ONTOLOGY-BASED RAILWAY INFRASTRUCTURE VERIFICATION
Planning Benefits

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Abstract: Planning new railway infrastructures is a complex process. We present an approach where the formalization of expert knowledge regarding the railway domain is motivated in order to improve the planning process. By applying ontologies as a representation of railway related knowledge we are able to make the coherencies of infrastructural elements explicit. Furthermore the integration of an ontology-based rule language provides the possibility of a semi-automated integrity verification of static infrastructure and safety components. Semantical inconsistencies potentially leading to unsafe conditions regarding train operations can be spotted within this verification process. This combination of conceptualization and correlation rules tends to be applicable for the creation of a formal and consistent model of specific railway infrastructures which are to be planned.

1 INTRODUCTION

While planning new railroad lines a lot of issues regarding the railway domain have to be addressed. The deployment and alignment of physical elements such as tracks, signals and so forth as well as their coherencies with abstract elements like train routes have to be considered during the planning process in which many parties are involved. On the one side there are federal offices commissioned with approvals, verification and certification issues. On the other side there are manufacturers producing physical parts of the railroad line. Interlocking manufacturers constitute an elevated status within the overall planning process. They produce interlocking blocks as important components of every railway station. An Interlocking block a central unit, where all train movements and security elements e.g. signals and switches are controlled. A station inspector uses the interlocking block to assign a specific track sequence to a specific train, so that sequence can exclusively be used by this train. Such a so called route is set up temporarily and blocks the corresponding tracks for exclusive usage. Security elements are used for the blocking procedure. For example switches nearby the route are moved into an opposite position in order to provide flank protection to the train occupying the route. These security operations are all to be done in order to prevent other trains from moving into the route and causing an accident. In short words: The correct application of signaling and safety technologies cooperating with the interlocking block is an important task of the railway infrastructure planning process in order to provide safe train operations. An importance resides in the correct and formalized planning process of the static infrastructure in general and the safety components in detail.

1.1 Motivation

Due to traditionally long cycles of innovation regarding the railway domain the planning process of new railway infrastructures is only supported by a minimum amount of computerization, automation and software tool support. Especially the railway infrastructure itself is not represented as a formalized computational model which can be shared and communicated among involved companies and authorities and most important: which can be used for computer-aided verification tasks. Almost all agreements of technical kind are exchanged as paper based documents. This fact implies an administrative overhead and a low integrability with respect to reusability. Apart from these issues, the planning company is highly dependent on the correctness of the so far developed railway infrastructure. The company has to

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ensure that the current work represents a consistent infrastructure regarding integrity and safety. The infrastructure verification is not realized within the planning company, but at the EBA[1] in a manual manner. Nowadays for verification tasks the planning documents have to be transformed into a specific table-based document format. Afterwards they have to be printed and sent to the EBA, where the infrastructure plans are verified against the legal guideline. After the manual verification process an error report is written and all documents are sent back to the planning company. Now the verified documents have to be digitalized again, error checked and transformed into the company specific format. This verification process is highly inefficient.

The motivation of our work is to develop a possibility for a semi-automated verification process of the static railway infrastructure with focus on the safety components. We are achieving this by the development of an ontological framework where implicit expert knowledge of the railway domain as well as the legal German guideline for railway infrastructures and their correlations are made explicit and stored in a conceptual model in order. It is obvious that the German guideline for railway infrastructure planning is a huge and complex collection of rules and standards. Our work does not claim to represent the complete guideline. It can be seen as a proof-of-concept to encode such a guideline into an ontological model in order to provide a method for verification issues. In general, the choice to use an ontological model resides in the fact that ontologies are *achieving interoperability between multiple representations of reality [...] and between such representations and reality, namely human users and their perception of reality.* (Hepp, 2007)

2 RELATED WORK

There are several approaches for infrastructural information representation in a domain specific ontological knowledge base. In (Métral et al., 2007) a methodology for modeling urban infrastructures within an ontology is introduced. The work is mainly focused on defining an ontological model as a communication contract between the parties involved in urban planning processes.

