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SUMO for Railway Applications

Enabling railway domain usage by implementing an import interface based on railway data exchange standard railML

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Abstract. SUMO is a simulation tool widely used in the road-based transport sector. However, railways play an important role in transport and transportation, too. In order to have a holistic approach in transport system simulation, railway networks and railway operation have to be modelled in a realistic scale and manner. Integrating railway infrastructure and operation with road-based transport system enables SUMO to be used for multi-modal and inter-modal transport system simulations. This paper presents an approach of integrating railway-specific data of infrastructure networks, timetable and rolling stock into SUMO's simulation environment by implementing a standardized railway data import interface based on the open and industry-driven data exchange standard railML.

Keywords: Railway data, Standardized data exchange, railML

1. Motivation

SUMO is a simulation tool widely used in the road-based transport sector. However, railways play an important role in transport and transportation, too. In order to have a holistic approach in transport system simulation, railway networks and railway operation have to be modelled in a realistic scale and manner. Integrating railway infrastructure and operation with road-based transport system enables SUMO to be used for multi-modal and inter-modal transport system simulations – a field that is getting more and more interesting.

Within the research project "Indres", funded by the German Federal Ministry of Transport, the consortium led by Bahnkonzept GmbH Germany built up a digital railway infrastructure repository designed for multi-purpose usage of small railway infrastructure managers [1], [2]. With this generic approach, these small railway infrastructure managers get a tool at hand, to provide information about their infrastructure in a digital form. This is an essential prerequisite for them to participate in a railway sector and economy that is becoming more and more digital. For example, these small railway infrastructure managers may use information about their infrastructure networks as input for the transport simulation tool SUMO as further explained in this paper.

Section 2 describes the approach by introducing the standardized railway data exchange format railML and providing an overview about potential and actual usage of SUMO in railway context. The following section 3 explains the implementation of a railML import interface, which allows infrastructure, timetable and rolling stock data to be loaded into SUMO. Finally, section 4 summarizes the approach and provides an overview about next steps on the way of SUMO to make fully use of railway sector data.

2. Approach

2.1 Standardized railway data exchange with railML

railML [3] is an XML based language for the machine-readable description of the railway system used for the exchange of data between digital railway applications worldwide. Originally started as data exchange standard for heavy rail, railML is also being adapted to fulfil the needs of light rail and tram systems as result of the project IDX4rail [4].

Development within the four railML subschemas (infrastructure, interlocking, timetable and rolling stock) is driven by an active international user community based on use cases, which are utilised to describe, characterize, standardise and register potential application scenarios [5]. For popular use cases – e.g. schematic track plan, network statement, ETCS, and timetable use cases – working groups are established for pushing the schema development based on these use cases.

railML is an open industry standard driven by the needs of its users, developers and partners from all over the world [6]. As such, its role for railway infrastructure modelling is comparable to the one of ASAM OpenDRIVE in the modelling of road infrastructure [7]. In contrast to the General Transit Feed Specification (GTFS) [8], railML goes beyond the passenger view and provides more detailed modelling of both, rolling stock and infrastructure, e.g. incorporating signals and stopping places along the tracks, speed changes, bridges and level crossings. Consequently, railML is considered being advantageous for microscopic train simulation.

The work presented in this paper is based on railML version 2.5. This version has been approved as international ISO standard ISO/TS 4398:2022 "Intelligent transport systems – Guided transportation service planning data exchange" [9]. This so-called "RailDax" (Railway Data Exchange) aims to improve interoperability between digital railway applications, and to reduce efforts for implementing data exchange interfaces, as depicted in figure 1.

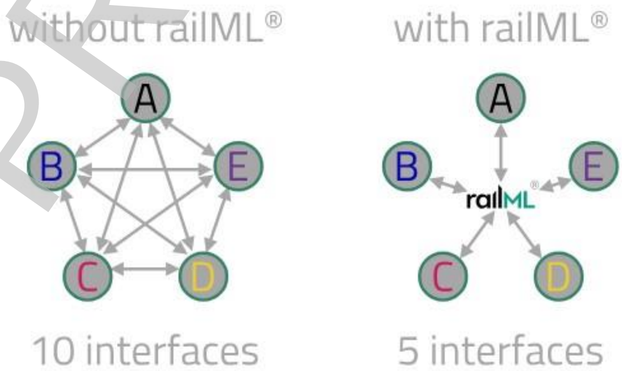

***Figure 1**: The benefits of using the standardized data exchange format railML in the communication between railway domain programs is the limitation of workload implementing interfaces and better cross-application interoperability [3].*

2.2 Using SUMO for railway operation simulation

SUMO has been steadily extended beyond road-based vehicular traffic to support rail-bound transportation. An early study on public transport, logistics and rail signal extensions within

SUMO can be found in [10], where rail signal logic and a logistics module are introduced that enable realistic simulation of rail-bound traffic in multimodal network disruption scenarios.

