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LINEAR POSITIONING OF RAILWAY OBJECTS

Summary. The article provides an explanation of the issue related to the linear positioning of railway objects in the context of preparing site data for automatic train protection systems, such as the European Rail Traffic Management System/European Train Control System (ERTMS/ETCS). This paper identifies and compares current approaches for an object's position based on a line chainage for orientation and documentation purposes, as well as the object's position based on a track axis for the calculation of real world distances, along with providing examples of measurement systems and presenting conclusions from test runs for ERTMS/ETCS Level 2 purposes.

Keywords: railway; ERTMS; ETCS; line mileage; safety systems; railway signalling; measurement

1. INTRODUCTION

Safety is one of the essential requirements related to railway systems. To increase safety on railway lines, different automatic train protection (ATP) and automatic train operation (ATO) systems are used, depending on the architecture. These provide drivers with lineside information related to the authorization to move, enabling them to carry out safe operations in the case of human failure (ATP) or automated operations on trains (ATO). Today, in the European railway network, a unified ERTMS/ETCS can be found, which meets the European

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ATP standard. The common element found in most safety-related systems (especially ERMTS/ETCS) is granting authorization to trains to move, using lineside information and trackside descriptions about the length of authorization, gradients and other information related to the track. Above all, it is essential that site data introduced to the specific application of the system will based on trusted and real data about the trackside.

2. ERTMS/ETCS REQUIRES TRUSTED AND REAL SITE DATA

In an ERTMS/ETCS system, a radio block centre (RBC) or balise grants specific trains authorization based on information from the lineside. For an RBC, this is based on interlocking information about the locked route or the kind of authorization; for a balise, this is based on information from a lineside electronic unit encoder about a signal aspect or the state of relay contacts. A system based on this information and site data, as specified in an RBC-specific application (Level 2 or 3) or a balise telegram (in Level 1), sends information about the authorized distance (distance to the end of authority in line with the last relevant balise group passed by the train). This means that the system is based on routing from element to element. Additionally, this information contains additional track descriptions, such as static speed profiles, speed limitations, gradient profiles or track conditions, axle load speed profiles, and the change in adhesion factor [7-8].

Based on this information, an onboard ETCS system, based on its odometry information, can calculate and supervise the braking curve to the end of authority or speed limitation.

Above all, it is essential that site data used for preparing specific ERTMS/ETCS applications must be trusted and based on:

- the real-world length for each track and route
- the list of passable tracks
- navigability between tracks

3. AXIS: TWO CONCEPTS

3.1. Line axis: traditional approach

Currently, in a railway transportation system, for orientation and documentation purposes, the railway object's (e.g., signals, points) position provide linear position information represented by a metric value based on a line chainage. The line chainage is a linear referencing system with a non-normed origin. Mostly, this is based on the instructions and regulations of the competent railway administration. In Poland, within the PKP Polskie Linie Kolejowe infrastructure, instruction Id-12 sets out the rules for line mileage and includes a list of all railway lines in the network. Similar rules are in force with regard to other railway administrations in the EU [1-4].

The line chainage is based on a line axis, which is traditionally used for positioning objects on one or more parallel tracks on the line or at a station. The mileage in this context is not able to reflect real distances travelled by a train because it cannot assume different distances on two or more tracks involving curves and connectors between tracks (see Fig. 1).

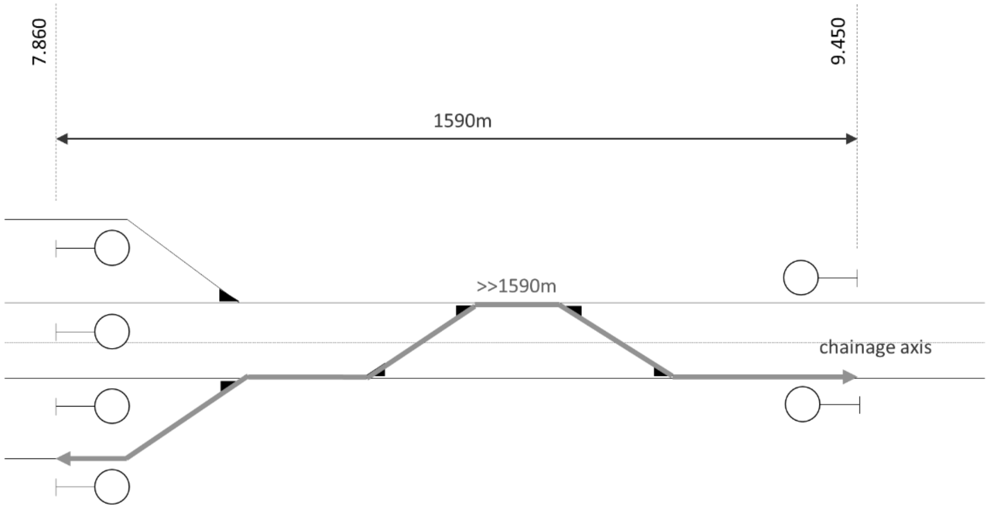

Fig. 1. Line chainage vs. real distance reflecting differences in route length

Moreover, in some cases on the line, when tracks have different longitudinal or plan profiles, chainage gaps or chainage overlengths are used (see Fig. 2).

