classes, types, property sets as well as geometric representations can be checked. However, in this work package, the MVD is used for data validation especially for the necessary semantic information of the IFC model. That means, it contains only rules for checking the user defined properties according to particular IFC element. In the following section, the MVDs are defined just with exemplary properties of particular IFC entities for each use case. All of the MVDs will be defined for the version IFC4.

2.3 MVD Examples for the Predefined Use Cases

In work package 4.2, several sets of properties for the pavement layers are defined. The information containers for the bridge inspection and pavement maintenance planning are defined. The necessary ontologies for the semantic information are developed. Following this preliminary work, three MVD examples are defined. They are listed below:

- MVD handover for operation
- MVD bridge inspection
- MVD maintenance plan

The properties and the associated entities will be described in each subsection. The entire mvdXML will be attached in the appendix.

2.3.1 MVD handover for operation

The as-built model must contain the relevant semantic information as a prerequisite for the use of BIM in operations. Therefore, an MVD is defined to check the delivered model to see if it meets the requirements defined by the asset owner. In the case drill cores are considered as

IFC entities with a property set in this MVD example. In version IFC 4.1, no specific IFC entity is available for modeling a drill core. However, the drill core can be modeled as *IfcBuildingElementProxy*. The following properties are defined for a drill core as an example. The complete mvdXML is attached as Appendix I.

ePSET_Stiffness_FourPointFlexuralTest

Name	Property Type	Data Type	Description
e6	P_SINGLEVALUE	IfcReal	strain, corresponding a long-term durability of 106 cycles
A0	P_SINGLEVALUE	IfcReal	parameter A0 of fatique curve
A1	P_SINGLEVALUE	IfcReal	parameter A1 of fatique curve

2.3.2 MVD for Model with current condition of bridge by inspection

For bridge inspection, the ontologies for damage description and condition assessment are already defined. However, this semantic information can also be captured alternatively within the IFC model. For example, the condition assessment according to the German guideline can be delivered within an IFC model. All bridge components are assessed with the condition rating. The mvdXML is attached as Appendix II.

ePSET_Condition

Name	Property Type	Data Type
durability	P_SINGLEVALUE	IfcReal
traffic safety	P_SINGLEVALUE	IfcReal
structural safety	P_SINGLEVALUE	IfcReal

2.3.3 MVD maintenance plan

Similar to the bridge inspection, the ontologies for the maintenance program are already defined. For example, the semantic data can also be defined as properties within the IFC model. Since IFC4.3 is not officially published, the road section is modeled in the MVD as *IfcBuildingElementProxy*. The mvdXML is attached as Appendix III.

ePSET_Maintenance_Measure

Name	Property Type	Data Type	Description
year	P_SINGLEVALUE	IfcDate	recommended year of measure
measure	P_SINGLEVALUE	IfcText	description of measure
cost	P_SINGLEVALUE	IfcReal	estimated cost of measure

3 Linking Guide of European Road OTL and National Classifications

3.1 *Introduction of Ontology Modelling and Linking*

In the previous work package, the necessary ontologies for bridge inspection and pavement maintenance plan are defined for three countries. Depending on the national standards and guideline, these ontologies differ to each other. However, a basic version of a European road object library (EUROTL) as ontologies were developed in the INTERLINK project for the gathering and exchanging the asset information throughout the life-cycle of assets. This ontology provides a set of classes, which support the basic information needs for asset management (see Figure 10). For using this efficiently, the nationally defined ontology should be linked with it.

In this part of the report, there are two constituents: how to model an ontology and how to link the user-defined ontology to EUROTL. These are considered to the recommendation from INTERLINK report (Böhms, O'Keeffe, Stolk, Wikström, & Weise, 2018).

