RAISO: RAilway Infrastructures and Signaling Ontology for Configuration Management, Verification and Validation

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***Abstract*— Signaling systems grant safety routes for railway transportation. Recently, the need of interoperable systems among different European countries increases in consequence of the increment of trades. This leads to data integration challenges. Railway operators provide nation-centric systems and tools. To tackle the complexity of this issue, an ontology-based railway model has been realized. Thus, this paper presents the development and the exploitation of model ontology which allows to formalize the layout of a railway network focusing on railway terminal (station) including the position of the track elements (signals, train detector etc...). Our investigation consisted in formalizing logical rules, which allow checking completeness, consistency of the model by automatically inferring the layout of the remaining installations (i.e., track circuit, signals and track sections) and the possible train routes through the network. A case study regarding the analysis of two different stations is also shown. The development has been produced in the context of RAISSS project with FESR from Europe to Region.**

Index Terms – Railways, Interlocking system, Ontology

I. INTRODUCTION

The interlocking data are typically written using a special-purpose programming language designed by signaling engineers, e.g., Ladder Logic. Because railways transportation systems involve person's movements, interlocking tools have to satisfy the CENELEC EN50128 [1]. In the last decade, academic-industrial join venture projects promoted the standardization of data exchange file formats for interlocking data exchange between railways and suppliers applications. Thus, the Euro-interlocking Data Preparation promoted the standardization of data exchange file formats for interlocking data exchange between railways and suppliers applications [2]. For example, InteGRail developed an information-sharing model to improve decision-making and performance [3]. In this paper, we present an ontological model to formally defining a railway infrastructure, routes and signaling principles on which corresponding validation and verification methods are applied. This approach has been adopted to create a knowledge base solution for validating railway track layouts and/or inferring missing elements, and thus supporting the experts in completing the configuration.

II. SHORT ANALYSIS OF RAILWAY DOMAIN

In this section, the domain part strictly related to interlocking functionality is presented. First, we discuss the interlocking area as part of a railway network then we introduce the safety properties and finally the trains' routes.

An interlocking area contains railway elements such as railway tracks, switches, buffer stops and devices installed alongside, i.e., signals and train detectors (track circuits, axle counters and balises) [4]. An interlocking area describes a part of railway infrastructure, and more Interlocking areas form a railway station. Railway lines connecting two or more railway stations forms a railway network. A High Speed railway line is a type of rail transport, which operates significantly faster than traditional rail traffic (e.g., reaching speed greater than 200km). Signals could be fixed showing information as speed limit or variables as semaphores. In **Figure 1 and Table I**, an example is drawn. Tracks are logically divided in track sections (e.g., TS1, TS2 … TS4), starting and ending at fictitious element junctions (e.g., J1, J2 … J7).

TABLE I: Control table of an interlocking area, see Figure 1.

Routes	**Track elements**		
	Signals	***Track sections***	***Switches***
s1-s2	s1, s2,s3	ts1, ts2	sw1 normal
s3-s2	s2, s3,s4,s5	ts2, ts3	sw1 reverse
s4-s5	s2, s3,s4,s5	ts4,ts3	sw1 normal

Each track section is associated with at least one train detector (to identify the presence of the train on the segment); a train protection element permits emergency brake and level crossing barriers where railway line crosses a road. Switches (e.g., SW1) are special devices connecting a track section with two or more other track sections per direction of movement. For example, TS3 with TS2 and TS4, starting at one junction and ending at two different junctions. Switches have two possible positions: normal and reverse. The normal position is when the switch allows trains to travel straight over while reverse is when trains branch off. Signals are placed between track sections and are used to inform the train driver and the automatic train protection system, ATP, about the acceptance or not of the train in the section. This information is visible only for its own corresponding driving direction. Semaphores visualize this information by color: green to proceed on the next section, yellow as warning and red to stop.

Some safety principles to be satisfied in railway domain are:

- No collision: no trains occupies the same section at same time;

- No derailment: trains keep moving on railroad, thus inhibiting the movement of mobile-elements (i.e., switches) during the train passage. From the configuration point of view, this means that all switches belonging to a route must be identified.