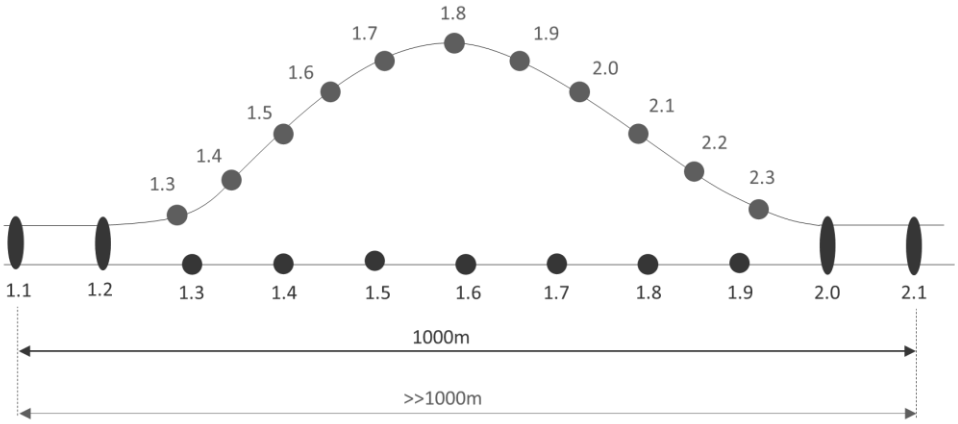

Fig. 2. Chainage gaps in the case of different plan profiles involving two tracks on one railway line

This approach is appropriate for driver orientation purposes, e.g., in the case of respective speed limitations. Information about line mileage is presented to the driver by mileage indicators. Other important information is also delivered to the driver by trackside indicators (e.g., about speed limitations, sections with lower pantograph). For documentation purposes and schematic plans with a track layout, this approach is sufficient.

3.2. Track axis: system distance

The track axis approach is based on a model that defines the topology for a network of railway tracks (node-edge model).

In this model, the node connects two or more adjacent edges. The node could be a signal, point or other infrastructure trackside object. Each edge defines its own linear referencing system used for linear positioning or railway objects related to the edge they belong to (see Fig. 3).

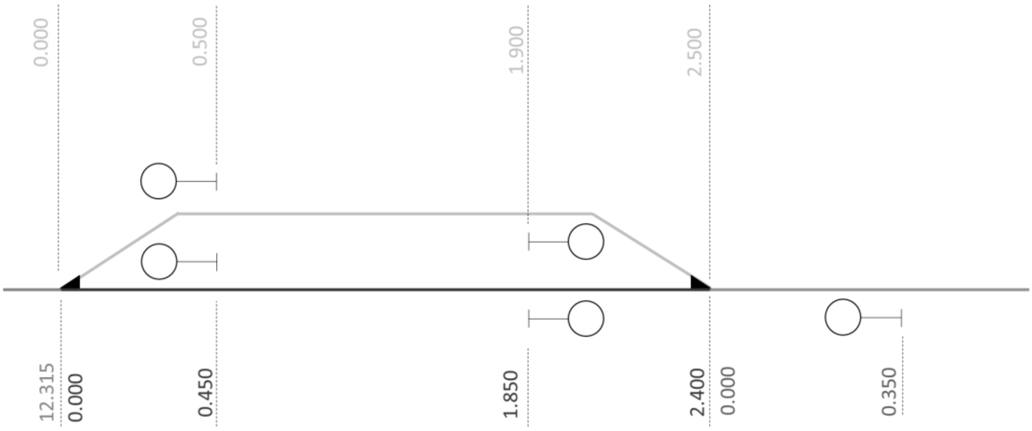

Fig. 3. Edge position of railway objects

As the measurement along the edge is based on the track axis (centre line of a pair of rails), this means that it is able to reflect the real distance travelled by a train. Based on this, it is possible to easily calculate the relative distance between neighbouring objects. For the ETCS, it could be used directly or after the calculation of the track-based distance for each track or route, which is understood as:

$$\sum \text{ length of each track segment (edge)}$$

4. METHODOLOGY OF MEASUREMENT TRACK AXIS

4.1. Measurement tool and process

For the measurement of the real distance between a neighbouring object on the track, systems are used, which can be installed on the locomotive and measure different data from different sources [5-6], namely:

