Information modelling of track geometry

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Abstract. The objective of this study is to substantiate a new method for modelling the railway track geometry. The method includes a new way of path measuring and the resulting method for modelling of track geometry. There can be two variants of track measuring with the new method. The first variant includes measuring only the lengths of line segments between the marked points. The second variant includes measuring lengths, angles and coordinates. The article describes the measuring technique and the modelling mechanism and compares the new method with the traditional one. The method is applicable for measuring and modelling any large spatial object such as a pipeline or a sea craft. The advantage of the new method is the efficiency of work and calculations. The modelling can be done on site using any portable computer.

1. Introduction
Information modelling uses information field [1] as a source of information. In many cases, modelling is associated with the extraction of tacit knowledge [2]. It is necessary to transform the initial data into an information resource to obtain the knowledge [3]. The initial data is obtained from geodetic works. Thus, geodetic support becomes the basis for obtaining spatial knowledge [4–6]. The railway track geometry is spatial knowledge that is obtained from geodetic measuring and information modelling. Formally, the railway track geometry can be modelled in a Cartesian coordinate system. However, for decades it was customary to measure the arc lengths, the chords and the radii of curvatures of a track section. These parameters were specified in regulatory documents. A railway track is usually a spatial linear object that is horizontal or has a limited slope. That is why a plane coordinate system is used when modelling and measuring it. A track curve to be measured is usually divided into equal intervals. The track model can be built using the theory of difference schemes. Such measuring and modelling has a disadvantage – it does not consider the random measuring errors of the measurement vector. Another drawback is the accumulation of residual error as the number of measurements and modelled sections increases. The main method for surveying railway curves under operation is the versine measurement from the overlapping 10 and 20 m chords. The geodetic survey of the railway track and the subsequent geometric modelling are performed in order to establish the correspondence of the actual track plan to the designed one and to determine the values of alignment necessary for track adjustment. In the places where the railway turns on the track curves, the geodetic survey task includes three stages: surveying the track configuration, comparing it with the design and assessing the discrepancy (violation) of the track parameters, calculating the adjustment (alignment) of the track.
2. Average approach to the curvature radius evaluation

In accordance with the regulatory requirements, when evaluating the curvature radius, a track section is divided into approximately equal segments. The coordinates of the points at the segment ends are measured and the curvature radius for the entire track section is calculated by these points. This problem is shown in figure 1.

![Figure 1. Asymmetric track curve and simplified evaluation of its curvature radius.](image)

In figure 1, the solid line shows the real curve representing the track on which six survey marks were measured. The dotted line denotes a geometrically correct curve. The circles denote the survey marks in which the coordinates of the points are measured. Symbol $R_0$ stands for the averaged curvature radius calculated over six survey marks. Symbol $S_0$ stands for the curvature centre for the averaged radius. Such calculations are made on the assumption that the track section has an ideal geometric shape described by a second-order curve.

In reality, the track section can be asymmetric and may have a non-ideal shape. This case is demonstrated in figure 1 by the dotted line. Two curvature radii $R_1$ and $R_2$ are possible for the real curve in this section. Accordingly, there are more than one real centres of curvature $S_1$ and $S_2$. The situation may take an adverse turn if the wrong track model and geometry is chosen for correct geodetic measuring. In this case, the error is found by repeated measuring or control. But this leads to additional works on track alignment. As a result, the time and cost of works may increase due to incorrect track model construction. The labour costs increase due to the fact that in this method the coordinates of points are measured by calculation.

The second adjustment method is called track alignment. The aligned track curve takes one of the possible positions within the confidence region, which is specified by the allowances. Its characteristics may differ from the designed ones if the value of the confidence region is large. Therefore, the curve is smoothed by the method of successive approximations. However, the probability that the curve will be coincident with the designed one with this method is rather small. The most common method is the transition from the evolvent model of calculating curves to the coordinate model and the joint processing of all measurements.

3. Description of the measuring and modelling method

The proposed alternative is the method that uses the principle of moving average. The moving average is evaluated at three points, which suggests a three-part model or a triad. The triad is a research instrument [7] and the most stable figure in geometry. Its application enables to solve modelling problems in geodetic support of the railway track geometry.

