openETCS “Determine Train Location” Procedure

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# openETCS “Determine Train Location” Procedure

## references

UNISIG Subset\_026 version\_3.3.0

Chapter 3.6 : Location Principles, Train Position and Train Orientation

## object

This document specifies how the position of a train is determined on a one-dimensional track. The intension is not to repeat the contents as specified in Subset 026, chapter 3.6, but to reduce the complexity of the train position calculation to an algorithm not more complex than the problem itself.

Therefore, the following are the essentials of train position calculation.

# Basic Inaccuracy Calculations

## Addition of independent Tolerance Values

is a triple of a nominal value with a minus tolerance (negative) and a plus tolerance (positive) so that

.

The addition of 2 such values leads to

.

For the addition of more values in general:

This equation in a different notation

... which means that the tolerances of the sum equals the sum of the tolerances.

This applies only, if each of the values has its own tolerances independent from each other.

## Subtraction of Tolerance Values

The substraction of 2 tolerance affected values leads to

The minimum and maximum tolerance limits are generated by the suitable combination of min/max of values 1 and 2:

## Distances between linked Elements (BaliseGroups, ...)

The rules of chapter 2.1 and 2.2 refer to distances between elements along the track in general.

But for distances between linked elements, there is an important difference: Linked elements like balises are – as specified in Subset 026-3.6 – thought to be positioned on an absolutely correct nominal position with a known min/max accuracy around the nominal position.

Therefore, the tolerances of 2 and more linking distances between balises must not be summed up as calculated in chapter 2.1. Instead, only the positioning inaccuracies of the first and the last balise group in a chain of linking distances is relevant for distance calculation:

This equation is also suitable, if the LRBGONB changes between linked balise groups, and balise groups distances have to be recalculated as references to the new LRBGONB .

# Sources of Location Inaccuracies

Location inaccuracies are caused by a couple of sources. Since this document relates on the determination of the train position from the train perspective, only those causes that can be seen on the train are of relevance.

As stated in chapt. 2.3, it has to be differentiated between inaccuracies caused by independent effects and “linked” inaccuracies.

## Sources of independent Inaccuracies

The effects of inaccuracy – as understood here – are independent if they are not correlated or related to each other, so that the rules from chapter 2.1 apply.

Such independent sources and effects are

* Odometry
* Distance between train front end and balise antenna = dbaliseantenna-frontend
* Distance between train front and rear end = dfrontend-rearend
* Inaccuracy of balise group center detection on the train = dbg\_centerdetection
* Time delays between the occurrence of an event and its recognition by the OBU:   
  ddelay = tdelay \* vactual with  
  ddelay = the distance passed during the time delay at the actual speed,  
  tdelay = the time delay.  
  vactual = the actual average speed during the time delay interval
* Time measurement inaccuracies on the train:  
  dtime\_inaccuracy = ttime\_inaccuracy \* vactual with   
  dtime\_inaccuracy = distance inaccuracy caused by time measurement inaccuracy,  
  ttime\_inaccuracy = the time measurement inaccuracy.  
  vactual = the actual average speed during the time delay interval

For example, the location determination accuracy of unlinked balise groups is affected by these causes.

## Location Inaccuracies between Linked Elements

The locations of linked elements are determined by calculating the distances to linked reference balise groups according to chapter 2.3.

This refers to all distances between linked elements without any linking hole in between like

* Distances between linked balise groups
* ~~Distances between linked continuous and non-continuous profile data~~

# Determination of the Train Location

The goal of this chapter is to design a procedure for determining the train location; it bases upon Subset 026, Chapter 3.6, but exceeds it with a practical approach.

## The OBU Coordinate System

As a measure for train location, the OBU makes up its own the one-dimensional coordinate system. It is private and only known by the OBU.

The origin of the OBU coordinate system can be chosen arbitrarily; to set it at system start up is a suitable choice.

The orientation of the coordinate system equals to the actual train orientation.

The train starts at location 0 at system start up.

The OBU coordinate system is preserved as long as the train is in operation; a reset of the coordinate system is permitted only when the OBU is restarted or all location and position information can be deleted.