Building on this foundation, [11] show that SUMO meets the requirements of modeling both operative train simulation and supply chain logistics at the same time. Using a case study in northwestern Germany, both train movements and individual container trajectories are simulated to evaluate operative implications such as conflicts and delays at the level of both trains and single transport units. Extending this line of research to a network-wide scale, [12] present an agent-based simulation methodology implemented with SUMO as modeling backbone that combines microscopic, domain-specific railway traffic control with a logistical perspective on the flow of goods. The approach addresses the divergent reliability perspectives of railway operators - who focus on train punctuality - and freight transport users, who perceive reliability at the level of entire transportation chains.

Building on the mentioned approaches, microscopic SUMO railway network simulation models can be set up based on microscopic or macroscopic timetable data, depending on the granularity of input schedules. Timetables can subsequently be mapped to microscopic train paths and routing conflicts are mitigated through edge-level comparison or comparable routines. For network generation, SUMO supports infrastructure import from OpenStreetMap. Station-internal track allocations are optimized using mixed-integer programming techniques. Applications as, e.g., to the German railway network show that a SUMO railway network simulation enables systemic modeling and evaluation of both train punctualities and transportation chains (or passenger journeys, respectively). Hence, delays emerging from the complex interaction of both trains and their underlying demand layers can be analyzed.

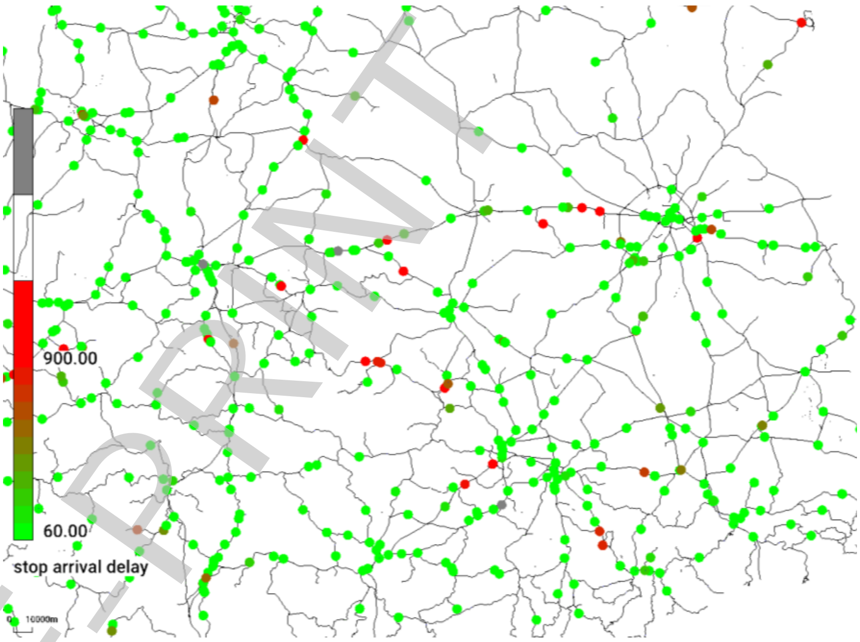

***Figure 2**: SUMO railway network simulation for middle east Germany*

Figure 2 gives an example for a railway network simulation in SUMO. Trains are visualized by circles and their corresponding arrival punctualities are colored by high delays (red) and no or low delays (green). The figure illustrates that SUMO manages to model and analyze the complexity of multi-train operation on a network scale while at the same time preserving detailed, microscopic interaction on the level of trains and infrastructure elements (e.g. signals).

A further example for a SUMO railway application is proposed by [13] in the context of the integration of railway planning with simulation. They develop a Python-based tool chain, which processes digital railway planning documents - including the PlanPro format and data from OpenRailwayMap - into SUMO simulation models. By unifying various railway data formats into a graph-based representation that captures topology, geography, signals and control infrastructure, the pipeline enables performance evaluation, bottleneck analysis and hardware-in-the-loop testing of railway networks directly from planning data.

