Matching Train Position Calculation Algorithms

This documents matches the train position calculations from "summary calculation of train position and coordinate system.pdf" (Jan Welvaarts) with those in DetermineTrainLocationProcedures (Uwe Steinke).

The left column in the following table lists the content of "summary calculation of train position and coordinate system.pdf", the right column links them with the corresponding calculations in in DetermineTrainLocationProcedures. Reference in double brackets [[…]] reference the appropriate calculation equations in in DetermineTrainLocationProcedures.

"summary calculation of train position and coordinate system.pdf"	Matches with DetermineTrainLocationProcedures
TRAIN POSITION IN REFERENCE TO THE DETECTED POSITION OF THE LRBG As agreed during the "Localisation workshop" of 28-10-14, the "Train Position" shall be known as a distance from the detected position of the LRBG. This can either be done by resetting the Train Position to "0" or by storing the value of the Train Position at the data structure for the LRBG. As this is an open point (to be decided) below TP_LRBG will be used for the detected position of the LRBG.	Jan: "The detected position is the position where the train finds the BG. This position differs maximum one meter (the detection accuracy) from the real location": $$TP\_LRBG = nominalLocation(LRBG) + \overline{centerDetectionInacc_{LRBG}}$$ Uwe: $$\overline{loc_{passedBG}} = nominalLocation(\overline{loc_{passedBG \, [[5.5]]}}) \qquad [[5.8]]$$ $$+ \overline{qLocAcc_{passedBG}}$$ $$+ \overline{centerDetectionInacc_{passedBG}}$$
Thus the actual Train Position (TP) = TP_LRBG + Dodo_LRBG: • TPmin = TP_LRBG + Dodomin_LRBG • TPmax = TP_LRBG + Dodomax_LRBG where Dodo_LRBG is the distance driven from the detected position of the LRBG • Dodomin_LRBG is the minimum distance driven from the detected position of the LRBG Dodomax_LRBG is the maximum distance driven from the detected position of the LRBG	$$\overline{pos_{train}} = \overline{loc_{passedBG}} + \overline{d_{(passedBG \rightarrow currentTrainpos),odo}} \qquad [[5.17]]$$

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DISTANCE FROM THE TRAIN TO A TRACK SIDE ELEMENT The location of a track-side element is given as a distance from the nominal position of a BG (called "original reference BG", ORBG) as an exact value (D_ORBG). So now the minimum and maximum distance between the train (antenna position) and the location of a track side element (Dmin_ant_loc and Dmax_ant_loc) are given by: • Dmin_ant_loc = D_ORBG – TPmax – TP_LRBG – the maximum distance from the nominal position of the ORBG to the detected position of the LRBG. • Dmax_ant_loc = D_ORBG – TPmin – TP_LRBG – the minimum distance from the nominal position of the ORBG to the detected position of the LRBG. *{TP_LRBG can be eliminated from the formula above as TPmax and TPmin can both be written as* *TP_LRBG + ……….}* To be able to calculate those distances the minimum and maximum distance from the nominal position of any passed BG to the detected position of the LRBG shall be determined.	The location of an announced track side element with reference to a BG (ORBG = "passedBG") is $$\overline{loc_{Element}} = \overline{loc_{ORBG}} + \sum_{i=ORBG}^{n} \left(\overline{d_{link}(i)} \right) + \overline{qLocAcc_{BG(n)}} \qquad [[5.9]]$$ $$+\ \overline{centerDetectionInacc_{BG(n)}}$$ For track side elements other than BGs is qLocAcc = centerDetectionInacc = 0. The distance between the train and the location of a track side element is according to [[5.17]] and [[5.9]]: $$\overline{d_{\mathbf{train \rightarrow Element}}} = \overline{loc_{Element}} - \overline{pos_{\mathbf{train}}} \qquad [[5.17]]$$
DEFINITION OF VARIABLES	

