Location in railway traffic: generation of a digital map for secure applications

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Abstract

This paper presents the modelling scheme for a digital map based on the node-link model. To use this map in combination with a sensor system that recognises turnouts by detection and classification of their components, these reference points must be modelled as spatially expanded objects and thus the node-link model must be extended. The digital map consists of the topological and geometrical level. Both levels are modelled using the Extended Entity-Relationship Model and hence easy implementation into a data base is given. The generation of the digital map for a small secondary line demonstrates performance of the successful modelling scheme. A location system for secure applications can be obtained by using an eddy current sensor system in combination with the proposed digital map.
Keywords: digital map, node-link model, Entity-Relationship Model.

1 Introduction

State-of-the-art digital maps are mainly used for non-secure planning functions or in combination with hardware installations along the track such as balises. The node-link model used in digital maps is not able to model reference points such as turnouts as spatially expanded objects [1]. A train-borne sensor system that is able to detect and classify turnouts cannot be used in combination with such maps. The aim of the digital map presented in this contribution is to introduce such reference points and to use classified turnouts to yield a track-selective location system.

The remainder of this paper is organised as follows: Section 2 describes the railway infrastructure and basic structures of digital maps. The data models of the topological and geometrical level are presented in Sec. 3. The resulting digital map for a secondary line is shown in Sec. 4 while Sec. 5 concludes the paper.

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2 Railway infrastructure representation

The infrastructure of a railway network is presented in different visualisation forms depending on the application, such as topological maps of the rail network for the dispatcher or geometrical maps for maintenance services. The following section describes different representation forms.

2.1 Topological representation of the railway network

The topological train station and rail network map contains not only the topological connections but it contains also further information such as signalling, turnouts, passenger platforms and level crossings. It is mainly used for dispatching purposes and by other staff members on the train station.

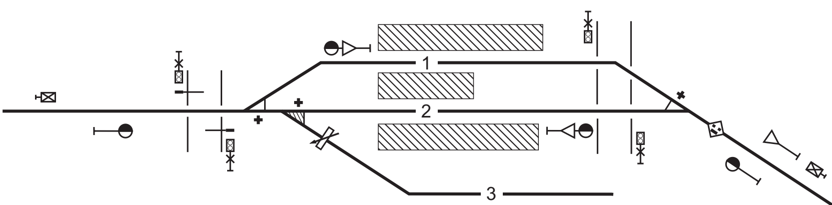

Figure 1: Topological example map of a train station and rail network.

2.2 Geometrical representation of the railway network

The geometrical representation of the railway network on a site plan is important for operational administration to organise maintenance and attendance services. On a site plan, all elements are represented geometrically correct in a defined coordinate system, e.g. Universal Transverse Mercator coordinate system. Such plans are edited with CAD programs or GIS systems and hence these data are already digitally available for use in a digital map.

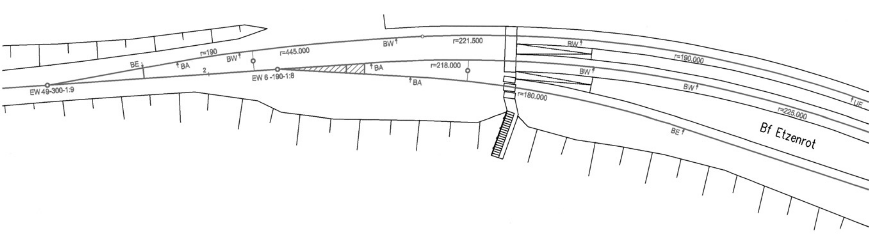

Figure 2: Example map of a geometrical train station site plan.

2.3 Basic structures of digital maps

The previous section describes different visualisation forms of the railway infrastructure with the goal to represent the infrastructure as detailed as necessary. In the following section, however, different models of digital maps are introduced. Also, various abstraction levels of the infrastructure are illustrated for different sensors and location methods.

One-dimensional maps are the most simple representation of the infrastructure with only one degree of freedom as displayed in Fig. 3. Thus a location system can be achieved by integrating the velocity and re-calibrating the system on discrete events, e.g. balises or turnouts.

Figure 3: Linear map representing the railway network.

In topological maps the infrastructure is modelled by a node-link model, where each link is a one dimensional track element without a branching point. Changing the route is only possible on nodes as shown in Fig. 4. A location system can also function by integrating over train velocity. However, attention must be paid to path changes at nodes.

