

Submarining Evaluation Tool – Readme v2.0 – 10/2026

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Contents:

1. What is new in v2.0
2. General information
 - a. Option 1 – Start a new simulation / parameter study
 - b. Option 2 – Simulation results already available, Using the Evaluator step by step, Outputs
3. Example test data
4. Description of the NND indicator (v2.0), Requirements for the simulation data

1. What is new in v2.0

- **Detection box around the ASIS** replaces the selection of the 14 laterally nearest belt nodes. The box has the size x 100 mm, $y \pm 3$ mm, $z \pm 100$ mm (default, editable) and is independent of the mesh of the belt.
- **Resultant distance** between ASIS and the selected belt node (from Δx and Δz) as main output, in addition the curves of Δx and Δz . A distance cannot be negative, therefore submarining is marked with the fixed value -10: as soon as no belt node is found in the box any more, the curves jump to -10.
- **Evaluation window**: optional “Evaluate from [ms]” can hide the first part of the simulation in all key figures.
- **New outputs**: three super plots (resultant, Δx , Δz), two scatter plots, an Excel file and CSV files with the same tables, including the number of belt nodes in the box per time step, the selected node with coordinates for every time step and the slope of the resultant.
- **Orientation of the model axes** (x rear/front, z up/down) can be set, so models with a different coordinate system can be evaluated.
- **GUI**: modern design, the main results open automatically in tabs inside the GUI.
- **Optional notch tolerance (x back)**: belt nodes up to a chosen distance behind the ASIS are also counted if they are at or below it. A second set of plots and tables and a notch hint plot are saved in a subfolder. This can be especially useful for THOR evaluations, where the belt may rest in a notch below the ASIS.

2. General information

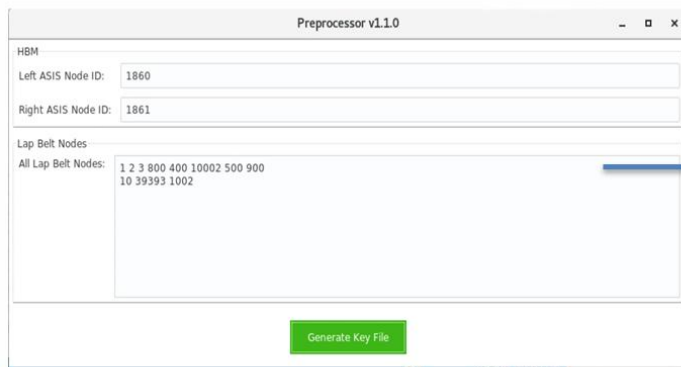
In the provided .zip-file you find two executable files: (1) a Preprocessing- and (2) a Postprocessing-GUI. Both are available for Windows and Linux. They run standalone, no Python installation is needed.

All indicators have common inputs: the time histories of both ASIS nodes of the HBM and of all lap-belt nodes must be tracked (by *DATABASE_HISTORY_NODE(_SET) and *DATABASE_NODOUT) in one of your simulation includes or in a newly added include .key-file. Two use cases exist:

- **Option 1:** You want to start a submarining evaluation on a new dataset / make a parameter study.
- **Option 2:** You already have simulation results (.binout-files) in which both ASIS nodes and all lap-belt nodes were tracked.

Option 1 – Start a new simulation / parameter study

1. Open the “Preprocessing” executable.
2. Type in the node-ids and coordinates of the two ASIS nodes of your model.
3. Include the nodes of the lap belt in the window below (best: generate a *SET_NODE in your preprocessor and copy the content here). This .key-file is later needed as input of the evaluation.



```
1 *KEYWORD
2 $
3 $
4 $
5 $ Submarining Evaluation Kit
6 $
7 $ BMW AG / Marius Rees
8 $ marius.rees@bmw.de
9 $
10 $
11 $
12 *TITLE
13 submarining_evaluation_addon
14 $
15 $
16 $ HISTORY of LAP BELT NODES
17 $
18 $
19 *DATABASE_HISTORY_NODE_SET
20 $ id1
21 99999850
22 $
23 $ do not delete the set-name!
24 *SET_NODE_LIST_TITLE
25 LapBelt_All_Nodes
26 $ sid da1 da2 da3 da4
27 99999850 0,0 0,0 0,0 0,0
28 $ id1 id2 id3 id4 id5 id6 id7 id8
29 1 2 3 800 400 10002 500 900
30 10 39393 1002
31 $ NODE-SET END (do not delete this line)
32 $
33 $
34 $ HISTORY of HBM / DUMMY ASIS NOD
35 $
36 $
37 *DATABASE_HISTORY_NODE_ID
38 1860 LEFT-ASIS
39 1861 RIGHT-ASIS
40 $
41 *END
```

4. Do not change or add lines in the created .key-file. The set-id of the lap-belt nodes must not be changed.
5. Click “Generate key-file”.
6. Add the .key-file to your main input deck with *INCLUDE.
7. Run your simulations. Make sure that a *DATABASE_NODOUT is used as well.