## Location of Track Elements

All track elements – linked as well as unlinked – are mapped to their appropriate location on the OBU coordinate system.

The location of these track elements on the OBU coordinate system is determined as follows:

* After system start, there typically is no linking information available. The location of the first balise group is then determined mainly by the odometry and the effects of chapter 3.1.
* The location of unlinked balise groups and track elements (distances given with reference to balise groups) (s. 3.1) or as long as no linking information is available is calculated with the rules of 2.1 and 2.2.
* The location of track elements (location known as the nominal distance from the balise group) with no linking holes in between is calculated via the addition of differences according to 2.3 in relation to the appropriate reference balise group.   
  The location of the first linked (reference) balise group results cannot be determined by linking distances and therefore has to assigned according to 2.1 and 2.2.
* ~~When the new location information is received from track that affects known track elements, their location at the OBU coordinate system has to be recalculated. To provide this, the originally information received from track should be stored as properties of the track elements.~~

In summary, all track elements are mapped to their location with the appropriate tolerances on the OBU coordinate system.

## Train Position = Location of the Train

The actual position of the train on the OBU coordinate system has to be calculated with the same methods as characterized in 4.2.

* It is a combination of summing up unlinked distances according to 2.1 and linked distances according to 2.3.
* The position of the train directly above a linked balise group is set to the location of this balise group plus the applicable inaccuracies from 3.1. In this case,
  + The train “jumps” to the location of the balise group.
  + The odometry is normalized with the balise group location (see Subset 026-3.6, fig. 13a).
* The normalization of the odometry with the balise group location means practically
  + To store the odometry value with its inaccuracies at the position of the balise group,
  + To compensate the distance and accuracy data received from the odometry during the following train movements with the stored odometry values.

## Train Position Reporting to the RBC

The train has to send position reports to the RBC regularly. These position reports inform the RBC about the actual train position, i. E. the actual distance of the train to the actual last relevant balise group LRBGONB.

With the OBU coordinate system the distance is quite simple:  
By subtracting the location of the LRBGONB from the actual train position by applying the rules of 2.2.

# Calculation of the Train Position

This chapter elaborates the train position and the distance to track elements in front of the train to concrete calculations.

## The Train Position at OBU System Start

At start of the OBU system, the actual train position in the OBU coordinate system as well as the odometry output are presumed o be 0.

ptrain (t = System Start) = lodometry (t = System Start) = 0

## The Train Position at the first Balise Group

Irrespective if the first balise group found after system start is linked or unlinked, the train moves towards the first balise group with the odometry as the only location source. The position of the train at the first balise group and the location of the first balise group in the OBU coordinate system is sampled from the odometry after detecting the balise group. The time delay and inaccuracy between the balise group detection and the odometry sample results in

ptrain (@firstBaliseGroup) + ddelay + dtime\_inaccuracy = lodometry(@firstBaliseGroup) + dbg\_centerdetection

ptrain (@firstBaliseGroup) = lodometry(@firstBaliseGroup) + dbg\_centerdetection - ddelay - dtime\_inaccuracy

The location of the first balise group in the OBU coordinate system is

loc(@firstBaliseGroup) = ptrain (@firstBaliseGroup)

The front-end position of the train:

pFrontend (@firstBaliseGroup) = ptrain (@firstBaliseGroup) + dbaliseantenna-frontend

The inaccuracy of pFrontend of is the sum of the combined inaccuracies of the several sources:

## The Train Position behind the first Balise Group

After passing the first balise group and as long as no other location reference is found, the train position is determined by the odometry in relationship to the first balise group.

The equation can be generalized for any referenced balise group with a known location:

## From a Reference BG to a linked Balise Group or Profile Element)

A linked balise group is announced with a distance dlink to a reference balise group. The reference balise group can be the first balise group or any other balise group with a known location. On trackside, the location of the linked balise group is

The inaccuracies of dlink are calculated from the D\_LINK and Q\_LOCACC parameters received onboard according to Chapt. 2.3 (real distance between both balise groups):

It’s important to understand, that dlink covers the inaccuracies on track side only. On the train, the distances measured between both balise groups are in addition affected by the detection impact of dbg\_centerdetection , ddelay and dtime\_inaccuracy for both balise groups.