InteGRail is a topic related project founded by the EU and has the ambition to homogenize the information retrieval and management within the railway world in order to enable optimization of decision making for improved performance on railway tracks. It uses an ontological model named "Railway Domain Ontology" to solve the integration challenge of the railway environment. This model is applied allowing a predictive maintenance strategy in railway components (Shingler et al., 2008) in comparison to common maintenance strategies like RCM (Reliability Centered Maintainance). Another similar publication of Cristina de Ambrosi (Ambrosi et al., 2009) discusses the integration of an embedded ontological system into railway vehicles. This system performs fault classifications within the vehicle. *InteGRail* is a good example for modeling railway related concepts using ontologies, but in contrast to our work in *InteGRail* the model is used as a data structure contract while we focus on the semantic verification of railway infrastructures.

Regarding the formalization of legal railway guidelines there are several works dealing with automated ontology extraction (Amato et al., 2008) and the representation of legislation in ontologies (Boer and Boer, 2003), but in contrast to them our work intends to make use of the ontology rule language SWRL for the representation of legal railway guidelines.

3 APPROACH

The railway infrastructure is modeled within an ontology by using the ontology description language OWL (W3C, 2004a). The correlation rules are phrased in the Semantic Web Rule Language (SWRL) (W3C, 2004b) syntax. SWRL rules follow the horn clause syntax, therefore they consist of antecedent-consequent pairs, and are stored as OWL individuals within the ontological model to which they are applied to. During the modeling process we enriched SWRL with so called built-ins which provide railway specific enhancements to the language while maintaining consistency and decidability.

We favor this ontological representation of the railway infrastructure planning data because of its expressiveness. It has the ability to represent the semantics of the railway domain in a more detailed way in comparison to a simple, syntax-only XML representation. Apart from semantical correlations expressed within the OWL-model, the integration of complex SWRL rules allows the creation of a more realistic model which as far as possible is in accordance with railway directive semantics and which can be used for the planning data verification task.

We followed a bottom up approach in formalizing railway domain knowledge into an ontological model.

[1] Federal Railway Authority: *german:* Eisenbahnbundesamt.

As a transfer format between the infrastructure planning tools and the ontological model we make use of an open source XML-schema named railML (Nash et al., 2004), which offers a structured description format for railway related content. We extended the railML schema in order to cover a majority of infrastructural elements and their attributes as they are defined in legal German directives for railway planning. Then we adapted the concepts and correlations of railML and created an initial conceptual OWL model. During fruitful discussions this model is extended and enriched by profound knowledge of railway experts.

3.1 railML - an XML Schema for the Railway Domain

The railML XML schema has been developed since 2001 by the railML initiative, intending to establish railML as an open-source standard format for data exchange between diverse railway applications. This includes tools for route simulation and disposition of trains as well as timetable systems and applications for railway infrastructure planning.

RailML consists of three subschemata covering different aspects of the railway domain. There is a subschema *rolling stock* in which elements and attributes regarding train constellations and wagon configurations are accumulated. A second is the *timetable* subschema which is developed in order to support the modeling of departure and arrival times and the whole scheduling of train movements. At last there is an *infrastructure* subschema. We focused on this subschema of railML in which the representation of physical elements concerning the railway route resides. The element definitions range from tracks, signals and level crossings to security related parts like train detection circuits or transponders for train deceleration and many more. Thus the *infrastructure* subschema offers a good starting point for the understanding of infrastructural concepts and their correlations. During our work we extended this subschema in order to be capable to formalize the description of interlocking elements as well.

3.2 Evolving a Formal Railway Infrastructure Domain Model

We translated the hierarchical railway representation of the railML infrastructure subschema into an enhanced ontological, meshed representation where the hierarchical structure is broken open. RailML has limitations thus is not comprehensive enough in order to represent all infrastructural elements and their attributes requested by , directives. In the ontological model most of the original concepts and relations of railML remain, but are augmented with sophisticated interrelations tending to represent the legal directives.