The Preprocessor is only a helper; you can also write the key-file in a text editor if the same definitions are used.

Option 2 – Simulation results already available

1. Open the Preprocessor, type in the information of the ASIS nodes and the lap-belt nodes and generate the .key-file. The Evaluator needs it to know which nodes to read from the binout.
2. Open the Submarining Evaluator, select the directory of your simulation runs and the key-file.
3. Continue as described in the next chapter.

ASIS and lap-belt nodes must have the same ids in all simulation runs you want to evaluate.

Requirements for the simulation data

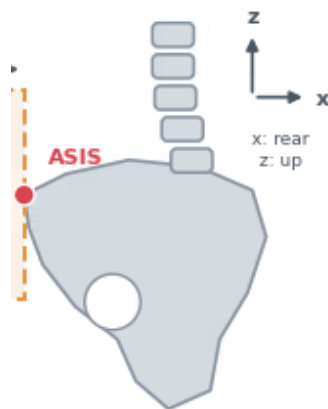
binout files

- LS-DYNA binout files (read with the library lasso-python): ``<name>.binout0000``, ``<name>.binout0001``, ... or ``binout0000``, ``binout0001``, ...; all parts of one name are read together.
- The binout must contain the group nodout with the quantities ids, time, x_coordinate, y_coordinate and z_coordinate (global coordinates) for both ASIS nodes and all lap-belt nodes of the key-file (*DATABASE_NODOUT with *DATABASE_HISTORY_NODE(_SET)).
- One run per folder. If a folder contains binout files with different names, only the first name (alphabetically) is used; subfolders are not searched.
- Not supported: d3plot, ASCII output (e.g. nodout text files), results of other solvers.
- Units: coordinates in mm; time in ms or s (set in the GUI).

Coordinate system

By default the Evaluator expects x pointing to the rear of the occupant (against the driving direction), so a lap-belt node in front of the ASIS has a smaller x than the ASIS, and z pointing up (superior). The direction of y is not relevant. The origin of the coordinate system does not matter, only the directions.

If your model uses the opposite orientation, select it in the frame “Detection box” (x axis points to the front, z axis points down). The sketch next to it shows the chosen directions. If the box is empty in the first time step on both sides but would contain belt nodes with reversed axes, a warning is shown after the evaluation.



Using the Evaluator step by step

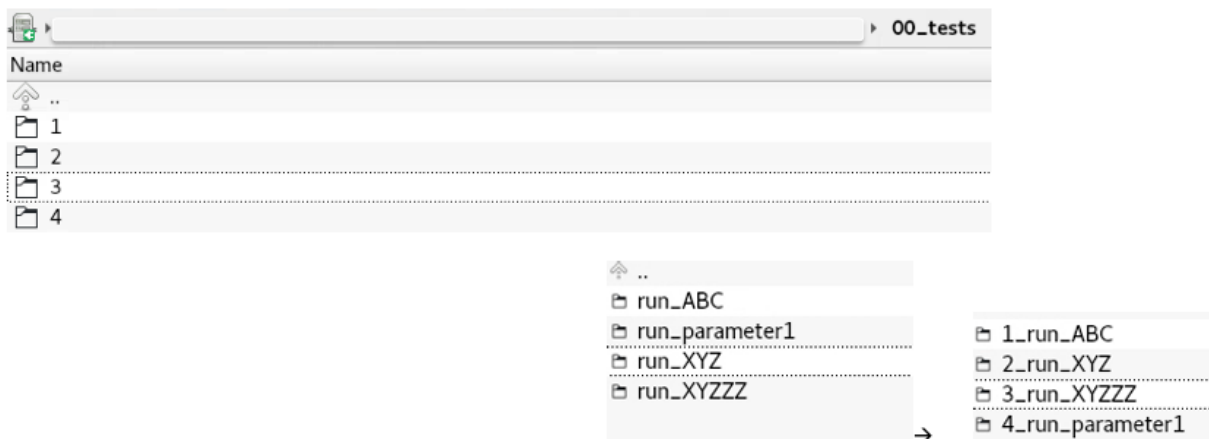
Open “Submarining_Evaluator_v2.0.0” by double-click (Windows and Linux). The window is divided into frames, work through them from top to bottom. On Linux the GUI can also be started from a terminal window, just typing the “Submarining_Evaluator_v2.0.0” and enter.

```
> Submarining_Evaluator_v2.0.0
```

Screenshots of the filled GUI and the generated outputs are given at the end of this chapter.

