UTILIZATION OF COMPUTER SIMULATION FOR DETECTION NON-STANDARD SITUATIONS WITHIN THE NEW DATA LAYER OF RAILWAY NETWORK MODEL

Jan Fikejz\(^{(a)}\), Emil Řezanina\(^{(b)}\)

\(^{(a)}\) Department of Software Technologies, FEEI, University of Pardubice, Pardubice, Czech Republic
\(^{(b)}\) Department of Information Technologies, FEEI, University of Pardubice, Pardubice, Czech Republic

\(^{(a)}\) Jan.Fikejz@upce.cz, \(^{(b)}\) Emil.Rezanina@upce.cz

ABSTRACT
The article deals with further development of a railway network design and its subsequent use within the simulation of rolling stock operation. The article primarily focuses on the options of rolling stock localization using the GNSS and secondly, on the description of the existing railway network model using a two-layer data model. Attention is further paid to the design of another data layer of the model reflecting a more realistic view of the rail infrastructures between the stations on regional routes. Consequently, simulation of the rolling stock traffic and induction of different non-standard situations is performed within the new model layer, whose detection could be used as an additional support to the dispatcher control system.

Keywords: Railway infrastructure models, train positioning, simulation of railway traffic, agent-based simulation

1. INTRODUCTION
Rolling stock localization has been a largely discussed issue involving a number of subjects. The problem can be divided into two main areas of interest: localization for the needs (i) of safety technology and localization for the needs (ii) of information and telematics systems. The earlier mentioned underlines the safety and reliability, however, these systems usually call for higher implementation costs because they require the complementing of railway infrastructure by additional construction elements, which represents higher costs of implementation as such. On the other hand, this localization type shows a high accuracy and reliability and is often used in safety technology. The system in question is the following:

- ETCS (Ghazel, 2014),
- Automatic train control (Lieskovský and Myslivec, 2010),
- Track circuit (Dorazil, 2008),
- RFID.

2. STATE OF THE ART TECHNOLOGY IN ROLLING STOCK LOCALIZATION
Rolling stock localization can be divided into the three crucial parts:

- Localization without GNSS,
- GNSS using localization,
- GNSS based, involving further support systems.

2.1. Localization without GNSS
This localization type often requires the rail network infrastructure by additional construction elements, which represents higher costs of implementation as such. On the other hand, this localization type shows a high accuracy and reliability and is often used in safety technology. The system in question is the following:

- ETCS (Ghazel, 2014),
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- Track circuit (Dorazil, 2008),
- RFID.

2.2. GNSS using localization
GNSS system used for different application levels requires a thorough consideration of the indicated position error usually based on the satellite navigation character. Systems that operate with the information about the position only on informative level can tolerate a certain error; however, such inaccuracy is unacceptable in safety technology. In such situations, various additional systems can be implemented to eliminate the error in whole or at least partially, thus increasing the tracked object’s position. The following systems can be listed in this group:

- EGNOS (Senesi, 2012),
- Differential GPS (O’connor1997;Winter and Xiaogang 2005).

2.3. GNSS based localization involving additional support systems
As it was indicated above, precise localization of rolling stock using GNSS, especially for the needs of signalling technology, is a priori impossible. Nevertheless, position of a rail vehicle can be put much more precisely with the use of additional systems. This concerns especially the solutions using inertial systems...
(Stadlmann, 2006), and also the less known GNSS using systems based on the GNSS and the contact free eddy current measurement (Becker and Poliak, 2008).

3. LOCALIZATION ON REGIONAL TRACKS

GNSS-only based rolling stock localization can be used e.g. for identification of certain position within single-track regional lines in the Czech Republic that, unlike the main corridors, do not dispose of such a high-level technical equipment as the modern ETCS safety systems.