- tachometer
- GPS/GNSS
- video data from high-resolution cameras installed on front and back of the locomotive
- accelerometer

Equipment is installed on the locomotive on a draisine (see Figs. 4 and 5)

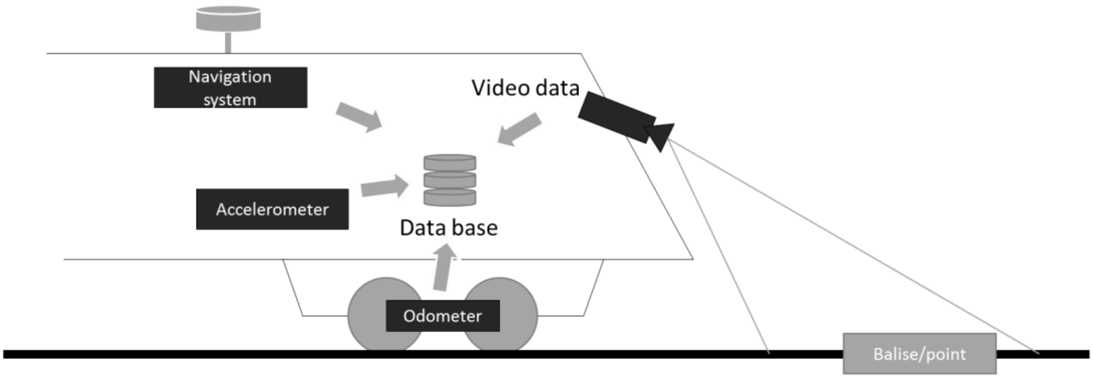

Fig. 4. Measurement tool schema

Fig. 5. Equipment installation on an EM120z draisine during a test run

This kind of system can collect a wide range of relevant information, such as track-related distances between infrastructure elements based on two independent sources, gradients, geographic position, and video data used in data processing.

Data are collected during a run on the line. Each edge between two nodes (points) must be travelled at least once.

These recorded data are used for data processing, which consists of three stages, as shown in Fig. 6.

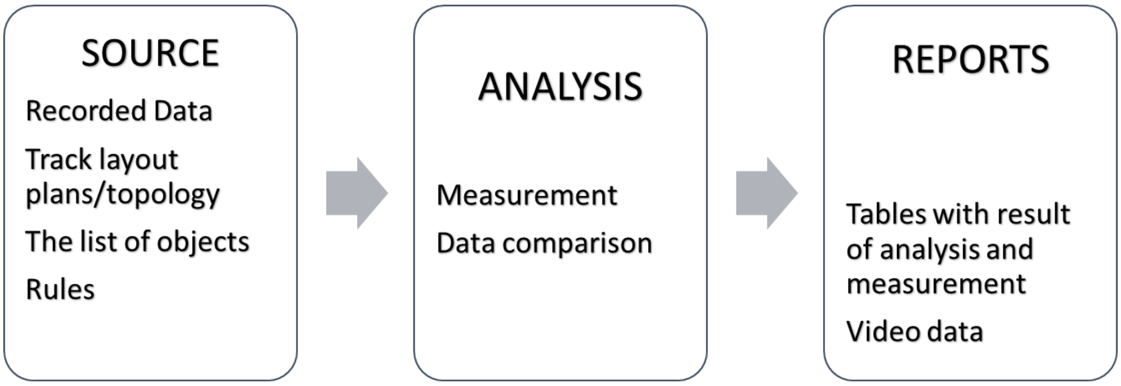

Fig. 6. Data process

Analysed data are treated as the source. It is also necessary to have track layout plans or topology in place with a list of measured objects.

Rules defining the requirements of analysis data for safety critical systems are found in [2-9]. These rules may mean that, during analysis, two independent persons are required, with analysis of the video data carried out from two sides (one from the travel direction during the measurement run and one from the opposite side).

During analysis, the measured and synchronized data are compared with the track layout plans and the list of objects being considered (these could be signals, points, balises, track joints, axle counters, indicators etc.). Additionally, when balises for the ERTMS/ETCS system are installed, it is possible to synchronize video data about the real position of balises with information recorded on the onboard Juridical Recorder for the ETCS concerning the content of particular balise (ID) in order to assess the installation and programming of particular balises.

The output report from the analysis contains at least a table with specific data, as shown in Table 1.