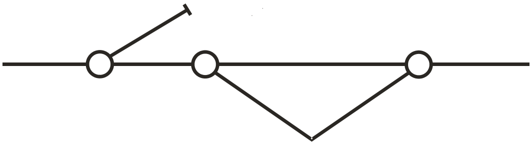

Figure 4: Topological map representing the railway network.

Basis for geometrical maps is also the node-link model, but in contrast to the topological map, all elements are displayed with their correct geometry and position. The geometrical track can be reconstructed by attaching all elements to each other. Train location is possible with all methods based on geometrical information.

Figure 5: Geometrical map representing the railway network.

3 Data models of the railway infrastructure

Digital data sets can be modelled in different ways; often set theory is used. This mathematical formalism is however difficult to understand and are often less demonstrative. To overcome this drawback more simple formalisms like the Entity-Relationship Model (ER Model) can be used. With this model, the system architecture and data flow can be easily illustrated. The extension to the ER Modell, the Extended Entity-Relationship Model (EER Model) has fixed semantics and a high expressiveness. Furthermore, it offers some constructs which do not expand the power of the model but increase its readability and manageability.

3.1 Extended Entity-Relationship Model

The EER Model is an extension to the ER-Model that was introduced by Chen [2]. Detailed definitions and descriptions of the EER Model explained on the basis of set theory are given in [3] and [4]. All fundamental terms necessary for modelling the digital map are explained in Fig. 6. Interested readers are referred to [5] and [6] for more information.

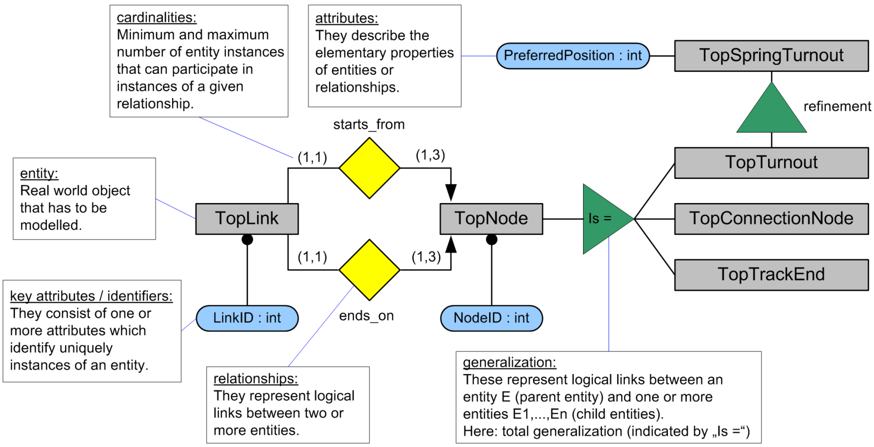

Figure 6: Introduction to the most important terms of the EER Model.

3.2 Modelling the topological level of the railway infrastructure

The topological level of the digital map reflects the railway infrastructure. Due to its net-like aspect, the concepts of graph theory can be used and thus nodes, links and the relationships between them must be defined. Figure 7 displays the node-link model of a single turnout with the associated right and left track and their continuation as suggested in [7] and [1]. The node *TopTurnout* represents a turnout as a zero-dimensional object that divides the rail track into two tracks.

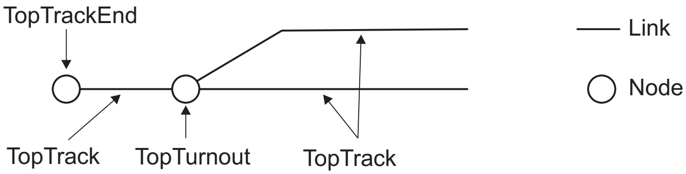

Figure 7: Representation of the topological level through the node-link model.

For a train location system that uses sensors which detect and classify turnouts [8], the node-link model of the topological level must be extended, so that turnouts are modelled as spatially expanded objects. One modelling approach is to divide the turnout into three elements: a branching point as node and both tracks as spatially expanded links. With this turnout representation, a sensor system, e.g. eddy current sensor system, can detect turnout elements, such as points, frogs or guard rails and can compare them with the turnout elements of the topological route map. An example for this extension displaying a single turnout is presented in Fig. 8.