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As the location of track side elements is given in reference to the nominal position of an already passed BG, the minimum and maximum distance from the nominal position of each BG "i" to the detected position of the LRBG shall be calculated: Dmin_i_LRBGdet and Dmax_i_LRBGdet It is decided to do this in an iterative way, i.e. in a backward calculation starting with the LRBG, for every BG the additional distance from it's nominal position to the detected location of the LRBG is calculated. Thus the difference in the distance from the nominal position of a BG "i-1" (the first BG in rear of BG "i") to the detected position of the LRBG, shall be calculated as a function of the distance between the nominal position of BG "i" and the detected position of the LRBG. The on-board only knows the detected position of BG's. The distance from the nominal to the detected position is only known as a tolerance from the detected location: • Dmin_nom-det_i *{minimum distance from nominal to detected in the driving direction}* • Dmax_nom-det_i *{maximum distance from nominal to detected in the driving direction}*	
Variables needed in the calculation: • Dlink_i-1_i: linking distance between the nominal positions of BG "i-1" and BG "i" • Dodomin_i-1_i: minimum distance driven between detected positions of "i-1" and "i" (calculated from stored raw odometer data) • Dodomax_i-1_i: maximum distance driven between detected positions of "i-1" and "i"(calculated from stored raw odometer data) • Dtol_i: installation plus detection tolerance of BG "i" thus Dtol_i = Q_LOCACC + detection inaccuracies. (typically Dtol_i = Q_LOCACC_i + 1 m)	Corresponding variables used in DetermineTrainLocationProcedures: • $\overline{d_{link}(i)}$ • Distance measured by odometry in vector notation: $\overline{d_{BG(i-1) \to BG(i),odo}}$ [[5.12]] • $\overline{qLocAcc_{BG(i)}} + \overline{centerDetectionInacc_{BG(i)}}$

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CALCULATING THE MINIMUM AND MAXIMUM DISTANCE BETWEEN THE DETECTED AND **NOMINAL POSITION OF A BG, AT THE MOMENT THE BG IS DETECTED**	
The distance between nominal and the detected position of a BG is never more than Dtol_i, thus: • Dmin_nom-det_i ≥ -Dtol_i • Dmax_nom-det_i ≤ Dtol_i	$$\overline{loc_{passedBG}} = nominalLocation(\overline{loc_{passedBG[[5.5]]}})$$ $$+ \overline{qLocAcc_{passedBG}}$$ $$+ \overline{centerDetectionInacc_{passedBG}}$$ [[5.8]]
If the linking distance is available, in some cases the minimum and/or maximum distance between the nominal and the detected position, is known more exact from the distance between nominal and detected for the previous BG, the linking distance and the distance travelled. Using the variables defined before this can mathematically be described as: • Dmin_nom-det_i ≥ Dmin_nom-det_i-1 + Dodomin_i-1_i – Dlink_i-1_i • Dmax_nom-det_i ≤ Dmin_nom-det_i-1 + Dodomax_i-1_i – Dlink_i-1_i Thus: • Dmin_nom-det_i = max(-Dtol_i , Dmin_nom-det_i-1 + Dodomin_i-1_i – Dlink_i-1_i) • Dmax_nom-det_i = min(Dtol_i , Dmin_nom-det_i-1 + Dodomax_i-1_i – Dlink_i-1_i) The minimum and maximum distance between the nominal and detected position of the BG shall be stored for later calculations.	$$\overline{loc_{BG(k)}} = intersectionOf(\overline{loc_{BG(k),linking}} \parallel \overline{loc_{BG(k),odo}})$$ [[5.13]] The min/max distances between nominal and detected are part of the $\overline{loc_{BG(k)}}$ vector.
CALCULATION OF THE MINIMUM AND MAXIMUM DISTANCE FROM THE NOMINAL POSITION OF A LINKED BG TO THE DETECTED POSITION OF THE LRBG	

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Distance from the nominal position of the LRBG to the detected position of the LRBG In case BG "i" is the LRBG then the distance from the nominal position of the BG to the detected position of the LRBG is equal to the distance from the nominal postion of the BG to the detected position of the BG itself: $\qquad$ Dmin_i_LRBGdet = Dmin_nom-det_i $\qquad$ Dmax_i_LRBGdet = Dmax_nom-det_i (with "i" is the LRBG)	