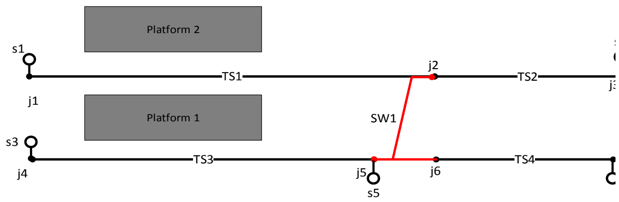

Figure 1: Railway track layout, see Table I

Please note that, the no collision principle is achieved by adopting a reservation policy for track elements involved in the train movement. A further improvement consists in considering overlapped sections and flank protection guidelines. Overlap section guideline assures a safety distance in case of failure stop while flank protection ensures that trains will not collide with another coming from branching or incoming tracks.

Routes are logical entities defined on track layout and consist of sequentially connected track sections that begin and end at signals. Routes are typically formalize4d by means of control tables, which are created when a railway yard is designed. A control table is a tabular representation of route settings on a railway track layout derived from the principles of safe working of trains described hereafter. The format of the control table is not standardized. **Table 1** shows a control table related to the track plan of **Figure 1**. The switch SW1 and signal s2 of route s4-s5 are flank protection elements while TS3 is an overlap section.

III. General Architecture and Process

In this section, the reference architecture of the proposed solution is described (see **Figure 2**). The main idea consists in creating a knowledge base model of the interlocking area under analysis. The model is created as a knowledge base grounded on the RAISO (RAilway Infrastructures and Signaling Ontology) ontology model. The obtained knowledge base can be used for validating the interlocking area by verifying logical constrains. The RAISO ontology (described in the next section) has been modeled in OWL [5] (Web Ontology Language) and has been represented in RDF (Resource Description Framework [6]) which is a system for expressing knowledge about things, or each resource with a URI or Unique Resource Identifier and by defining relationships between resources and/or explicit data values. The knowledge-based system consists of an RDF store containing the ontology meta-model and models of railway stations. Each construct of OWL language has a formal specific in Description Logic, DL, which is also a family of knowledge representation languages extending First Order Logic (FOL). Open World Assumption (OWA) and the absence of Unique Name Assumption (UNA) characterizes OWL because enables an OWL reasoner to infer new knowledge. In an information system, OWA states that a relation not explicitly defined among elements is always deducible. A RDF store is framework used for storing and querying RDF data. It provides a mechanism for persistent storage and access of RDF model and graphs. Moreover, Stardog [7] has been used as RDF-store since it incorporates a pellet's version implementing integrity constraint checking, adopted in the validation of track layout. What triggers a constraint violation in closed world systems leads to new inferences in standard OWL systems. In the last decade, Tao et al., with the authors of Pellet Reasoner, engaged that problem. In fact, in [8], they showed how to define an Integrity Constraint, IC, semantics for OWL axioms and they discussed possible semantics for ICs. Moreover, they give a model theoretic semantics based on the Closed World Assumption and a weak variant of the Unique Name Assumption for OWL axioms that are thereby interpreted as ICs. A SPARQL endpoint enables users (human or other) to query a knowledge base via the SPARQL language, which is the W3C recommended language for querying of RDF data, or RDF graphs. Similarly the authors have worked on other knowledge base solutions for smart city, mobility and transport such as Km4City in [9].

IV. Overview of RAISO Ontology

RAISO ontology models railway domain taking into accounts: network and stations layers. The network layer describes a railway network composed of stations (terminal or pass-through) and connections among them. In order to model the concepts, this layer has been realized by extending the limited railway concepts which are present in OTN (Open Transport Networks) [10]. OTN is simple a general-purpose ontology modeling transportation nets. In the following paragraph a partial presentation of the RAISO ontology is provide to give at the reader the idea of the main relationships among RAISO and the exploited vocabularies.