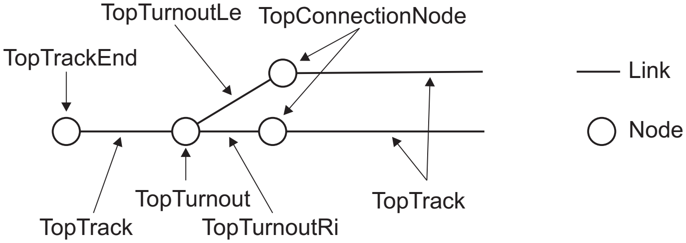

Figure 8: Extension to the topological node-link model for spatial modelling of turnouts.

3.2.1 EER Model of the topological level

By using the previously presented extension of the node-link model, an EER Model of the topological level can be designed as illustrated in Fig. 9.

3.2.2 Entity and relationship definitions of the topological EER Model

This section describes in detail the entities and relationships used in the topological EER Model shown in Fig. 9.

TopLink

The region of the digital map will be divided into an finite number of disjunctive elementary tracks. Each track is represented by the entity *TopLink* with the key attribute *LinkID*. The connection to the entity *TopNode* is modelled through the relationships *start_from* and *ends_on*.

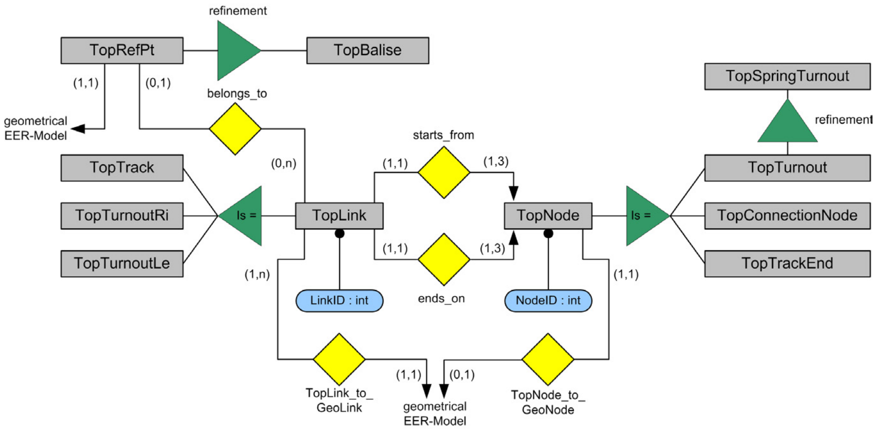

Figure 9: EER Model of the topological level.

TopTrack*, *TopTurnoutRi* and *TopTurnoutLe

The entities *TopTrack*, *TopTurnoutRi* and *TopTurnoutLe* are total generalisations of the entity *TopLink*. *TopTrack* represents the topological rail track. The entities *TopTurnoutRi* and *TopTurnoutLe* model the spatial expansion of the turnouts with the orientation, right or left, in the entity name.

The relationship *start_from* and *ends_on* between *TopLink* and *TopNode*

This relationship represents the connection between *TopLink* and *TopNode*, where each *TopLink* can be connected at minimum with one and maximum with three *TopNode* instances.

TopNode

Each *TopNode* is the juncture between one, two or three *TopLink* instances and has the key attribute *NodeID*.

TopTurnout*, *TopConnectionNode* and *TopTrackEnd

The entities *TopTurnout*, *TopConnectionNode* and *TopTrackEnd* are total generalisations of the entity *TopNode*. *TopTurnout* is connected with three, *TopConnectionNode* with two and *TopTrackEnd* with only one *TopLink* instance.

TopSpringTurnout

The entity *TopSpringTurnout* models a turnout with an predefined orientation clamped by a spring.

TopRefPt

This entity describes a reference point placed on a *TopLink* instance.

The relationship *belongs_to* between *TopLink* and *TopRefPt*

Many instances *TopRefPt* can be connected with one instance *TopLink*, but only one instance *TopLink* can be connected with each instance *TopRefPt*.

TopBalise
The entity *TopBalise* is an refinement of *TopRefPt* with additional attributes.

The relationships *TopLink_to_GeoLink* and *TopNode_to_GeoNode*
It describes the connection between the topological level and the geometrical level.

3.2.3 Consistency checks of the topological EER Model

For data verification and validation of the topological EER Model, several consistency checks must be implemented. The following section describes only a few checks to illustrate their use:

1. One instance of *TopConnectionNode* can connect min/max two instances of *TopLink*.
2. The sum over the *TopLink* instances that are connected with the relationship *start_from* and *ends_on* with a *TopNode* instance, is at minimum one and at maximum three.
3. Each instance of one entity must have a different key attribute.

And so on.