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Distance from the nominal position of the first linked BG in rear of the LRBG to the detected position of the LRBG The distance from the nominal position of first linked BG ("i-1") in rear of the LRBG to the detected position of the LRBG can be calculated using 1. Linking: the linking distance (if available) from BG "i-1" to the LRBG and the min and max distance between the nominal and detected position of the LRBG, and/or 2. Measured distance: the measured distance from the detected position of BG "i-1" to the detected position of the LRBG and the min and max distance between the nominal and detected position of BG "i-1". In formulas: criterion 1 (if the linking distance is known), with i is the LRBG: • Dmin_i-1_LRBGdet ≥ Dlink_i-1_LRBG + Dmin_i_LRBGdet • Dmax_i-1_LRBGdet ≤ Dlink_i-1_LRBG + Dmax_i_LRBGdet criterion 2 (using measured distance): • Dmin_i-1_LRBGdet ≥ Dodomin_i-1_LRBG + Dmin_nom-det_i-1 • Dmax_i-1_LRBGdet ≤ Dodomax_i-1_LRBG + Dmax_nom-det_i-1 As both criteria are always valid Dmin_i-1_LRBGdet shall be calculated as the maximum and Dmax_i-1_LRBGdet as the minimum of the two criteria.	$$\overline{loc_{BG(k)}} = \left(\overline{loc_{passedBG}} - \sum_{i=k+2}^{passedBG} \left(\overline{d_{link}(i)} \right) \right) \qquad [[5.11]]$$ $$- \left(\overline{d_{link}(k+1)} \right) + \overline{qLocAcc_{BG(k)}}$$ $$+ \overline{centerDetectionInacc_{BG(k)}}$$ $$\overline{loc_{BG(k),odo}} = \overline{loc_{BG(k+1)}} - \overline{d_{BG(k)\to BG(k+1),odo}} \qquad [[5.12]]$$ $$\overline{loc_{BG(k)}} = intersectionOf\left(\overline{loc_{BG(k),linking}} \, \| \, \overline{loc_{BG(k),odo}} \right) \qquad [[5.13]]$$

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Distance from the nominal position of any (but not the first) linked BG in rear of the LRBG to the detected position of the LRBG The distance from the nominal position of any linked BG ("i-n") in rear of the LRBG (except the first BG in rear of the LRBG) to the detected position of the LRBG can be calculated using: 1. Linking, as far as available 2. Measured distance to the LRBG criterion 1 (if the linking distance is known), with i is the LRBG: The way the distance from the nominal position of any linked BG ("i -n") to the detected position of the LRBG is calculated (using linking information) depends on the situation. A. If the linking distance to the next BG ("i-n+1") is available: • Dmin_i-n_LRBGdet ≥ Dmin_i-n+1_LRBGdet + Dlink_i-n_i-n+1 • Dmax_i-n_LRBGdet ≤ Dmax_i-n+1_LRBGdet + Dlink_i-n_i-n+1	$$\overline{loc_{BG(k)}} = \left(\overline{loc_{passedBG}} - \sum_{i=k+2}^{passedBG} \left(\overline{d_{link}(i)} \right) \right) \\ - \left(\overline{d_{link}(k+1)} \right) + \overline{qLocAcc_{BG(k)}} \\ + \overline{centerDetectionInacc_{BG(k)}}$$ [[5.11]]
B. If the linking distance to the next BG ("i-n+1") is not available and the linking distance between BG "i-n+1" and BG "i-n+1" is known: • Dmin_i-n_LRBGdet ≥ Dmin_i-n+1_LRBGdet + Dodomin_ i-n_i-n+1 + Dmin_nom-det_i-n – Dmax_nom-det_i-n+1 • Dmax_i-n_LRBGdet ≤ Dmax_i-n+1_LRBGdet + Dodomax_ i-n_i-n+1 + Dmax_nom-det_i-n – Dmin_nom-det_i-n+1	Choose [[5.11]] for the sections with linking information available and $$\overline{loc_{BG(k),odo}} = \overline{loc_{BG(k+1)}} - \overline{d_{BG(k)\to BG(k+1),odo}}$$ [[5.12]] … for the sections without known linking distances.
C. If the linking distance to the next BG ("i-n+1") is not available and the linking distance between BG "i-n+1" and BG "i-n+1" is not known: • Dmin_i-n_LRBGdet ≥ Dmin_i-n+1_LRBGdet + Dodomin_ i-n_i-n+1 + Dmin_nom-det_i-n – Dmin_nom-det_i-n+1 • Dmax_i-n_LRBGdet ≤ Dmax_i-n+1_LRBGdet + Dodomax_ i-n_i-n+1 + Dmax_nom-det_i-n – Dmax_nom-det_i-n+1	Choose [[5.11]] for the sections with linking information available and $$\overline{loc_{BG(k),odo}} = \overline{loc_{BG(k+1)}} - \overline{d_{BG(k)\to BG(k+1),odo}}$$ [[5.12]] … for the sections without known linking distances.