Figure 2: RAISO System Architecture for Railway Verification and Validation

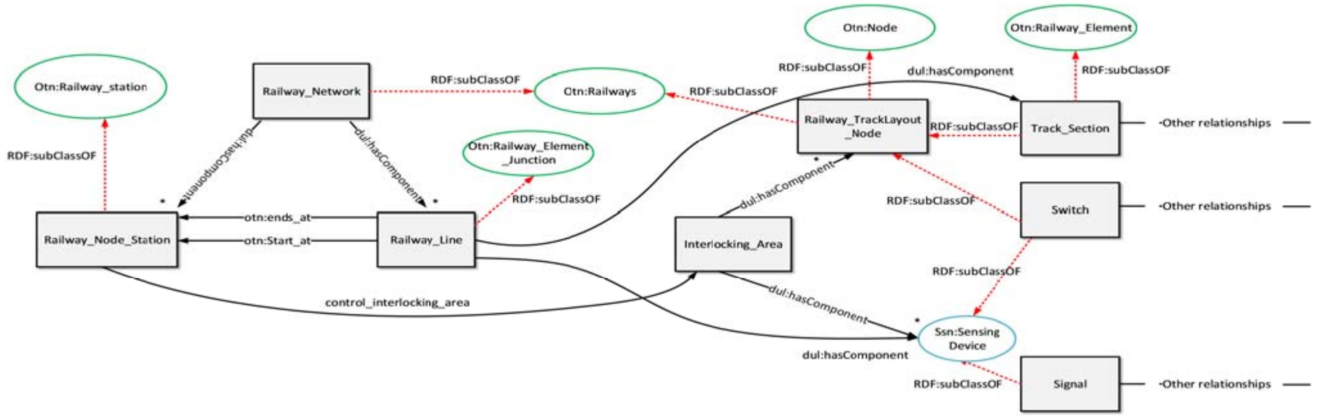

Figure 3: Railway network model (a part) where ellipses depict elements of external ontology concepts and square depicts newly defined RAISO ontology concepts

Indeed, *Railway_Network* class has been defined as subclass of *otn:Railways* with object property cardinality restriction *otn:contains* on *Railway_Line* and *Railway_Node_Station* classes**.** *Railway_Line* extends *otn:Railway_Element* with object properties (*otn:start_at, otn:ends_at*) restriction on class *Railway_Node_Station* and object property DUL*:hasComponenent* restriction on class *Track_Section* and *ssn:SensingDevice* which are detailed furthermore. DUL ontology [11] provides a set of upper level concepts useful for interoperability among many middle and lower level ontologies. Because *otn:Railway_Station* describes a station and it lacks of network information, we needed to extend it with *Railway_Node_Station* which is also a subclass of *otn:Railway_Element_Junction* and has restrictions on *Interlocking_Area* class (see **Figure 3**). High-speed lines are conceptualized by *Railway_Line_HS* class, which is a subclass of *Railway_Line* and has restrictions on the speed of contained *Track_Section* typed individuals. Station layer describes relationships among elements of railway station layout. The terminology adopted to describe the concepts is compatible with RailML [12]. A railway track layout is represented by class *Interlocking_Area* which has been defined as restrictions of object property DUL*:hasComponenent* on class *ssn:SensingDevice* and *Railway_TrackLayout_Node*.

SSN (Sematic Sensor Network) [13] ontology enables expressive representation of sensors, sensor observations, and knowledge of the environment and was chosen because railway signaling device forms a large sensor network. This layer includes also temporal concepts permitting to observe the state of elements (e.g., occupied, moving). TIME [14] W3C has been developed for describing the temporal content of Web pages and the temporal properties of Web services. A *Track_Section* is declared as subclass of *Railway_TrackLayout_Node* and *ssn:Platform***.** This class is characterized by starting and ending at a *Railway_Track_Layout_Junction* via object properties *begins_at* and *finishes_at*. These properties are completed with the following inverses *beginning_for* and *ending_for. Railway_Track_Layout_Junction* is a specialization of *otn:Railway_Element_Junction* enriched with a general axiom, which is clarified later when discussing about switches. A *Track_Section* has also associated instances of subclass of *ssn:SensingDevice* class *Train_detection_Element Train_Protection_Element and Level_Crossing* which represent the passive part of signaling. Speed and gradient information of *Track_Section* individuals are obtained by object properties restriction on class *Speed_Change* and *Gradient_Change*. Routes are conceptualized extending *otn:Route* with *Railway_Route* which is a subclass of *otn:Railways*. For each layer we defined different class of routes. At network layer, a route is represented by *Railway_Line_Route* defined as extension of *Railway_Route* and object restriction *otn:hasComponent* on class *Railway_Line*. At station layer, a route is conceptualized by the class *Railway_Element_Route* which is defined as a subclass of *Railway_Route* and restriction of object property *otn:has_component* on class *Railway_TrackLayout_Node* and on has_entry_signal and has_exit_signal on class *Signal.*

V. VALIDATION AND CASE STUDY

For the validation phase, we choose SPARQL as formal language. To this end, queries using "SPARQL 1.1 "property path" features to identify track sections and switches elements have been developed per route which permitted us to formalize safety paths. Consistency and completeness properties verification were also formalized as SPARQL queries searching missing or wrong relations. For example, we search if all instances of *Railway_TrackLayout_Node* class and related to instance of *Railway_Track_Layout_Route* class are connected each other and form a path (Consistency) or each *track_section* of *Interlocking_Area* has at least one *Train_Detection_Element* (Completeness).

