High Speed Rail Alignment and Maintenance – Data Modelling, Data Acquisition and Analysis

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ABSTRACT

The requirement of a reliable data management of sensitive geometrical data can be outlined taking the example of rails for modern high speed trains or for municipal rail systems.

An alignment is a one dimensional representation of a roadway or a railway. The process of finding the proper alignment includes the determination of the geometrical parameters of the alignment which is essential for design and maintenance.

The geometrical information describes the alignment curve and its relation to the respective objects in space. The global spatial connection is defined by points with coordinates x, y, z. The parameters of the individual alignment parameters locally describe the geometrical properties of the elements in consideration. The relations between the global reference frame and the local geometry are defined mathematically.

In this paper the strategy of finding the correct alignment in the maintenance process for rails for high speed trains will be described. The analysis is integrated into a commercially available program system which is now the standard system for German Rail. The powerful link of the program system to the global railway GIS will be shown.

ZUSAMMENFASSUNG

In dem Beitrag wird gezeigt, dass bei Bau und Unterhalt von schienengebundenen Verkehrswegen bei Nahverkehrsbetreibern, insbesondere jedoch bei Hochgeschwindigkeitsbahnen hohe Zuverlässigkeitsforderungen an die komplexe Verwaltung der anfallenden geometrischen, topologischen und objektbezogenen Daten gestellt werden müssen. Die Trasse ist der gemeinsame Bezug dieser Daten, sie stellt eine eindimensionale Darstellung von Strassen- oder Schienenwegen dar. Der Prozess der exakten Trassenfindung als Teilaufgabe beinhaltet die Berechnung der Elementenparameter der Trasse, was von besonderer Bedeutung für Planung und Unterhalt ist.

Die geometrische Information enthält den Trassenverlauf und dessen Position in lokalem Bezug zu den räumlichen Objekten. Die Parameter der Trassierungselemente beschreiben deren geometrische Eigenschaften. Die Verbindung zwischen dem globalen geometrischen Bezugssystem und den Trassierungselementen ist repräsentiert durch Punkte auf der Trasse mit globalen Koordinaten X,Y, Z.

Der Beitrag beschäftigt sich mit den Werkzeugen zur Berechnung der tatsächlichen Trasse, beim Trassenunterhalt auch von Hochgeschwindigkeitsstrecken, welche von der DB Netz AG als Prüfprogramm zur Gewährleistung konsistenter Transaktionen eingesetzt werden.

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1. INTRODUCTION

Who drives fast should drive safely. This short formula describes best the principle of the embedded rail body technology. The ICE3-train built by SIEMENS reaches 330 km per hour. The dynamical forces, which have to be taken care of, are too big for the ordinary ballast track building technology. New techniques have to be applied, like the embedded rail or deck track body technology. Only with this technology the dynamical forces can be reduced, and its effect can be handled safely.

The track will be built in concrete in the shape of very long trough, to which the sleeper will be attached to. In order to avoid an undesired movement of the track, the troughs will be filled with concrete after the ties have got their proper position. The rails will be fastened with clamps to the ties. This building method has very high requirements of precision. In addition to the precise alignment, the settlement of the tracks in use to be tolerated is limited to 15mm.

The required accuracy for the layout and the construction calls for the development of new alignment elements in order to reduce the dynamical forces.

Like sensitive plant equipment in production a railroad track has to be maintained. It needs preventative maintenance! Improper maintenance may lead to a derailment causing extensive repairs and disruption of service. In order to design an increase of speed, or to accommodate today's longer, heavier and faster locomotives and rail cars, outdated or light rail tracks have to be rehabilitated. The above mentioned tasks require a number of specific actions:

- Emergency Track Repairs and Preventative Maintenance
- Repair Switches
- Spot Surface and Tie Replacement
- Removal and Reconstruction of Tracks
- Change of broken/defective rails
- Reconditioning of turnouts, switches and frogs by welding.

Due to the complex consistency requirements for rails and switches all tasks can only be handled properly if the large amount of interrelated geometrical, topological and descriptive data is taken care of by a suitable database management system – the Track Net Database. Its concept for German rail was designed and realized as a part of the DB GIS system(Gielsdorf , et al.1993).