3.3 Modelling the geometrical level of the railway infrastructure

In the geometrical level, each elementary track of the railway infrastructure can be described by its geometrical position defined by start- and endpoint as well as its geometry. In this model, only three different geometrical types are distinguished: straight track, curved track and transition curved track. With the aid of the node-link model the geometrical representation of the railway infrastructure can be completely reconstructed.

Figure 10 illustrates the node-link model of a single turnout. If a link belongs to a turnout, an additional differentiation, e.g. "geometrical track turnout right" or "geometrical curved track turnout left", is done to indicate the left or right route. A detailed description of the used entities is given in Sec. 3.3.2.

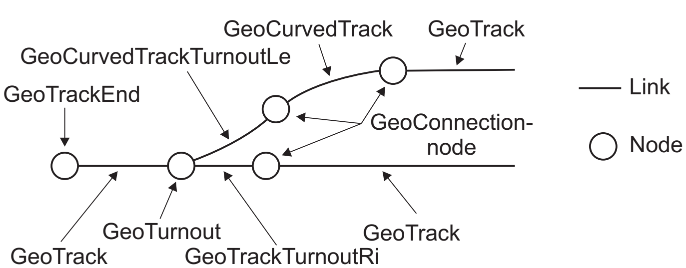

Figure 10: Representation of the geometrical level through the node-link model.

3.3.1 EER Model of the geometrical level

Applying the node-link model presented in Fig. 10 to the railway infrastructure, an EER Model for the geometrical level can be designed. For better readability, the relationships *GeoLink_to_TopLink* and *GeoNode_to_TopNode* connecting the geometrical and topological level are plotted in both EER Models.

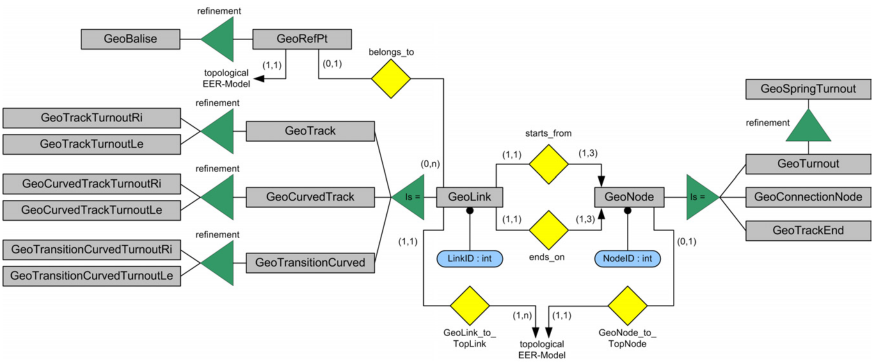

Figure 11: EER Model of the geometrical level.

3.3.2 Entity and relationship definitions of the geometrical EER Model

Due to the fact that both EER Models are constructed from similar node-link models only entities having major differences are explained in this section. Entities having minor differences are *GeoLink*, *GeoNode*, *GeoTurnout*, *GeoConnectionNode*, *GeoTrackEnd*, *GeoSpringTurnout*, *GeoRefPt* and *GeoBalise*. All used relationships having also only minor differences and thus their explanation is given in Sec. 3.2.2.

GeoTrack*, *GeoCurvedTrack* and *GeoTransitionCurved

These entities are total generalisations of the entity *GeoLink*. Additionally, each entity has further attributes describing its geometry such as radius, orientation and so on.

The refinement of the previously given entities into *GeoTrackTurnoutRi*, *GeoTrackTurnoutLe*, *GeoCurvedTrackTurnoutRi*, *GeoCurvedTrackTurnoutLe*, *GeoTransitionCurvedTurnoutRi* and *GeoTransitionCurvedTurnoutLe* are necessary to complement the possible routes over a turnout.

3.3.3 Consistency checks of the geometrical EER Model

Data verification and validation of the geometrical EER Model must be done in a similar manner as with the topological EER Model. Again, only a few checks are written down to illustrate their use:

1. Each start- and endpoint of a *GeoLink* must be on the position of a *GeoNode*
2. Each instance *GeoLink* must have a connection to an instance *TopLink*.

And so on.

3.4 Summarising the modelling of the railway infrastructure

With the introduced topological and geometrical models, a complete and consistent representation of the railway infrastructure is possible. The extension of the topological node-link model, which includes turnout components, is necessary for a train-borne location system that uses turnouts as reference points [9]. Furthermore, the combination of both levels enables the use of various location methods, where the topological and geometrical information are used to determine the train position.