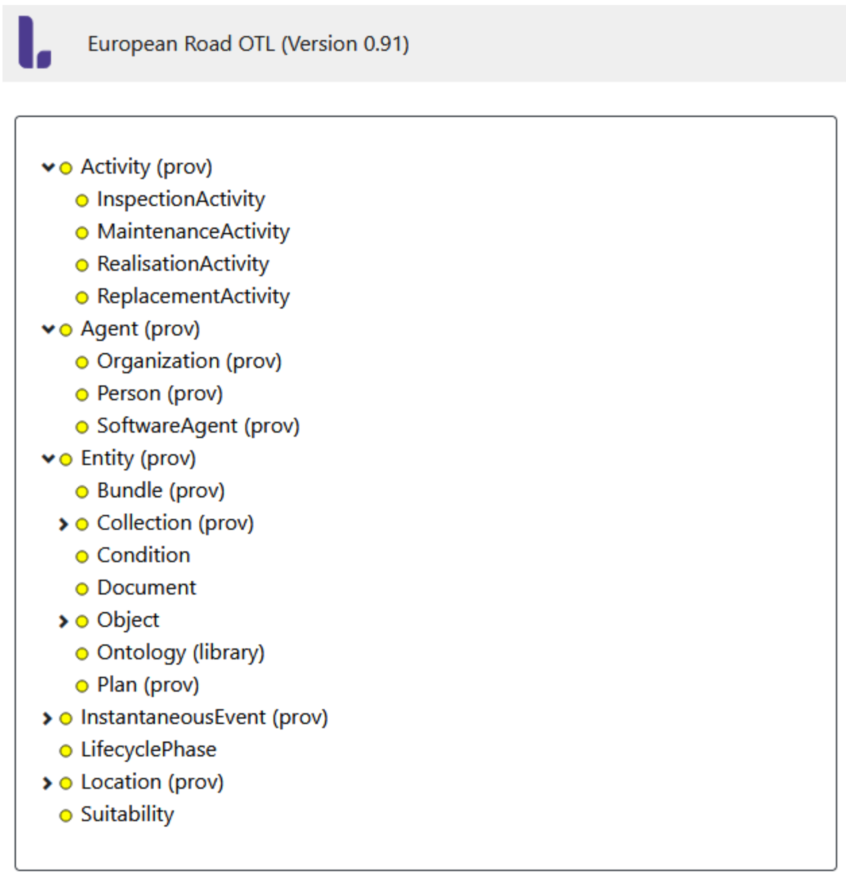


Figure 10: Overview of Classes in the EUROTL Ontology (European Road OTL (Version 0.91), 2021)

3.2 *Modelling of Ontology According to INTERLINK*

In order to take into account the different national requirements and guidelines, domain-specific ontologies are created for them. The recommendations from the INTERLINK project are followed to create understandable and reusable ontologies. In general, an ontology can be defined by the languages RDFs, OWL and SHACL. These languages provide classes, data, their relationships, and restriction types that can be used to define attributes and objects as well as constraints. The difference between the languages is that RDF and OWL are typically used for Open World Assumption (OWA) and SHACL for Closed World Assumption (CWA). The OWA means "the truth of a statement is independent of whether it is known" (ISO 21597-1, 2020). The CWA means "what is not formally established as true is false" (ISO 21597-1, 2020). The CWA with a unique resource identifier (URI) for each OWL element (class, property, data type, etc.) is required for asset information management.

As suggested by INTERLINK, the ontology should be modeled in "The Simple Way" (Böhms, O'Keeffe, Stolk, Wikström, & Weise, 2018). This means that OWL and SHACL are combined for modeling in the direct way. The value attributes can generally be modeled as owl:DatatypeProperty's, and the relationship as owl:ObjectProperty's. Although the constraints can be modeled as OWL constraints, SHACL should be used for all constraints with CWA. The class, property and data type names should be human readable. To improve readability for classes, properties, and data types, additional annotations can be added using rdfs:label. The rdfs:comment can be used for the description.