Tab. 1

Element list

Content	**Description**
Basic structure	Track topology
Elements	E.g., switch, signal, train detection (axle counter, isolating joint), platform (begin/end), indicator
Attributes	• Name/ID • Direction • Mileage
Measurement data	• Relative distances between trackside elements [m] • Geographic coordinates of trackside elements [latitude/longitude] • Gradients [‰]

Data can be provided in Excel format (see Fig. 7) or in one of the XML formats (e.g., RailML format) for further action.

LineName	LineSection	EdgeLevel	EdgeNumber	ToEdgeLevel	ToEdgeNumber	ElementTypeKey	ElementTypeNameExtern	ElementName	CommentExtern	RelPosition	StateCurrent	EdgeGroupPos	ref_BT_EBIToolEdge	ref_BT_ElementName	ref_BT_PlanKilometer	ref_BT-SE_RelPos_to_EdgeBegin	DELTA RelPosition on edge	DELTA PlanPosition
E65	03	R	01			J_AC	TrackJoint	nsk16_17		44,6	Verified	59153	nsk16-2_nsk17-0	nsk16_17	59154	46	-1,4	-1
E65	03	R	01			PT	SwitchPoint	nsk17		49	Verified	59158	nsk16-2_nsk17-0	nsk17	59157	49	0,0	1
E65	03	R	02			PT	SwitchPoint	nsk17		0	Verified	59158	nsk17-1_nsk53-1	nsk17	59157	0	0,0	1
E65	03	R	02			SPEED_CHA	SpeedChange	NSK_SpeedChange		0	Verified	59158	nsk17-1_nsk53-1	0	59157	0	0,0	1
E65	03	R	02			BG	BaliseGroup	02814_0		67,8	Verified	59226	nsk17-1_nsk53-1	02814_0	59224	67	0,8	2
E65	03	R	02			J_AC	TrackJoint	nsk17_t5		69,7	Verified	59228	nsk17-1_nsk53-1	nsk17_t5	59227	70	-0,3	1
E65	03	R	02			BG	BaliseGroup	02814_1		71,6	Verified	59229	nsk17-1_nsk53-1	02814_1	59228	71	0,6	1
E65	03	R	02			S_C	CombinedSignal	nskE		141,6	Verified	59299	nsk17-1_nsk53-1	nskE	59299	142	-0,4	0
E65	03	R	02			BG	BaliseGroup	02817_0		146,5	Verified	59304	nsk17-1_nsk53-1	02817_0	59304	147	-0,5	0
E65	03	R	02			BG	BaliseGroup	02847_0		871,3	Verified	60029	nsk17-1_nsk53-1	02847_0	60028	871	0,3	1
E65	03	R	02			BG	BaliseGroup	02847_1		875,1	Verified	60033	nsk17-1_nsk53-1	02847_1	60032	875	0,1	1
E65	03	R	02			S_C	CombinedSignal	nskR		879,4	Verified	60037	nsk17-1_nsk53-1	nskR	60037	880	-0,6	0
E65	03	R	02			J_AC	TrackJoint	nskt5_53		909	Verified	60067	nsk17-1_nsk53-1	nskt5_53	60066	909	0,0	1
E65	03	R	02			BG	BaliseGroup	02851_0		911,8	Verified	60070	nsk17-1_nsk53-1	02851_0	60069	912	-0,2	1
E65	03	R	02			PT	SwitchPoint	nsk53		978,5	Verified	60136	nsk17-1_nsk53-1	nsk53	60138	981	-2,5	-2
E65	03	R	03			PT	SwitchPoint	nsk53		0	Verified	60136	nsk53-0_nsk57-2	nsk53	60138	0	0,0	-2
E65	03	R	03			SPEED_CHA	SpeedChange	NSK_SpeedChange		0	Verified	60136	nsk53-0_nsk57-2	0	60138	0	0,0	-2
E65	03	R	03			PT	SwitchPoint	nsk57		38,5	Verified	60174	nsk53-0_nsk57-2	nsk57	60176	38	0,5	-2
E65	03	R	04			PT	SwitchPoint	nsk57		0	Verified	60174	nsk57-0_nsk58-2	nsk57	60176	0	0,0	-2
E65	03	R	04			SPEED_CHA	SpeedChange	NSK_SpeedChange		0	Verified	60174	nsk57-0_nsk58-2	0	60176	0	0,0	-2
E65	03	R	04			J_AC	TrackJoint	nsk57_58		3,9	Verified	60178	nsk57-0_nsk58-2	nsk57_58	60178	2	1,9	0
E65	03	R	04			PT	SwitchPoint	nsk58		39,3	Verified	60214	nsk57-0_nsk58-2	nsk58	60216	40	-0,7	-2
E65	03	R	05			PT	SwitchPoint	nsk58		0	Verified	60214	nsk58-0_nsk61-0	nsk58	60216	0	0,0	-2
E65	03	R	05			SPEED_CHA	SpeedChange	NSK_SpeedChange		0	Verified	60214	nsk58-0_nsk61-0	0	60216	0	0,0	-2
E65	03	R	05			BG	BaliseGroup	02863_0		2,4	Verified	60216	nsk58-0_nsk61-0	02863_0	60217	1	1,4	-1
E65	03	R	05			J_AC	TrackJoint	nsk58_61		4,5	Verified	60218	nsk58-0_nsk61-0	nsk58_61	60219	3	1,5	-1
E65	03	R	05			BG	BaliseGroup	02863_1		6	Verified	60220	nsk58-0_nsk61-0	02863_1	60221	5	1,0	-1
E65	03	R	05			PT	SwitchPoint	nsk61		8,7	Verified	60222	nsk58-0_nsk61-0	nsk61	60222	6	2,7	0
E65	03	R	05	B	13	PT	SwitchPoint	nsk61		0	Verified	60221	nsk61-1_nsk62-1	nsk61	60222	0	0,0	-1
E65	03	R	05	B	13	SPEED_CHA	SpeedChange	NSK_SpeedChange		0	Verified	60221	nsk61-1_nsk62-1	0	60222	0	0,0	-1
E65	03	R	05	B	13	J_AC	TrackJoint	nsk61_62		35,9	Verified	60257	nsk61-1_nsk62-1	nsk61_62	60257	35	0,9	0
E65	03	R	05	B	13	PT	SwitchPoint	nsk62		86,8	Verified	60308	nsk61-1_nsk62-1	nsk62	60309	87	-0,2	-1
E65	03	R	06			PT	SwitchPoint	nsk61		0	Verified	60222	nsk61-2_nskWk6	nsk61	60222	0	0,0	0
E65	03	R	06			SPEED_CHA	SpeedChange	NSK_SpeedChange		0	Verified	60223	nsk61-2_nskWk6	0	60222	0	0,0	1
E65	03	R	06			PT	SwitchPoint	nskWk63		51,4	Verified	60274	nsk61-2_nskWk6	nskWk63	60273	51	0,4	1
E65	03	S	01			PT	SwitchPoint	nsk17		0	Verified	59158	nsk17-2_nsk18-0	nsk17	59157	0	0,0	1
E65	03	S	01			SPEED_CHA	SpeedChange	NSK_SpeedChange		0	Verified	59158	nsk17-2_nsk18-0	0	59157	0	0,0	1
E65	03	S	01			J_AC	TrackJoint	nsk17_18		69,6	Verified	59228	nsk17-2_nsk18-0	nsk17_18	59227	70	-0,4	1
E65	03	S	01			BG	BaliseGroup	02806_0		74,4	Verified	59232	nsk17-2_nsk18-0	02806_0	59232	75	-0,6	0