Moreover, [14] propose a reinforcement learning (RL)-based traffic signal control approach that demonstrates the utility of SUMO at rail-road interfaces. Using SUMO, a simulation environment is established that consists of two signalized intersections and two railroad crossings. Subsequently, different algorithms are compared to optimize signal control while incorporating railway sensing information. Results show that train flow significantly affects overall traffic efficiency due to the periodic opening and closing of railroad crossings.

Summarized, SUMO has evolved into a versatile simulation environment for railway applications that includes network-wide reliability and punctuality assessment, integrated train-logistics simulation, digital railway planning document processing and RL-based approaches such as the optimization of traffic control at rail–road interfaces. Its detailed modelling of railway domain specifics and agent-based intermodality make SUMO a tool for both railway operations research and the development of intelligent transportation management systems.

3. Implementation

3.1 railML 2.5 Import Interface

The implemented import interface consists of two separate programs written in the python programming language which fulfill the distinct tasks of importing railML infrastructure definitions to build a SUMO network file and trainStop file (henceforth referred to as program P1 (*railml_importInfrastructure.py*) and importing railML timetable and rollingstock definitions to build a SUMO route file (henceforth referred to as program P2 (*railml_importTimetable.py*)). Both programs require a working python installation with version 3.9 or greater. Program P1 can be used independently (i.e. to use the rail network with traffic definitions from other sources such as GTFS, whereas program P2 is designed to optionally load outputs from P1 (the network and trainStop files) for generating validated SUMO route files.

3.2 Infrastructure import capabilities (P1)

The railML 2.5 data exchange format allows for a wide variety of rail network representations and the following are supported:

- **Abstract rail networks with display coordinates** (<trackVis>): this will result in an equivalent abstract network where all coordinate values are interpreted as meters and scaled by a configuration option (--scale)
- **Geographic rail networks with geo coordinates** (<geoMapping>): this will result in to-scale projected network (using the UTM projection). Each coordinate in the SUMO network will be associated with a corresponding lon,lat value.
- **rail networks without track-level coordinate information**: this will result in an abstract network with matching topology that is laid out horizontally according to absPos (with scaling) and with configurable spacing between tracks and and lines. Geographic coordinates that are only defined for OCPs (i.e. in macroscopic networks) are not yet imported

It should be noted, that the sumo-gui application for visualizing SUMO simulations supports loading abstract and geographic networks at the same time (with option --alternative-net-file) and seamlessly switch between them at runtime. Hence, if a railML input provides different coordinate representations, it is possible to run P1 twice with different options and use both visualizations jointly.

SUMO network models make bidirectional track use configurable by providing distinct edge elements for travelling in either direction and constraining direction if only one directional element is present. The usable directions are imported from track attribute @mainDir (interpretation of missing values is configurable). It is also possible to enforce bidirectional usability on all tracks.

In addition to the railroad tracks and switches, the following functional infrastructure elements are imported because they directly correspond to features modelled in SUMO:

- main signals (according to applicable track direction)
- stopping locations along tracks as SUMO <trainStop> elements in a separate output file
- speed changes
- level road crossings with orthogonal stub roads and junction type rail_crossing for automated operations
- points of interests such as river crossings

Several Interlocking and Safety assets provided by railML are not imported because SUMO is not yet able to make use of them. Instead, SUMO synthesizes the safety infrastructure at runtime using best-case assumptions (i.e. axle counters directly after each switch). Importing such assets is planned for future versions.

The following figure 3 shows the railway network of Indres project partner Eisenbahnen und Verkehrsbetriebe Elbe-Weser GmbH (EVB) in Lower Saxony after successful import into SUMO. Processing 174MB of railml input files took 6m and resulted in a 16MB SUMO .net.xml file with a total track length of 540km and 170 trainStops.