2. DATA MODELLING

If we model the track network as part of the reality there will be a large number of track elements, all with interrelated geometrical properties. By abstraction of the geometrical situation a topological description can be developed and represented as a part of the graph theory (Gielsdorf 1997). For the database management we aggregate track elements to railway lines. The database structural description can be giving in the following.

The kernel data of the logical database are established by the two groups:

- Geometrical data
- Topological data.

The geometrical data include:

Information about representative track points

- Coordinates
- Heights
- Benchmark type

Information about the track elements

- Start and end point
- Element type
- Element parameter

The topological data include:

- Track junctions
- Logical information about the driving properties (switches)
- Selected lines (aggregation of alignment elements to rail way lines)
- Technical workflow information (Line ID, Track ID, switch ID, etc.).

In the following we will concentrate on the geometrical data layer.

2.1 Geometrical Data

The geometrical data consist of global coordinates of points and element parameters.

2.1.1 Point

The points are considered only with respect to its geometrical information. The point address is the key. Metrical attributes are planar coordinates and heights describing the position in the space.

2.1.2 Element

The following types of elements are allowable:

- Straight line

– Circular arc
– Clothoid
– S-polynom
– Bloss-polynom
– S and Bloss polynom with one turn.

In addition for applications of high speed magnetic suspension railways:

– Polynom 5
– Sinus – line.

2.2 Data Transfer

Typical tasks to be supported are reconstruction of a certain rail lines, the change of alignment due to rail maintenance or a the construction of a new line which has to fit to existing parts. All these tasks require the complex mutation of the data base of rail objects. In order to avoid inconsistencies the data needed for the mutation have to be extracted from the data base, modified according to the requirements of the specific task, and passed then on to the data base. For modification specific independent programs will be used, and then a database transfer table, guaranteeing consistency via suitable checks, will be prepared. In order to avoid any loss of information during the data base exchange procedure, each data set of the transfer file corresponds to a data set of the data base relational tables.

This concept has been realized in the program system VERM.ESN (Adelt, Milev, 2002) .The system has a modular structure. A specific characteristic of the program system are its features for highly precise calculations. Due to consistency requirements, the coordinates of the points have to correct to 10^{-6}m, the precision limit for tangent directions is 10^{-7}gon.

3. DATA ACQUISITION

It is of special importance to make the process of data acquisition efficient and guaranteeing consistency at the same time. This can be achieved by strict definitions of points and elements and by efficient tools for alignment calculations.

3.1 Point Acquisition

At German Rail the point keys consist of information with respect to a coordinate system type, with respect to the line number and with respect to a area code (s. Figure1). A specific coding based on key-Ids and Point-Ids allows for a higher flexibility for the identification of points. The format of the point keys is Key-ID.Point-ID (21.0450= Key 21 and point 450).