1. Simulation data

- **One Simulation Run:** select the directory that contains the .binout-files of the run.
- **Multiple Simulation Runs:** select the parent directory in which every run is saved as a subfolder. The subfolder names must start with the run index (“1_name”, “2_name”, ...). If they do not start with numbers, click “Rename”: all folders get a number in front (“Undo rename” reverts this). See picture below.
- Enter the **Simulation indices** to evaluate, e.g. “1”, “1,4,5” or “3-10”. A value is always required. After the parent directory is selected, the numbered subfolders are suggested automatically (e.g. “1-2,5,9”); the entry can be edited.
- [optional: “Confirm” is only needed if you want to type in true labels by hand; the label table appears below. Without it, the evaluation starts with the entered indices.]



2. Key file

Select the .key-file that was generated with the Preprocessor; the file dialog opens in the directory of your simulation runs. If every simulation folder contains its own key-file, choose “No” and enter the common part of the file names.

3. Time window

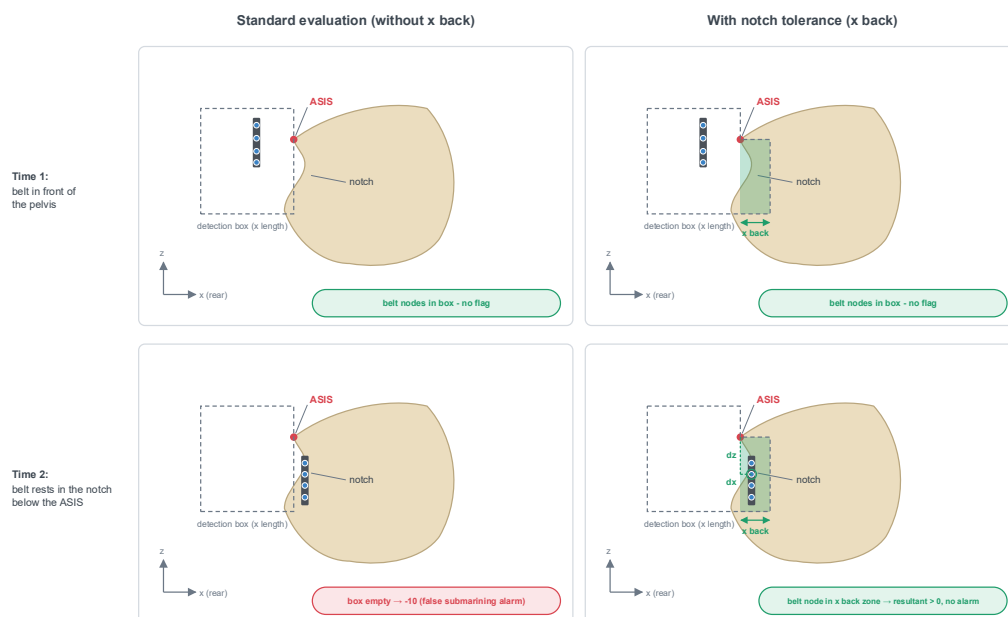
- **Max time [ms]:** latest time that is evaluated. It can be equal to or shorter than the time available in the binout, but not longer (an ending rebound phase can be excluded this way).
- **Time unit in the binout:** ms (default) or s. All inputs of the GUI are entered in ms; with “s” the binout times are converted automatically.
- **Evaluate from [ms] (optional):** default 0 = whole curve. Enter e.g. 30 to ignore the first 30 ms in all key figures (minimum, time below/above 0, first -10, slope). The curves are still plotted completely, a grey area marks the part that is not evaluated.

4. Detection box around the ASIS node

- **x length** (default 100 mm): the box reaches from the ASIS in negative x direction, i.e. in front of the ASIS. An empty field means no limit.
- **y $\pm$** (default 3 mm) and **z $\pm$** (default 100 mm): the box extends plus/minus around the ASIS. Keep y below 5 mm; a warning appears otherwise.
- **Orientation of your model:** default is x pointing to the rear of the occupant (against the driving direction) and z pointing up. Select the opposite directions if your model is oriented differently; the sketch shows the chosen axes.
- **zmax (default):** the lowest belt node in the box. zmin: the belt node closest below the ASIS – more conservative, but more prone to false classification.
- The defaults are recommended.