4 Results

The following section describes the implementation of the digital map for the Albtalbahn (secondary line) in Germany. The input data to the digital map are gained by a surveying team and thus accuracy of only a few inches is achieved. With the use of a CAD/GIS program, the elementary tracks have been extracted and all necessary attributes are attached. After applying the consistency checks to verify the imported data, the topological and geometrical objects are exported into a MySQL data base. By using the EER Models, these objects can be easily mapped into the data base. A further advantage of using MySQL is the standardised interface into other software projects. Having all information of the railway infrastructure in the data base, the topological or both, the topological and geometrical levels can be used in location systems.

For the secondary line with a line mileage of 26 km, the implementation of the digital map results in about 1800 instances with 17500 attributes subdivided into 877 nodes and 911 links. Along this secondary line there are nine train stations and about 60 turnouts. Figure 12 shows a small cut-out of the digital map printed on a topographical map. The creation of the digital map for this secondary line by applying the presented models and exporting the objects to the data base indicates the successful modelling and implementation. Using this digital map in combination with an eddy current sensor system, a train location system for secure applications is obtained.

5 Conclusions

This contribution has proposed models for generating a digital map for secure applications. The map is subdivided into a topological and geometrical level to accomplish the use of both parts individual or together. With the use of the EER Model, the railway infrastructure and its system architecture can be modelled with fixed semantics. By extending the node-link model to represent turnouts as spatially expanded objects, it is also possible to use an eddy current system for detecting turnouts as reference points and hence achieve a location system for secure applications.

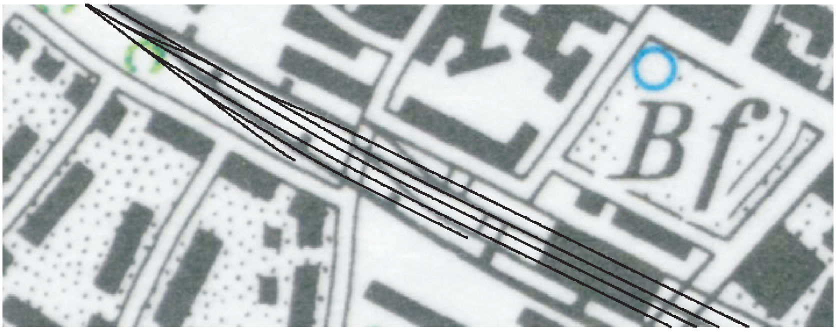

Figure 12: Visualisation of the geometrical level on a topographical map.

References

[1] Bikker, G., Klinge, K.A., Schroeder, M. & Schnieder, E., Concepts of an intelligent route atlas for localisation in guided traffic. *4th International Conference on Vehicle Navigation*, EURNAV 98: Hannover, 1998.

[2] Chen, P., The entity relationship model - towards a unified view of data. *ACM Transactions on Database Systems*, volume 1, pp. 9–36, 1976.

[3] Hohenstein, U., *Formale Semantik eines erweiterten Entity-Relationship-Modells*. Teubner: Stuttgart/Leipzig, 1993.

[4] Gogolla, M., *An Extended Entity-Relationship Model*. Springer: Berlin, 1998.

[5] Maschek, U., *Datenmodell zur Planung von Stellwerken*. Ph.D. thesis, Technische Universität Braunschweig, Institut für Eisenbahnwesen und Verkehrssicherung, 2002.

[6] Böhringer, F., Generierung einer digitalen streckenkarte zur ortung im schienengebundenen verkehr. Technical Report AV 02/05, Universität Karlsruhe (TH), Institut für Mess- und Regelungstechnik, 2005.

[7] Gielsdorf, F., *Datenmodellierung für Gleisnetze und Schaffung eines einheitlichen Raumbezugssystems*, volume Reihe C, Nr. 491. Verlag der Bayerischen Akademie der Wissenschaften: München, 1998.

[8] Geistler, A. & Böhringer, F., Detection and classification of turnouts using eddy current sensors. *Computers in Railways IX*, eds. J. Allan, R.J. Hill, C.A. Brebbia, G. Sciutto & S. Sone, WIT Press: Southampton, pp. 467–476, 2004.

[9] Geistler, A., Train location with eddy current sensors. *Computers in Railways VIII*, eds. J. Allan, R.J. Hill, C.A. Brebbia, G. Sciutto & S. Sone, WIT Press: Southampton, pp. 1053–1062, 2002.