For example, the Condition Assessment (COAS) country-specific ontology has an understandable name with a prefix, as shown in Figure 11. For more readable and clear description of the class, the rdfs:comment and rdfs:label are also used as shown in Figure 12.

```
# baseURI: http://amsfree.eu/ontology/conditionassessment
# prefix: coas

@prefix coas: <http://amsfree.eu/ontology/conditionassessment#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
```

Figure 11: Overview of the ontology condition assessment (coas)

```
coas:RoutineMaintenance
  rdf:type owl:Class ;
  rdfs:comment "If a routine maintennace be carried out at the time of inspection."@en ;
  rdfs:label "Routine maintenance at inspection needed"@en ;
  rdfs:subClassOf owl:Thing ;
.
```

Figure 12: Class definition with annotation and description

3.3 *Linking Guide to the OTL*

In the case of decentralized data, ontologies and datasets are usually created, edited, and stored by different parties. To link this data, RDF, OWL and SHACL have specific vocabularies that can be used to define the links. To actually mark two things as the same, owl:sameAs must be used, as suggested by INTERLINK. It also introduces three levels of linkage:

1. Class-level linking means how to map classes and properties in different ontologies.
2. Model-level linking means how to relate the different models to each other
3. Instance-level linking means how to relate the instances or objects to each other

The linking data sets make the connection between instances and objects. The information container according to (ISO 21597-1, 2020) provides the opportunity to create and collect link sets. The linking Ontology for the class-level can be realized by creating an alignment ontology. For instance, during the INTERLINK project, five existing alignment ontologies are created to link different domain-specific ontologies to EUROTL (see Table 1). The classes of a domain-specific ontology are usually defined as corresponding subclasses of eurotl.

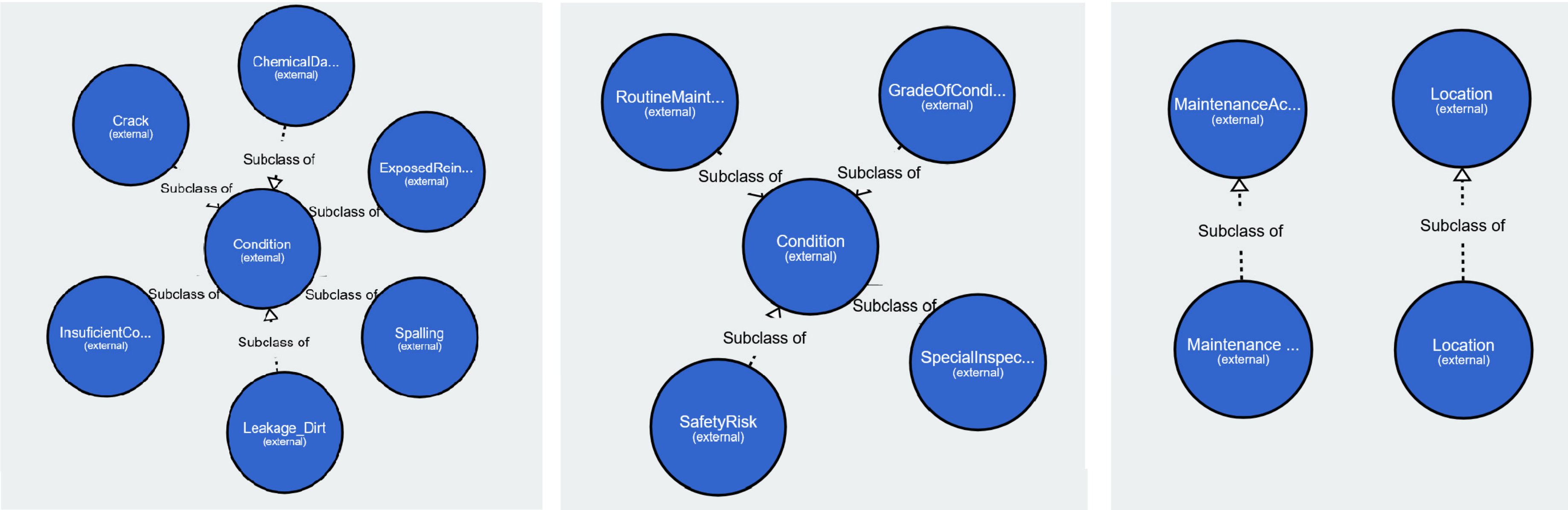
Table 1: Overview of the five existing alignment ontologies by INTERLINK project