As a concrete example we can have a look at the concept *signal* in railML. A signal can be of the types main-signal or distant-signal among others. In the German railway infrastructure guidelines the correlations between main and distant signals are defined in a very detailed way. A distant signal, for instance, is always placed before a main signal in order to notify the engine driver what he has to be aware of. The correct distances between the signals depend on the maximum speed on the track as well as on the visibility of the signals, for example when they are placed in bends. These directives cannot be encoded and verified using an XML schema, whereas the expressiveness of OWL and SWRL as ontology modeling languages permit the representation of such directives.

Our starting point was the key concept *track*, where all other physical elements are aligned with. Tracks as well as switches have a spatial extent and can be interconnected among each other. All other physical elements like signals, balises, train detection elements and so forth are point-shaped and related to tracks or switches. There do exist virtual elements like routes and railway control centers, but these elements are an overlay of physical elements and subsume their spatial extent.

At figure 1 an excerpt of the class ontology is shown. Classes are represented as ellipses. Individuals as red squares. Whereas datatype properties are represented as named connections from classes to blue squares showing their data type. At last object properties are represented as named connections between classes. *Base* is the class where all other elements are derived from. It contains the data type properties *id* and *name* which provide a unique identifier and a human readable name for all instantiated objects. Direct subclasses of *Base* are the classes *RelationalObject*, *DirectedPointObject* and *VirtualObject*. *RelationalObject* is a base class for all physical elements which have a spatial extend namely *Tracks* and *Switches*. *DirectedPointObjects* are unidimensional aligned along the *RelationalObjects* via the object property *isOnRO* and its corresponding inverse property *hasDPO*. As an example the *Signal* class is shown at figure 1. It features a relation to the class *SignalType* which basically consists of an enumeration of possible signal types as defined individuals. In extracts the classification classes for the verification tasks are shown. E.g. after a verification process the class *Correct_S_Placement* contains all signals which are correctly positioned within the bounds of their corresponding track elements re-

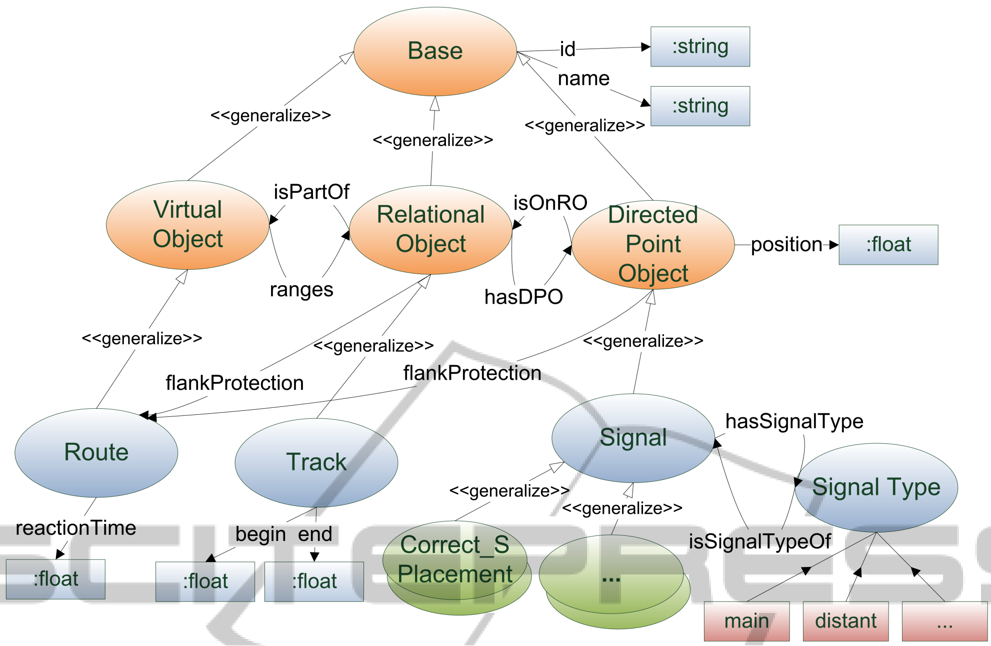

Figure 1: Class ontology (excerpt).

garding the first SWRL rule described in the following chapter 3.3. *VirtualObjects* are all non-physical objects like *Route* and *InterlockingBlock*. These objects are mapped to an accumulation of *RelationalObjects*. Route elements, as it can be seen on the figure, have a direct relation to *RelationalObjects* and *DirectedPointObjects* via the object properties *flankProtection*. With this construct route definitions are augmented with an additional security concept which had to be formalized while modeling railway infrastructure related context. In reality a route is secured by flank protection elements in order to ensure no other train can cross the route. A flank protection element can be for example a signal signaling stop or a switch which is locked in a position not leading into the route.