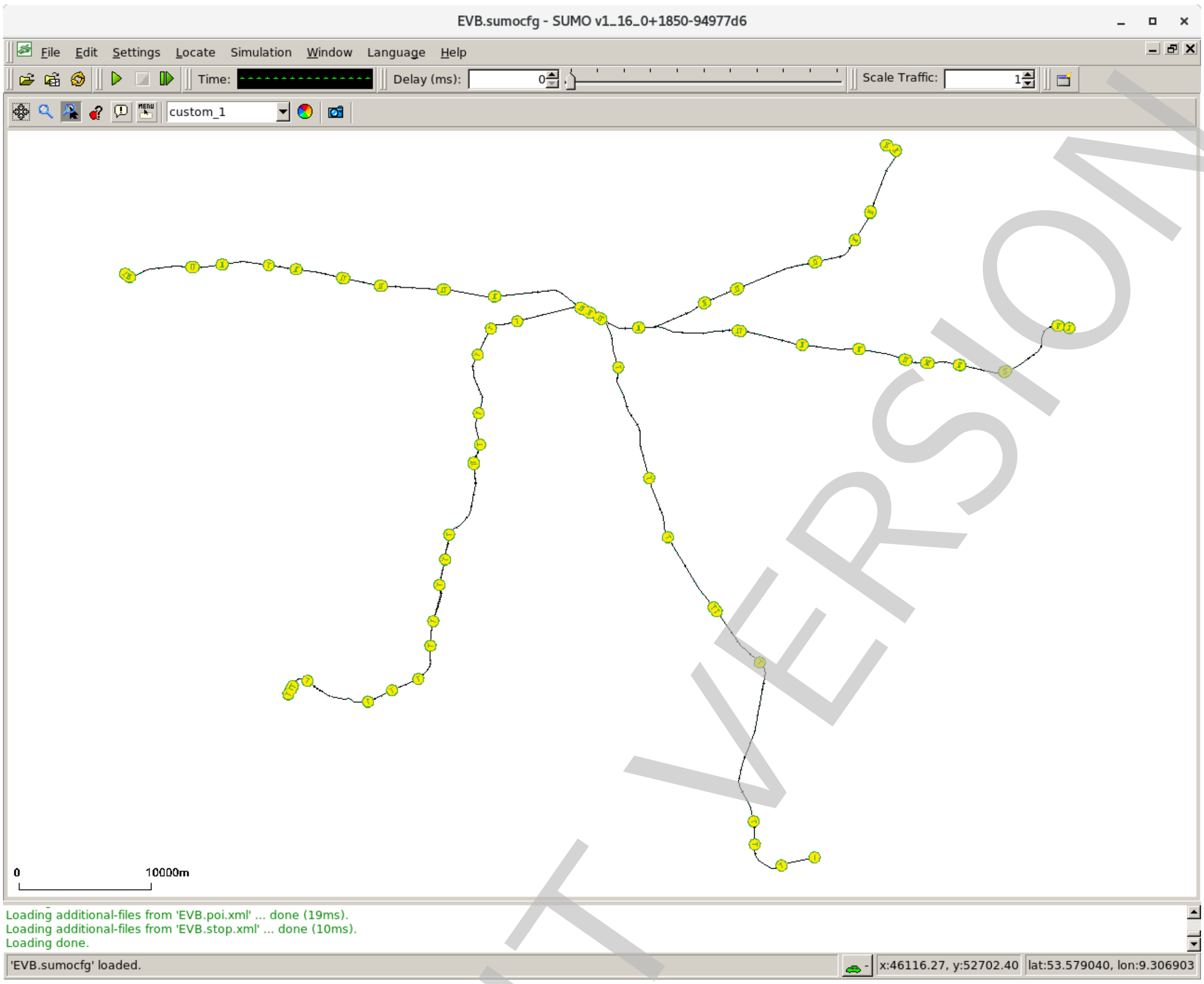

***Figure 3**: Railway network of EVB after import via SUMO's railML 2.5 import interface*

3.3 Timetable and rollingstock import capabilities (P2)

The import program P2 is designed to create a SUMO-route file that defines train movements and scheduled stops on a network and trainStop-file imported by program P1. The user must declare the time range to simulate. Currently, the range can only be specified as a single calendar day.

At the time of writing, all operational trains and their stops (<ocpTT>) that operate on the configured date are imported by P2. The split/join relationships of trains are not yet handled and each operational train is modelled as one independent SUMO vehicle.

When passing a SUMO network file and trainStop file as additional arguments, stops will be filtered according to those that could be imported from the infrastructure definitions and routes are patched (by using a 'jump' declaration) whenever the infrastructure does not permit connectivity between stops. This may happen if the infrastructure is defined as "macroscopic" model without explicit connectivity between tracks.