Prefix	Namespace	Description
AM4INFRA--EUROTL	<http://www.roadotl.eu/AM4Infra--eurotl/def/>	Linking main classes of AM4Infra to class eurotl:PhysicalObject
INSPIRE--EUROTL	<http://www.roadotl.eu/inspire--eurotl/def/>	Linking between INSPIRE and the eurotl
ISO19148--EUROTL	<http://www.roadotl.eu/iso19148--eurotl/>	Linking between ontology for ISO19148 and eurotl
GEOSPARQL--EUROTL	<http://www.roadotl.eu/geosparql--eurotl/def/>	Linking of schema level between GeoSPARQL and eurotl
IFC4x1_Final--EUROTL	<http://www.roadotl.eu/IFC4x1_Final--eurotl/def/>	Linking of IfcOWL and eurotl including linearElement and Geometriy

In a similar way, predefined ontologies for bridge damage, condition assessment, and maintenance programs for pavements can also be linked to EUROTL using alignment ontologies shown in Table 2. The alignment ontologies are attached as ttl files in the appendix.

Table 2: Overview of alignment ontologies for the predefined inspection and maintenance ontologies linking with eurotl

Prefix	Namespace	Description	Illustration
CODEX2EUROTL	<http://www.roadotl.eu/codex2eurotl >	Linking between bridge damage ontology cod, codex and the eurotl	Figure 13-a
COAS2EUROTL	<http://www.amsfree.eu/ontology/ coas2eurotl/>	Linking between ontology of condition assessment and eurotl	Figure 13-b
MAINTP2EUROTL	<http://www.roadotl.eu/maintp2eurotl/def/>	Linking between ontology maintenance program and eurotl	Figure 13-c



a. CODEX2EUROTL **b. COAS2EUROTL** **c. MAINTP2EUROTL**

Figure 13: Overview of alignment ontologies

4 Conclusion

This report includes three specific topics for information delivery, data exchange, and alignments of different ontologies. The first section of the report introduces a general IDM for the integration RDF-based information into the existing AMS commonly established in relation database structure. It provides a basis to transfer the data between domain-specific ontology and national AMS. Besides the semantic information collected with ontology, the IFC Schema provides a manner as well to capture this information as extended properties. It uses particularly for the handover of an as-built model to the operation. Using MVD realizes a rule-based exchange for the IFC model. The second section of the report gives an overview of the data structure of the mvdXML and examples for three use cases. The third section gives an overview of the guideline of modeling and linking user-defined ontology with EUROTL ontology in the INTERLINK. Three alignment ontologies are created for linking the ontologies defined in work package 4 with the EUROTL.

5 Bibliography

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6 Appendix

6.1 MVD for as-built model of pavement by handover construction to operation

Temporary download link as mvdXML file:

https://ruhr-uni-bochum.sciebo.de/s/Id5hKNomPUbg6PE

6.2 MVD for Model with current condition of bridge by inspection

Temporary download link as mvdXML file:

https://ruhr-uni-bochum.sciebo.de/s/5LpVkmTeMtpB8XE

6.3 MVD for Model with maintenance plan of pavement by inspection

Temporary download link as mvdXML file:

https://ruhr-uni-bochum.sciebo.de/s/azw9E8jah4nuQ7O

6.4 Alignment Ontology CODEX2EUROTL

Temporary download link for the ttl file:

https://ruhr-uni-bochum.sciebo.de/s/T0nMq6ijGhqlRGW

6.5 Alignment Ontology COAS2EUROTL

Temporary download link for the ttl file:

https://ruhr-uni-bochum.sciebo.de/s/nyXtzdGv3mgeXiP

6.6 Alignment Ontology MAINTP2EUROTL

Temporary download link for the ttl file:

https://ruhr-uni-bochum.sciebo.de/s/IzplJ5DLqENHJq2