At regional lines it is often only possible to record a train entering/leaving a station, however, a rail car localization on a wide line without complementing the infrastructure by identification elements is much more complicated. As it was said above, GNSS-based localization is always loaded with an error resulting from the satellite navigation character. Despite this, the GNSS using localization can be applied, for example within additional support of dispatcher's control or in various information systems working with a rail vehicle position. Among the essential methods of a rail car localization is the option to use a communication terminal involving the GNSS system, that selected rail cars are equipped with (Fikejz and Kavička 2012). Selected rail cars in the Czech Republic are currently equipped with the following communication terminals:

- Telerail TLR-ZJ (producer Unicontrols, a.s.),
- Radiostation VS67 (producer T-CZ, a.s.).

These remotely configurable communication terminals periodically send defined messages including information about a rail car position. Data messages are transferred to the dispatching centre by means of the UDP protocol. GSM-Ra (Global System for Mobile Communications – Railway) transmission network is primarily used for data transfer. In the case of unavailability hereof, the data is transferred by means of classical GSM network, see Figure 1.

- Milepost / hectometres,
- Super-routes table,
- Railway stations table and,
- Definition supra-sections table.

where the key connector between individual tables is always the line definition section (LDS). Basic aspects of a railway network description are shown in Figure 2.

Figure 2: Railway network description methodology

The designed algorithms enabled the authors (Fikejz and Kavička, 2011) to design a railway network (RN) infrastructure reflecting the data structure non-oriented graph in two data layers (micro/macro layer) and three visualization layers (micro/mezo/macrolayer).

This model include data layer:

- **Data-micro**, consisting of vertices and edges,
- **Data-macro** containing super-vertices and super-edges.

The visualization layer then consists of the following layers:

- **Visual-micro**, containing the stations, mileposts representing the vertices and Data-micro layer edges,
- **Visual-mezo**, containing the stations and Data-micro layer edges,
- **Visual-macro**, containing the super-peaks and super-edges from the abstract Data-macro layer, see Figure 3.

Figure 3.
The data structure non-oriented graph was implemented directly in the ORCLE database using the ORACLE Spatial Network Data Model (Kothuriat al. 2007) technology. This technology enables the user to build a network representation, involving also the object scheme and the communication interface API. The objects scheme includes metadata and network tables. The interface contains on the server side PL/SQL API (an SDO_NET packet) for the creation, control and analysis of the database network, and a middle layer Java API (on client’s side) for the network analysis. The actual network is then defined by means of two compulsory tables:

- Node table,
- Link table.

Concept of the technology is described in Figure 4.

4.1. New layer of the model

The third data layer, the Data-mezo attempts to remove this disadvantage by means of the super-edge decomposition. The original two layers used an equal database for vertices, hectometres table, while other vertex types representing individual stations entered the new mezo layer. The formation of a new Data-mezo layer has three parts:

1. Preparation of new input data and layer formation,
2. Loading the layer with data,
3. Generating additional data.

The designed algorithm was implemented directly on the database level by means of the PL/SQL language. However, the algorithm had to be adjusted several times and to be generalized because of the occurrence of various non-standard situations, such as mileposts jumps (non-linear growth of the kilometric sequence between the mileposts) or a change in the growing kilometric sequence to the declining type or vice versa.

4.1.1. Preparation of input data and Data-mezo layer formation

Prior to the launch of the main algorithm, it was essential to prepare the input data and to create individual Data-mezo layer. The input data of the algorithm was obtained from the detail (Data-micro) and the abstract (Data-macro) layers. Within this step, a path in the Data-micro is formed for each super-edge. It is required to consequently find out the initial and ending vertex at each super-edge, located in the Data-micro layer. Dijkstra algorithm of the shortest ways was used in the next step to find the partial edges sequence for each super-edge in the Data-micro layer. One auxiliary SEQ_TUDU_ABS_LINKS_KM view and two auxiliary coupling tables SUPERNODE_BINDING and STATION_BINDING were formed in the data preparatory stage.