Fig. 7. Example of an element list format

Processing is divided into two stages: measurement and validation

The measurement stage is mostly dedicated to the existing line and without good quality documentation (line book) for collecting the necessary data for design purposes. It can be skipped when the line is new and the geodesists' documentation is of good quality.

The validation stage is the final verification step after the installation of the trackside equipment (such as balises). In this stage, data from the design documentation are compared while being measured, with any deviations analysed. These measured data can be directly used in the specific application of a system (e.g., as an input in an electronic XML format).

5. SUMMARY

The author participated in the test run, as described in Chapter 4, involving the measurement tool and the review of the reports following analysis. The test was carried out in January 2017 in the Nasielsk area on the E65 line between the Warszawa Praga Towarowa and Świercze stations.

Due to the existing installation of balises and current design documentation for ERTMS/ETCS Level 2 purposes, the test was based on the validation stage and carried out with an EM120z draisine, equipped with an onboard ERTMS/ETCS.

Measurement of this particular area was carried out over three days.

The collected data were related to distances, gradients and the validation of the balise telegram. During the test run, some intentional bugs were inserted during the balises' installation in order to check whether the tool and the process were able to find them; this part of test was executed with a positive result.

Deviations between plans and measured data mainly occurred if one edge on two parallel tracks involved a curve. Depending on the curve, the difference was about 10-20 m in distance between the objects located on two tracks.

The above results allow us to conclude that, for specific purposes such as collecting site data for an ERTMS/ETCS Level 2 system, track axis data ensure that we have data that are relevant to the real distance travelled by the train in question.

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