The three-part model for measuring curves is proposed as an alternative to the traditional method of measuring track geometry. It can be used not only for railway tracks, but also in measuring and modelling of any engineered structures, including sea craft and aircraft. The geometric plotting of the measuring scheme for subsequent modelling is shown in figure 2.
The three-part model is formed by three spatial track points (A, B, C). Line segments $L_1, L_2, L_3$ are the overlapping chords. Two techniques of measuring and modelling are possible here. The first technique includes measuring only the lengths of the line segments while the second one includes measuring lengths, angles and coordinates. The main measuring device is either a laser ranging device or an electronic total station. The accuracy of angular measurements by a modern total station reaches 0.5–2 angular seconds. The accuracy of distance measurement is (see https://ru.wikipedia.org/wiki/%D0%A2%D0%B0%D1%85%D0%B5%D0%BE%D0%BC%D0%B5%D1%82%D1%80 - cite_note-1) up to 0.5 mm + 1 mm per km. Let us consider the variant with measuring only the lengths since it is operational and simple. The sequence of work in relation to the figure is as follows:

- install the equipment at point A and determine its coordinates in the local coordinate system;
- mark point B;
- measure the length of line segment $AB = L_1$;
- mark point E if $AE \approx L_1/2$;
- measure the length of line segment $BC = L_2$;
- mark point D if $CD \approx L_2/2$;
- measure the length of line segment $CD = l_{11}$;
- measure the length of line segment $DB = l_{12}$;
- measure the length of line segment $DE = L_3$;
- measure the length of line segment $BE = l_{21}$;
- measure the length of line segment $BA = L_1*$;
- formally, $L_1$ and $L_1*$ must be equal;
- measure $EA = l_{22}$. The arrows show the sequence of measuring.

Next, the distances $h_1, h_2, h_3$ between the chords and the arcs are calculated. Auxiliary variables $x_1, x_2, x_3$ are introduced for this purpose. Omitting detailed geometric calculations, let us present the working formulas for calculating $x_1, x_2, x_3$:

$$x_1 = \frac{1}{2} \sqrt{l_{11}^2 - l_{12}^2 + L_2^2}$$

$$x_2 = \frac{1}{2} \sqrt{l_{12}^2 - l_{21}^2 + L_3^2}$$

$$x_3 = \frac{1}{2} \sqrt{l_{21}^2 - l_{22}^2 + L_1^2}$$

Distances $h_1, h_2, h_3$ between the chords and the arcs are calculated using simple formulas:
Variables $h_1$, $h_2$, $h_3$ and $L_1$, $L_2$, $L_3$ also enable to quickly find the radii of track curvature or other track configuration and to comply with the regulatory methods of evaluating tracks by their curvature. These algorithms are fast enough and can be implemented on any portable computer. Thus, it is possible to perform calculations in the field and check the conformity of real values to the design ones. The measuring scheme is closed and, due to this, the errors can be equalized and the residual error is 1–2 mm.

4. Comparing with the prototype
Let us describe the traditional method for comparison [8]. The curve surveying is often performed by measuring the versines of the track curves. In preparation for surveying, the curve and the adjacent 30–40 m straight segments are divided into 10-meter segments or, if the curve radius of less than 400 m, into 5-meter segments along the outer track rail with a tape measure. The obtained points are marked on the inside of the rail web. The surveying is performed using a cord and a ruler. When marking the points with a tape measure, the line segments are marked off with an accuracy of about 5 mm. The disadvantage of this method is the accumulation of measurement errors from the beginning of the curve to its end. It makes the determined values of rail alignment unreliable. By the end of the given section, the root-mean-square errors reach the values of $m_x=63$ mm and $m_y=292$ mm. All of these calculations assume correct track geometry. If there is asymmetry due to large spacing between the survey marks, the errors increase.

5. Conclusion
Compared to the traditional track section measuring method, in which the coordinates are measured, in the proposed method only the lengths of the line segments are measured, which is much faster and more accurate using a laser distance meter. The scheme, in contrast to alternatives, is closed. Due to this, it is possible to perform measuring adjustments. The proposed scheme can be extended to any number of points as it is possible to calculate curves by sliding along the track. The method is also closed for a larger number of points, and the forward and backward run can equalize the errors. There is a modification of the proposed method, in which the directional angles are additionally measured and hence the coordinates for the points of survey marks are calculated. This modification is also useful, but it is significantly more time consuming in terms of operational efficiency. The method operates in the local coordinate system. A reference point must be located in the work field for binding to an external coordinate system. The measuring results obtained by using both methods have a higher accuracy than when using the satellite methods.

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