4.1.2. Loading the new data layer network

An algorithm for building a new Data-mezo layer in the preparatory stage was implemented. This algorithm for each found way will look up the railway stations and super-vertices located on them. The found vertices are inserted in the network including the edges between them. The main algorithm then performs the following actions:

1. Initial vertex processing – the initial vertex is tested for its repeated occurrence in the network. If the vertex is already found in the network, then it is inserted as a new one and recorded in the coupling table (table of edges).
2. Processing of track route sections – this step presents a crucial part of the algorithm serving for the railway stations inclusion as vertices into the network and forming the relevant links/edges.
a) **Check up of the vertices linking** – the check up of the correct sequence of the first vertex. In the case that the whole section is not found in the same sequence, the initial and end vertex of the first partial edge must be swapped for the correct operation of the algorithm.

b) **Finding out the route direction** – route direction detection.

c) **Finding out the route sections** – finding out all the sections located on the route in the order from the route beginning to the end. An identification number is recorded at each route section found this way, as well as the initial and final kilometre of the section.

d) **Finding out the railway stations** – for each route section in a given kilometic interval are determined the relevant railway stations. The stations are returned in the ascending or declining order according to the route direction found out in step b.

e) **Processing of the railway stations** – each railway station is tested for its occurrence in the railway network. In the case of its existence, a new vertex is formed and included in the network and in the coupling table (edges table).

f) **Processing of a new edge** – a new edge is formed in this step. The previously inserted/found vertex is selected as an initial one, and as a final vertex, it is the newly inserted/found one.

3. **Processing the final route vertex** –

   The final vertex is tested accordingly to the initial route one. Providing that the vertex is not located in the network, it is inserted as a new one and recorded in the coupling table. The last step is the formation of a new edge between the penultimate inserted/found vertex and the final route vertex; consequently, the new vertex is inserted in the generated network.

4.1.3. **Generating additional data**

After creating and filling new Data-mezo layer by the algorithm which is described above it was important to complete the network by the correct shapes (the corresponding data type form SDO_GEOMETRY) for the required data visualization. Also the relations between the initial and final vertices needed to be solved. To set up the correct geometry, an algorithm was used going through individual edges of the Data-mezo layer calculating the geometry from the GPS coordinates of the initial and final vertex of the relevant edge.

In the processing of the initial and final route vertex not yet inserted in the network, it is necessary to additionally solve the situation when a vertex not only is a super-vertex but also a railway station. In such case, it was needed to include additional information in the coupling table (edges table).

Figure 5 shows a new concept of a railway network model containing three data and four visualization layers.

![Figure 4: New concept of railway network model](image)

**Figure 4: New concept of railway network model**

5. **VISUALIZATION**

Taking in consideration a railway infrastructure model visualization, we have to solve the way of multi-dimensional data storage. In the case of using an ORACLE database with a supra-structure Spatial, a visualization tool MapViewer can be applied (Murray et al. 2010) developed in Java language. MapViewer is a J2EE service for drawing map-type documents based on spatial data (e.g. an object data type SDO_GEOMETRY) administered by means of the ORACLE Spatial. This technology helps to establish a scalable map layers with different detail level of the described information (Fikejz and Kavička, 2011). The basic concept of the MapViewer architecture is demonstrated in Figure 6.

![Figure 5: Basic concept of MapViewer service](image)

**Figure 5: Basic concept of MapViewer service**

Figure 7 shows all the three data layers. The black line presents the highest abstraction level layer Data-macro (the vertex is defined only in the rail embranchment nodes, i.e. the super-vertex).
The blue line shows the Data-micro layer (the peak of this layer is each milepost, i.e. the hectometer). The red line (the sickest line) shows the Data-mezo layer. This layer’s vertices are formed by the super-vertices and by the stations. The new Data-mezo layer also represents a good compromise between the actual railway infrastructure to be reflected in the model and the number of elements by which is the layer represented. Overall data reduction is almost 28 times higher compared with the elementary Data-micro layer. Such a data reduction than has a positive impact on the total time required for the visualization.