A case study for the validation, we decided to analyze Diecimo Pescagli station which is a typical Italian pass-through station (see **Figure 4**) and Dutch Santpoor Noord Station (see **Figure 5**). In the first phase, the RAISO model for each station has been built. This was possible by starting from a formal description of the Italian station compiled in RailML XML file. For the Dutch Station the RailML was gathered from [15]. In the first phase, the RAISO model for each station has been built. This was possible by starting from a formal

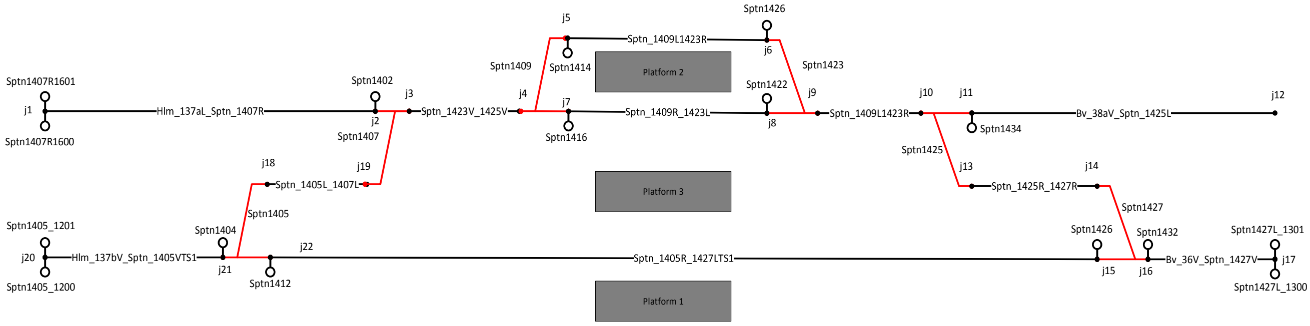

Figure 5: Santpoor Noord station

description of the Italian station compiled in RailML XML file.

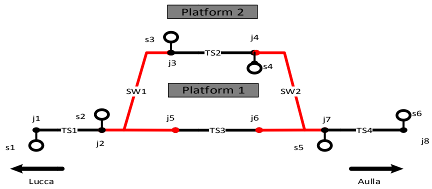

Figure 4: Diecimo Pescagli station

As a second phase, the RailML descriptive files have been translated into RDF triples of RAISO using a XLST based script. As a third phase, we have generated routes information applying suitable SPARQL queries. The resulting data has been inserted into the RDF store based on RAISO. The last phase consisted in testing consistency and completeness properties that were conducted injecting some errors and verifying our detection capabilities. In **Table II,** a summary of the validation phase for each station is reported.

TABLE II: Study results conducted on Italian and Dutch stations

Station	***RDF***	***routes***	***routes detected***	***Num. of errors injected***	***Num. of errors detected***
Diecimo Pescagli	367	12	12	21	21
Santpoor Noord	961	36	36	58	58

For the validation and verification of the approach, comforting results have been obtained since errors occurred during evaluation of a preliminary version of safety properties check queries due a presence of cycles in the RDF graph, where detected and solved. To tackle the problem we have required filtering the track sections that are delimited by two switches (e.g., TS2 and TS3 in Figure 7).

VI. CONCLUSIONS

This paper discussed the development and the exploitation of RAISO model and ontology which allows formalizing the layout of a railway network focusing on railway terminal (station) including the position of the track elements (signals, train detector etc...). Our investigation consisted in formalizing logical rules, which allow checking completeness, consistency of the model. A case study regarding the analysis of two different stations is shown. The experiments conducted have shown once the RAISO model is created, relevant information and verification procedures are easily achieved by automatically inferring the layout of the remaining installations (i.e., track circuit, signals and track sections) and the possible train routes through the network.

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