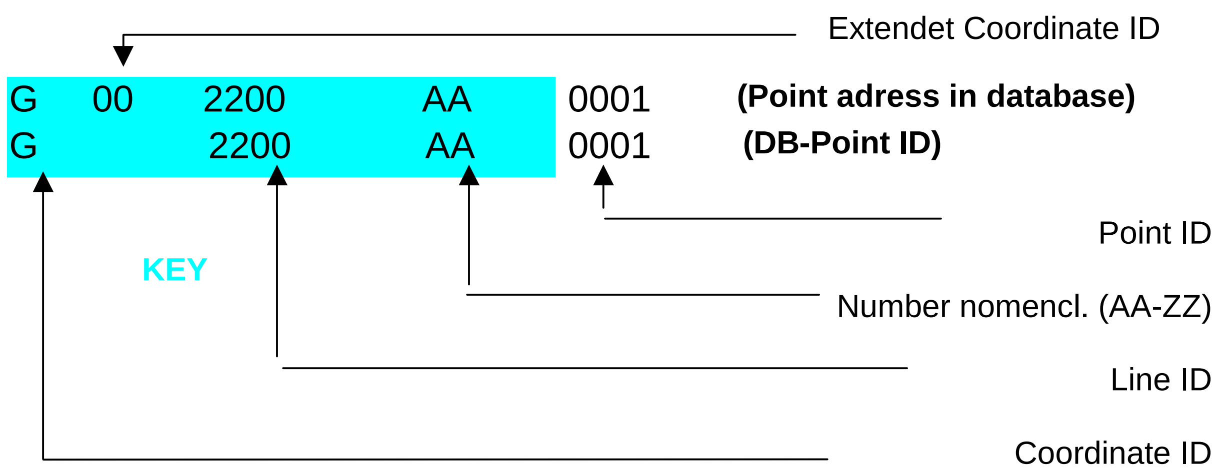

Figure 1 : Structure of a coordinate key

3.2 Definition of the Horizontal and Vertical Alignment

Due to the specific maintenance requirements the definition of rail alignments is based on the cainage alignment and the actual alignment of the right or left rail. Due to the complexity of maintenance tasks of alignment the actual task can only be carried out in sub-tasks. Afterwards the result has to be merged in a consistent way. This way requires a specific structural information. For a number of tasks a three line alignment model – cainage and right and left rail - will be sufficient, for complex data however a seven line model is required. There the vertical alignment and the superelevation is additionally required. In VER-ESN all possible alignment calculations for rails are realised in the modules track/elevation/switches.

3.3 Rail Optimisation with Additional Geometrical Conditions

The curvature property is the only criteria to describe the characteristics of a line in space. Translation and rotation of the coordinate system will not cause any changes in the curvature, the curvature is invariant. However the aim of the alignment is to find the curvature parameter in each point of the track. This can only be achieved in a stepwise manner, namely introducing elements, due to the numerous geometrical constraints the alignment has to fulfil. In addition the curvature function can not be integrated in general.

A typical task for improving an alignment in order to achieve a higher speed limit will start with the starting and ending point of the alignment and the tangent directions in these points. In addition the element sequence is required and rough values for the parameters (Figure 2). The first step of the calculation will end in a consistent sequence of parameters. Additionally specific parameters of the elements might be fixed (i.e. minimal or fixed radius in Figure 3), or compulsory points might be enforced to be on the alignment curve or with a given tolerance to the alignment curve.

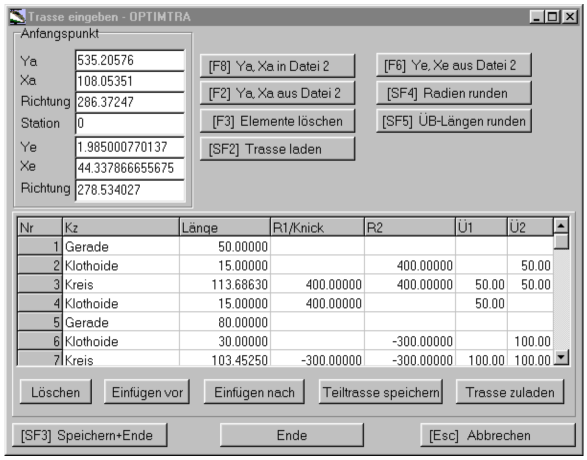

Figure 2:modification of element parameters

The optimal alignment can be visualised and compared to other optimisation results (Figure 4).

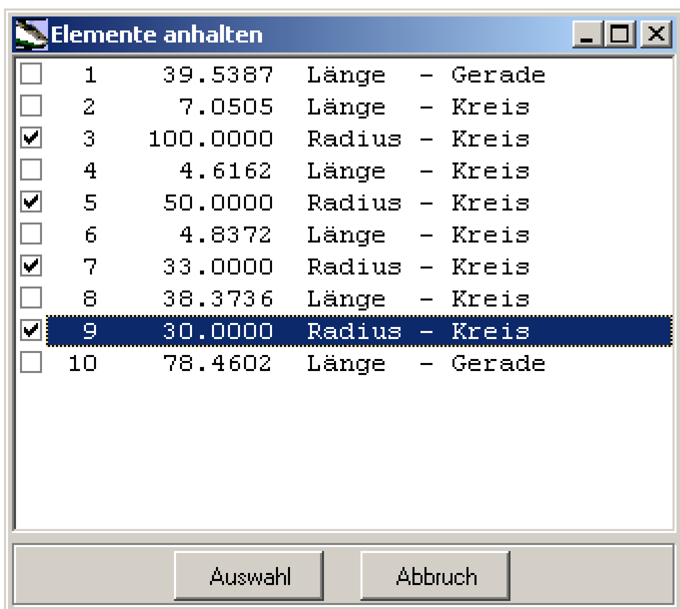

Figure 3: Fixed Parameter

Upon acceptance of the result it will be stored in a project data base.