3.3 Refine the Model with Semantic Rules

OWL allows the definition of restrictions on classes. E.g. a common signal containing attributes for a specialized signal (e.g. entry signal) can be classified as such by defining the necessary restrictions and applying the OWL reasoner. These restriction definitions are a powerful tool within OWL, but they have limitations. Complex correlations among different attributes and classes cannot be expressed within these restrictions. We decided to enhance our model not only with restrictions but also with semantic rules written in SWRL and stored directly within the ontological model. SWRL rules can be defined in horn clause syntax as antecedent-consequent pairs. This allows the creation of a realistic model which is tends to be in accordance with railway directive semantics and which appears to be applicable for verification tasks of railway infrastructure planning data.

As a rule example, the following directive shall be considered: *A signal needs to be placed within the range of the corresponding track it is assigned to.* The SWRL rule defined in an abstract syntax is as follows:

```
Signal(?s) ˆ Track(?t) ˆ to(?t, ?to) ˆ
signalIsOnTrack(?s, ?t) ˆ from(?t, ?from) ˆ
SignalPosition(?s, ?pos) ˆ
swrlb:greaterThanOrEqual(?pos, ?from) ˆ
swrlb:lessThanOrEqual(?pos, ?to)
-> Correct_S_Placement(?s)
```

Rule consequents (results) can be integrated into antecedents of other rules, thus allowing a hierarchization of rules and a reduction of complexity. Thereby rules can make use of signals which are already assigned to the *Correct_S_Placement* class only, hence incorrectly placed signals will be omitted. As shown in the example, SWRL allows the definition of finer constraints and the expression of complex correlations among infrastructural elements. With SWRL an extensive formalization of German legal guidelines is possible.

As a specific German legal guideline directive the following sentence shall be focused: *A station area must be secured by entry signals*. This directive can be formalized with following SWRL rule (simplified):

```
Track(?t1) ˆ Track(?t2) ˆ
hasConnection(?t1, ?t2) ˆ
hasTrackType(?t1, 'open') ˆ
hasTrackType(?t2, 'station') ˆ
CorrectPlacedSignal(?s) ˆ
hasSignalType(?s, 'entry') ˆ
signalIsOnTrack(?s, ?t1)
-> CorrectStationSecurity(?t2)
```

The rule is interpreted as follows: ”If there are two tracks which are connected to each other and between which there is the (imaginary) border of a station, the track abutting to the station area has to have a signal which has to be an entry signal in order to secure the station area.” Note that in the context of this rule not only a signal is used but a *Correct_S_Placement*. This shows the hierarchization mechanism and implies that only correctly placed signals are considers to be part of this rule.

The power of SWRL and especially the protégé (Stanford-University, 2009) implementation can be shown with the following rule which represents the verification of the overlap dimension of train routes. An overlap is a track segment behind a train route which has to be blocked because of security reasons. If a train is not able to stop at the end of a train route in time it runs into the overlap. It is a legal directive that the dimension of an overlap is (among other factors) dependent on the maximum speed at which a train is allowed to move on the specific route. To formalize such a directive, mathematical operations are required within the corresponding SWRL rule. Such operations can be performed by using the protégé built-in *eval*.

```
Route(?r) ˆ Overlap(?o) ˆ
hasOverlap(?r, ?o) ˆ vMax(?r, ?v) ˆ
overlapLenght(?o, ?l) ˆ
eval(?result, "v * 3.6 * 2", ?v) ˆ
greaterThanOrEqual(?l, result) ˆ
-> CorrectOverlapPerRoute(?r)
```

In natural language this (simplified) rule can be phrased as follows: ”For every route which has a vMax in km/h and which has an overlap of a length in meters this length must be at least the distance a train can move at vMax during two seconds. Only when this conditions hold, a route is classified as a *CorrectOverlapPerRoute*”. The *eval* method is very powerful. A lot of mathematical expressions like sine, cosine, abs, floor, sqrt and many more can be used. The range of SWRL expressiveness is sufficient for the purposes of the formalization of German legal guidelines for railway infrastructure planning.