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criterion 2 (using measured distance): For all three situations (A, B and C) the minimum and maximum distance to the detected position of the LRBG are also limited by the measured distance to the LRBG: • Dmin_i-n_LRBGdet ≥ Dodomin_i-n_LRBG + Dmin_nom-det_i-n • Dmax_i-n_LRBGdet ≤ Dodomax_i-n_LRBG + Dmax_nom-det_i-n As both criteria are always valid Dmin_i-n_LRBGdet shall be calculated as the maximum and Dmax_i-n_LRBGdet as the minimum of the two criteria.	$$\overline{loc_{BG(k)}} = intersectionOf\ (\overline{loc_{BG(k),linking}}\ \|\ \overline{loc_{BG(k),odo}}\ )\qquad [[5.13]]$$
CALCULATION OF THE MINIMUM AND MAXIMUM DISTANCE FROM THE NOMINAL POSITION OF AN UNLINKED BG AND THE DETECTED POSITION OF THE LRBG	
Unlinked BG in advance of the LRBG (BG "i" is the LRBG, BG "i+1" is the unlinked BG): • Dmin_i+1_LRBGdet = - Dodomin_i_i+1 + Dmin_nom-det_i+1 • Dmax_i+1_LRBGdet = - Dodomax_i_i+1 + Dmax_nom-det_i+1	The location of an "unlinked" BG with reference to the previous "linked" BG astern is $$\overline{loc_{"unlinked"BG(astern)}} = \qquad\qquad [[5.14]]$$ $$\overline{loc_{"linked"BG,astern} + d_{("linked"BG,astern\to"unlinked"BG),odo}}\ )$$
Unlinked BG in rear of the LRBG (BG "i" is the LRBG, BG "i-1" is the unlinked BG) and in advance of the first linked BG in rear of the LRBG: • Dmin_i-1_LRBGdet = Dodomin_i-1_i + Dmin_nom-det_i-1 • Dmax_i-1_LRBGdet = Dodomax_i-1_i + Dmax_nom-det_i-1	The location of the same "unlinked" BG with reference to the next "linked" BG ahead is $$\overline{loc_{"unlinked"BG,(ahead)}} = \qquad\qquad [[5.15]]$$ $$\overline{loc_{"linked"BG,ahead} - d_{("unlinked"BG\to linkedBG,ahead),odo}})$$
Unlinked BG in rear of the first linked BG in rear of the LRBG, thus between the linked BG's "i-n" and "i-k" (BG "i" is the LRBG, BG "i-m" is the unlinked BG): The distance from an unlinked BG (positioned between two BG's not being the LRBG) can be calculated in three different ways: 1. Using the distance from the BG in rear ("i-n") to the detected position of the LRBG 2. Using the distance from the BG in advance ("i-k") to the detected position of the LRBG 3. Using the measured distance to the LRBG	