The train runs towards the linked balise group by using the odometry. Therefore, the odometry inaccuracy for the distance dlink,real has to be taken into account too.

If the odometry inaccuracy is much less than the measured distance, all inaccuracies can be accumulated. After recognition of the reference balise group, the train expects the linked balise group at

is the odometry inaccuracy after a travel distance .

The train then expects to find the linked balise group behind the reference balise group after a travelling distance measured by odometry (expectation window):

On the train, the linked balise is expected in the interval to , behind the reference balise group, measured by odometry.

This relationship is in general valid

* between any two linked balise groups,
* from a balise group to corresponding (i. e. linked) continuous and non-continuous profile data, (profile data don’t have any inaccuracies)

as long as the distances between both are measured by odometry.

While passing a linked balise group, the train position is corrected to the location of the (previously by linking announced) passed balise group as specified in chapter 4.3. Therefore, the preceding equations will be typically applied only for the last passed balise group.

## Odometry Model and Train Position Correction

The odometry subsystem is assumed to provide their own inaccuracies with the nominal, minimum and maximum travelled distance since system start as inputs to the OBU software:

* = nominal value
* = minimum value
* = maximum value

At system start all values are 0.

= = = 0

The distance between two odometry locations is presumed to

The original outputs of the odometry must never be manipulated by the OBU software. Instead, corrections of locations or positions required for the train location determination, have to been made to derived variables by the OBU software.

When the train has passed a known location locref and afterward determines it’s position with reference to locref with the odometry, the calculation is as follows:

and are the odometry values at and at the train position .

This equation eliminates the accumulated odometry inaccuracies (chapt. 4.3) by replacing them at : then equals , and

When the train – after a trip from a reference balise group at – detects a linked balise group at , the train position has to be corrected to the known location :

is the correction value (with the appropriate inaccuracies that must be applied to the actual train position when detecting the linked balise group at . It makes up the train jump and compensation value mentioned in chapt. 4.3.

Has to be modified to the center of the common interval.

## Location of unlinked Balise Groups

When a train detects an unlinked balise group behind a linked LRBG, the unlinked balise is located by using the odometry at:

Let’s assume, that the train afterwards reaches a balise group linked to the LRBG:

is the train position correction at the linked BG. Then, the location of the unlinked balise group can be determined also with reference to the linked balise group to

Until the train has not reached the linked BG only can be calculated. But when the linked BG has been passed, and compete for the best accuracy. The most accurate value has to be taken for further calculations:

This leads to a correction of

and has to be applied to all elements (like temporary speed restrictions) linked to the unlinked balise group.

After passing the unlinked balise group, the distance between the actual train position and the unlinked balise group in the rear, measured by odometry, is

and after passing the following linked balise group and applying

In this way the (usually growing) distance between the train and the unlinked balise group can be determined by using a combination of odometry and linked balise groups in between.

## Distance to Track Elements referred to unlinked Balise Groups

When the train runs along a track equipped with linked balise groups and passed an unlinked balise group in between, it has to range from the unlinked balise group to the corresponding track elements announced by the unlinked balise group. These track elements are linked to the unlinked balise group. The train has to calculate its actual distance to them during the trip.

The location of an unlinked balise group with reference to a linked balise group is calculated as in chapter 5.6.

The distance between the unlinked balise group and a track element announced by and so linked with the unlinked balise group is given by the appropriate linking distance (see 5.4):

The distance from the actual train position to the track element in front is then

and with the linking distance to the announcing unlinked balise group:

- )

The second term is the distance from the unlinked balise group to the actual train position as calculated in 5.6:

can be substituted by the calculation in 5.6. After passing the unlinked balise group announcing the track element, the distance from the actual train position – measured to the track element in front is

and after passing a following linked balise group and applying

In this way the (usually decreasing) distance between the train and the track element in front can be determined by using a combination of odometry and linked balise groups in between. Typically, the latest passed linked balise group should be used to minimize the inaccuracies caused by the odometry.