Figure 4: visualisation of different alignments

It is a useful tool to provide the coordinates of the main points of one rail alignment calculation as initial values for the second rail.

4. DYNAMICS

For the alignment for high speed trains the dynamic behaviour plays an important role. The oscillation has to be controlled:

- Car oscillations may only be initiated when alignment elements change.
- Horizontal Alignments for which the second derivatives of the curvature exist do not initiate oscillation of the wagons.
- The amplitude of the oscillations depends on the discontinuity in second derivative of the curvature when passing the main points, if transition curves of the type Bloss line or of the clothoid have been used.

In the following the maximal grade of differentiation of the curvature diagram is given for specific element types for high speed trains, applying $q = (s - s_i)/(s_{i+1} - s_i)$.

Type 0:	Clothoid	$f(s) = q$
Type 1:	Bloss-Polynom	$f(s) = 3q^2 - 2q^3$
Type 3:	Sinus-Line	$f(s) = q - (1/2\pi)\sin(2\pi q)$
	Polynom 5	$f(s) = 10q^3 - 152q^4 + 6q^5$

5. GIS CONECTION

In order to guarantee the consistency of the track net data base the exchange of optimised lines is crucial. Only the cainage line carries global information. The other lines are stored in the data base with respect to their relative positioning to the cainage line. By storing the relative positioning the controlled redundancy and the integrity of the geometric information is enforced in the data model. Whenever global data has to be retrieved from the database it has to be calculated based on the relative positioning to the cainage line.

In the following structure will be observed:

- Cainage axis (cainage line)
- Rechtes track (i.e. +2,00 m besides cainage line)
- Right gradient
- Superposition of the right rail
- Left rail (i.e. –2,00 m besides cainage line)
- Left gradient
- Superposition of the left rail.

The assignment of lines with respect to the cainage line is shown in Figure 5.

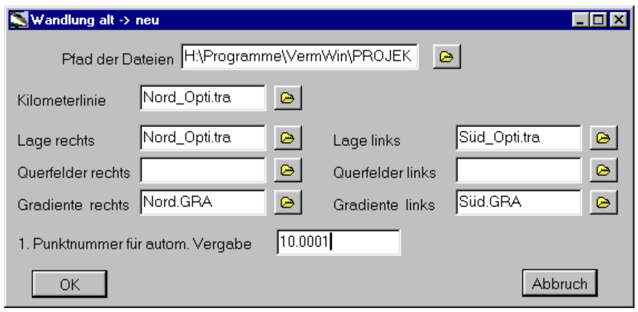

Figure 5: generation of a Track Net Data project consisting of several alignments

6. CONCLUSIONS

When maintaining complex geometric situations with long transactions and strict consistency requirements like in a rail network data base it proves necessary to reduce the absolute geometrical information to a minimum and reference the objects in a relative way. This approach proves to be powerful and reliable.

Relative geometrical information is only considered as a view of the absolute geometrical information. This is the classical view of the surveying engineer.

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BIOGRAPHICAL NOTES

Dr. Ivo Milev, born in 1963. Graduated in 1988 as Dipl.-Ing. in Surveying and Mining from Technical University of Sofia. Obtaining doctorate degree in 2000 from Technical University of Berlin. Since 1998 scientific director of technet GmbH Berlin.

Prof. Dr. Lothar Gründig, born in 1944. Graduated in 1970 as Dipl.-Ing. in Surveying and obtaining doctorate degree in 1975, both from University of Stuttgart. From 1970 to 1977, work as Assistant Professor and until 1987 senior research assistant at University of Stuttgart. Scientist at Scientific Center of IBM in Heidelberg on data bases 1984-1982 and guest scientist at Calgary University for 4 months in 1983. Since 1988 Professor of Geodesy and Adjustment Techniques at the Department of Geodesy and Geomatics, Technical University of Berlin.