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Criterion 1 (always valid): • Dmin_i-m_LRBGdet ≥ Dmin_i-n_LRBGdet - Dodomax_i-n_i-m – Dmax_nom-det_i-n + Dmin_nom-det_i-m • Dmax_i-m_LRBGdet ≤ Dmax_i-n_LRBGdet - Dodomin_i-n_i-m – Dmin_nom-det_i-n + Dmax_nom-det_i-m	The location of an "unlinked" BG with reference to the previous "linked" BG astern is $$\overline{loc_{\text{"unlinked"}BG(astern)}} = \overline{loc_{\text{"linked"}BG,astern} + d_{(\text{"linked"}BG,astern\rightarrow\text{"unlinked"}BG),odo}})\qquad [[5.14]]$$
Criterion 2a (valid if the linking distance from BG "i-k" to the next BG ("i-k+1") is known: • Dmin_i-m_LRBGdet ≥ Dmin_i-k_LRBGdet + Dodomin_i-m_i-k – Dmax_nom-det_i-k + Dmin_nom-det_i-m • Dmax_i-m_LRBGdet ≤ Dmax_i-k_LRBGdet + Dodomin_i-m_i-k – Dmin_nom-det_i-k + Dmax_nom-det_i-m	The location of the same "unlinked" BG with reference to the next "linked" BG ahead is $$\overline{loc_{\text{"unlinked"}BG,(ahead)}} = \overline{loc_{\text{"linked"}BG,ahead} - d_{(\text{"unlinked"}BG\rightarrow linkedBG,ahead),odo}})\qquad [[5.15]]$$
Criterion 2b (valid if the linking distance from BG "i-k" to the next BG ("i-k+1") is not known: • Dmin_i-m_LRBGdet ≥ Dmin_i-k_LRBGdet + Dodomin_i-m_i-k – Dmin_nom-det_i-k + Dmin_nom-det_i-m • Dmax_i-m_LRBGdet ≤ Dmax_i-k_LRBGdet + Dodomin_i-m_i-k – Dmax_nom-det_i-k + Dmax_nom-det_i-m	The location of the same "unlinked" BG with reference to the next "linked" BG ahead is $$\overline{loc_{\text{"unlinked"}BG,(ahead)}} = \overline{loc_{\text{"linked"}BG,ahead} - d_{(\text{"unlinked"}BG\rightarrow linkedBG,ahead),odo}})\qquad [[5.15]]$$
Criterion 3 (always valid): • Dmin_i-m_LRBGdet ≥ Dodomin_i-m_i + Dmin_nom-det_i-m • Dmax_i-m_LRBGdet ≤ Dodomax_i-m_i + Dmax_nom-det_i-m	Criterion 3 is appropriate only if no linking information is available. Then, [[5.15]] has to be applied for the LRBG instead of the next linked BG ahead.
Dmin_i-m_LRBGdet shall be calculated as the maximum and Dmax_i-m_LRBGdet as the minimum of the valid criteria.	The best known location of the "unlinked" BG is $$\overline{loc_{\text{"unlinked"}BG}} = intersectionOf\ (\overline{loc_{\text{"UNLINKED"}BG(astern)}}\ \|\ \overline{loc_{\text{"unlinked"}BG(ahead)}}\ )\qquad [[5.16]]$$
CALCULATION OF THE MINIMUM AND MAXIMUM DISTANCE FROM ANNOUNCED BG'S TO THE LRBG	
The distance from the nominal position of the first announced BG (i+1) to the detected position of the LRBG (i) is given by: • Dmin_i+1_LRBGdet = Dmin_i_LRBGdet - Dlink_i_i+1 • Dmax_i+1_LRBGdet = Dmax_i_LRBGdet – Dlink_i_i+1	With passedBG as the LRBG: $$\overline{loc_{BG(n)}} = \overline{loc_{passedBG}} + \sum_{i=passedBG}^{n}(\overline{d_{link}(i)})\qquad [[5.9]]$$ $$+ \overline{qLocAcc_{BG(n)}}$$ $$+ \overline{centerDetectionInacc_{BG(n)}}$$

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The distance from the nominal position of a further announced BG (i+n) to the detected position of the LRBG (i) is given by: • Dmin_i+1_LRBGdet = Dmin_i+n-1_LRBGdet – Dlink_i+n-1_i+n • Dmax_i+1_LRBGdet = Dmax_i+n-1_LRBGdet – Dlink_i+n-1_i+n	With passedBG as the LRBG: $$\overline{loc_{BG(n)}} = \overline{loc_{passedBG}} + \sum_{i=passedBG}^{n} \left(\overline{d_{link}(i)} \right)$$ $$+ \overline{qLocAcc_{BG(n)}}$$ $$+ \overline{centerDetectionInacc_{BG(n)}}$$ [[5.9]]