4 MODEL PARTITIONING

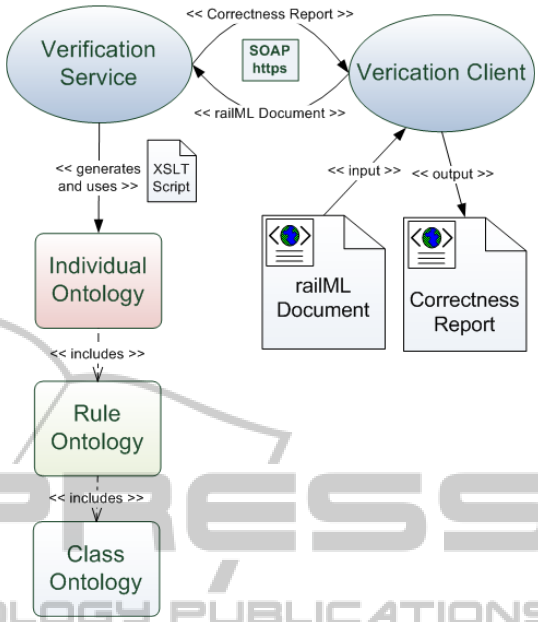

Figure 2: Ontological verification system.

We segmented our verification system into different logical and physical parts. Figure 2 shows the components of the verification system. At the bottom resides the class ontology which contains the railway concepts taken from the railML schema augmented by knowledge taken from railway experts. Apart from that the class ontology contains categorization classes. These classes are used to mark verified elements like ”[In]CorrectlyPlacedSignals” or ”[In]CorrectStationSecurities” etc.

The rule ontology resides at the upper level and includes the class ontology so that it is able to make use of its concept definitions. These concepts are used within the rules in order to represent more complex semantic correlations of the classes and properties. As mentioned before, the rules are mostly formalized infrastructure planning guidelines representing legal directives for German infrastructure planning.

At the uppermost level of the knowledge base the individual ontology is located. It is generated by applying XSLT scripts to a document in (the extended) railML format. This document contain the actual planning data such as precisely defined infrastructure objects extracted from infrastructure planning tools. As it can be seen the individual ontology is data specific, whereas the class and rule ontologies build the unmodifiable knowledge base. Invoking the verification service, the objects within the individual ontology are to be verified automatically against the German railway directives modeled in the class and rule ontologies.

At the application side of the system the verification service is a web service which wraps the ontology and reasoning framework. It is invoked by a client program, which communicates with the service via standard SOAP mechanisms. A user can upload planning data in the (enhanced) railML format via a client. The planning data is transformed via an XSLT script into the individual ontology in OWL language. Using an import statement the individual ontology includes the rule and conceptual ontologies. At this point the verification service performs the actual verification using the ontological knowledge base and generates a correctness report containing the verification results. This report is transfered to the client, again via SOAP, that displays the verification results to the user. The client also provides an interface for changing as well as grouping and (de)activating rules. This mechanism allows the verification of only parts of the planning data for example if they reflect an early stage of the planning process where not all data is available yet.

5 CONCLUSIONS

The application of ontologies for verification issues especially within the railway domain is inconvenient. Our experiences with the approach described in this paper seem to be very promising. The separation of concepts, rules and individuals provides a loose coupling which is common application design for years. The ascertainment of expert knowledge regarding the railway domain into a formal environment tends to be a step towards the standardization of railway infrastructure planning. With straightening the heterogeneous communication and verification processes, development periods can be shortened and optimized. Similarly the formalization of legal German infrastructure planning directives seems to be necessary and tend be achievable by applying SWRL. Although we only focused on a small excerpt of all guidelines for infrastructure planning, we gave examples to show that formalization can be accomplished with complex issues as well.

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