Figure 6: Visualization of all data layers

6. OPERATION OVER SPATIAL DATA

It is possible to use different operators and functions over the ORACLE database objects with the Spatial supra-structure. One of them is operator SDO_NN (Near Neighbor) enabling its users to determine the nearest geometry (i.e. a neighbour). In this case it is the nearest vertex or an edge of a non-oriented graph. If we dispose of a GPS-based information about the real rolling stock position, this operator can be applied for the location of the nearest vertex/edge and then perform e.g. visualization of the position into the map built by means of the MapViewer technology. Besides the rolling stock localization, we can obtain a number of other information closely relating to the rolling stock position and to the railway network infrastructure, especially:

- The node on which the rolling stock is located,
- Kilometric position according to the mileposts,
- Train occurrence in the station area,
- Direction of the rolling stock motion by means of azimuth (to/from a station),
- Distance to the nearest station,
- Name and number of the route according to the regular civil schedule,
- Relevance of the real GPS position.

7. SIMULATION OF RAILWAY TRAFFIC

As it was indicated above, the selected driving cars are equipped with the communication terminals transmitting the data that include the real GPS coordinates of the rolling stock. In the event that a car is in motion, the communication terminal sends the information containing the position data every 30 seconds.

Table 1 contains the data obtained from the communication terminals.

The designed simulation model contains the core of a discrete simulation using a standard calendar of events performed within the simulation according to their time stamp, see Figure 8.

The simulation model was consequently implemented in a demonstration application InfraRail designed for additional support to the dispatching control.

Simulation of the rolling stock traffic can be divided into two parts on the basis of:

- The real historical data (traffic emulation)
- The generated data.

Table 1: Recorded time-stamped train movements data

<table>
<thead>
<tr>
<th>Train number</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Speed</th>
<th>Azimuth</th>
<th>Train vehicle identifier</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>48701</td>
<td>50.02274</td>
<td>15.33554</td>
<td>78</td>
<td>57</td>
<td>91547123022</td>
<td>14.02.11 04:34:25</td>
</tr>
<tr>
<td>48701</td>
<td>50.02654</td>
<td>15.34246</td>
<td>80</td>
<td>43</td>
<td>91547123022</td>
<td>14.02.11 04:34:55</td>
</tr>
<tr>
<td>48701</td>
<td>50.03077</td>
<td>15.34873</td>
<td>68</td>
<td>43</td>
<td>91547123022</td>
<td>14.02.11 04:35:25</td>
</tr>
<tr>
<td>48701</td>
<td>50.03495</td>
<td>15.35505</td>
<td>61</td>
<td>45</td>
<td>91547123022</td>
<td>14.02.11 04:35:55</td>
</tr>
</tbody>
</table>
Simulation based on the generated data enables the user to induce different non-standard situations. For example, a motion of the rolling stock moving against each other can be simulated on a single track without rail embranchment. A new data model provides for a more precise detection of such situations because railway stations can be located on single-track routes without embranchment (super-edges – macro-layer); the rolling stock can be shunted to a rail siding at such a station. Figure 9 shows a running demonstration application in a situation where two cars are moving against each other on a single-track route.

8. CONCLUSION
The article deals with the design of a new layer of the Data-mezo railway network. The purpose is to complete the previous two-layer model built on the basis of the SŽDC-TU DC data analysis. The newly designed model thus contains a significantly reduced base of data elements than the detailed Data-micro layer. Despite this, the model is rather realistic in the reflection of physical railway network infrastructure. The new data model was built by means of the designed algorithm, which is described in the article in detail. The newly designed model was then implemented into the demo application InfraRail, and using a discrete simulation, the rolling stock traffic on a rail network was simulated and various non-standard situations on single-track regional routes lacking the track embranchment. The system was able to correctly detect such non-standard situations and can be used as an additional tool of dispatching control of the railway traffic.

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