The following features are planned for future inclusion by extending the import interface:

- splits/joins
- circulations
- train properties (length, mass, passengerCapacity, category, traction parameters)

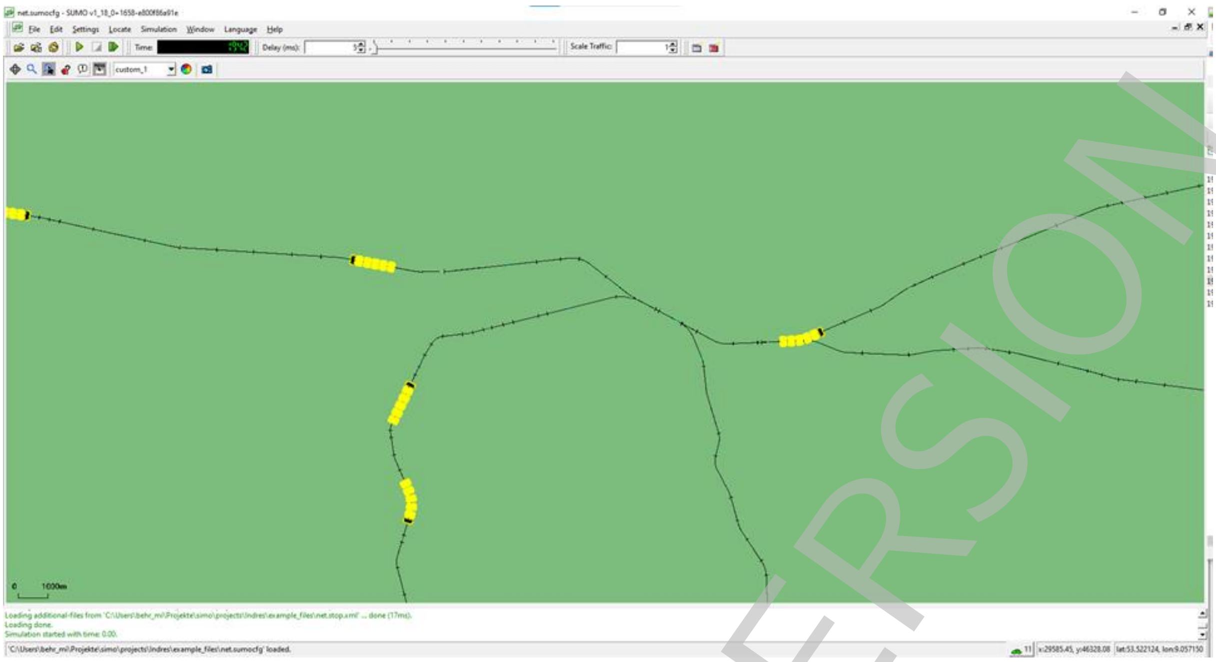

***Figure 4**: Simulated trains running on the EVB track network in SUMO. Each operational train is modelled as an independent SUMO vehicle with standard length. Specific train properties are not yet modelled.*

4. Conclusion

Using SUMO for simulating railway operations requires railway specific data. This data spans beyond the classical geodata scope: Some elements do not only have a location in terms of geographic coordinates, but also a topological and/or relative location in a railway-specific line coordinate system. Other elements like timetable or rolling stock components exist without any geo-spatial reference. In order to enable usage of these railway specific data within SUMO an import interface for the open and industry-driven railway data exchange standard railML has been developed.

This paper shows the current state of implementation of SUMO's railML 2.5 import interface. At the time of writing, it already includes the macroscopic railway infrastructure as well as few microscopic elements of functional infrastructure required for railway operations simulation. Additionally, the import interface covers basic information about timetable and rolling stock, which are also essential for building up a holistic model of railway operations within SUMO.

Future work will focus on further improvement and completion of the railML import interface. In particular, more detailed modelling of timetable and rolling stock information is on the agenda. In order to fully make use of the railML import interface within SUMO, an official certification of the interface by railML.org is required [15]. This process has been initiated. Last, but not least, SUMO's railML import interface should be adapted following the evolution of the railML standard: railML 2.5 is the last version of railML baseline 2 and the railML baseline 3 is gaining more and more importance with railML 3.4 scheduled for release later this year. Data exchange use cases like "Routes for timetable simulation" [16], "Integrated Traffic Management System" [17], or "Run Time Calculation Input Data" [18] are already documented and indicate a wide variety of future benefits using SUMO in the railway and intermodal domain. The authors invite you to actively contribute to this future of SUMO for railways.

Competing interests

The authors declare that they have no competing interests.

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