5. Optional additional evaluation, especially for ATD applications

- **Notch tolerance (optional, off by default):** tick “Additionally evaluate with notch tolerance” and enter “x back [mm]” (default 15). Belt nodes that lie up to x back posterior the ASIS are then also counted, provided they are at or below the ASIS ($\Delta z \geq 0$). This can be especially useful for THOR evaluations: in pre-tests the belt often lay in a notch that sits even further posterior (in x) than the ASIS point, depending on where the ASIS node is selected in the ATD, which makes these dummies somewhat more susceptible. The two pictures on the right illustrate this issue.



With the notch tolerance the evaluation is less sensitive: it counts additional belt nodes (posterior to the ASIS, but at or below it), so the detection box is empty less often and the flag -10 appears later or not at all. The tolerance can only prevent or delay flags, it never creates additional ones.

If the belt really rests in a notch, this avoids false alarms. The result with notch tolerance should always be compared with the standard evaluation (tab “Notch hint”), and cases in which both differ should be checked in the animation.

6. True labels (optional)

The section at the bottom is collapsed; click “[+] True labels” to open it. If you know whether submarining occurred, enter 1 (yes) or 0 (no) for the left and right side, or load an .xlsx/.csv file based on the provided template (use the template only). The results are then classified as TP, TN, FP or FN and precision and recall are calculated.

7. Save results

- The directory field is filled in automatically with the directory of your simulation runs; you can change it or type a new name (a directory that does not exist yet is created).
- The results are saved in a new subfolder “submarining_evaluation_<timestamp>” of this directory; all files start with the same name. Earlier results are never overwritten.

Start evaluation and results

Click “Start evaluation”. When the evaluation is finished, the three main results (super plot of the resultant, scatter plot of the minimum, scatter plot of the time until submarining) open automatically in tabs. The buttons in the frame “Results” open them again and give access to the further results (super plots of Δx and Δz , Excel overview). The Excel overview opens as the last tab.

Outputs

All files are saved in the subfolder “submarining_evaluation_<timestamp>”; “<name>” stands for “submarining_evaluation_<timestamp>”.

If the notch tolerance is used, the same files are written a second time into the subfolder

“notch_tolerance” with the suffix “_notch_tolerance” (e.g.

“notch_tolerance/<name>_notch_tolerance_superplot_resultant.png”). In addition, the plot

“<name>_notch_hint.png” is saved there and opens automatically as a tab (“Notch hint”): per simulation and side it marks in orange the time ranges in which the selected belt node lies behind the ASIS (belt probably in a notch) and in red the ranges in which the standard evaluation would show -10 but the notch tolerance does not.

File	Content
<name>_superplot_resultant.png	Resultant distance over time, one subplot per simulation, left and right side.
<name>_superplot_delta_x.png	$\Delta x = x_{\text{ASIS}} - x_{\text{node}}$ over time (same layout).
<name>_superplot_delta_z.png	$\Delta z = z_{\text{ASIS}} - z_{\text{node}}$ over time. Negative values: the belt node lies above the ASIS (which can happen initially due to pelvic or belt orientation).
<name>_scatter_min_resultant.png	Minimum of the resultant per simulation
<name>_scatter_time_until_submarining.png	Last time step before the curve jumps to -10, per simulation and side (no point = no submarining).
<name>.xlsx and <name>_*.csv	Result table and details per time step (see below)

Excel file

Sheet	Content
Results	One row per simulation: true label, submarining yes/no (left, right),

Sheet	Content
	classification, and for each side the key figures: first -10 at [ms], t before crossing [ms], min resultant [mm], time below/above 0 [ms and %], resultant at 45, 55, 65, 75, 85, 95 ms, slope to minimum, 40 ms back [mm/ms], slope 45 to 95 ms [mm/ms], time of minimum [ms]. If true labels are given, precision and recall are listed below the table.
n_box per time step	Number of belt nodes inside the box for every time step, per simulation and side (with zmin also the number of nodes below the ASIS). 0 means empty box = -10. A value of e.g. 5 or 6 means that 5 or 6 belt nodes are candidates; the lowest is selected.
Node selection details	For every time step and side: ASIS coordinates, the selected belt node (id, x, y, z, Δx , Δz), the resultant and the two next-ranked candidates in the box.
Empty box diagnostics	For every time step with -10: number of belt nodes that miss the x, the y and the z condition (counts are not exclusive). Shows why the box is empty.
Settings	All parameters of the evaluation.

3. Example test data

The example folder contains two runs with THUMS v4.1-50P in the Uriot et al. environment: run 1 without and run 2 with submarining. Both folders contain the binout-files, folder 1 additionally the key-file “evaluation_file_for_GUI.key” (output of the Preprocessor). You can test one simulation run (run 1 or 2) or the multiple-runs option with the parent directory.

Submarining Evaluator v2.0.0

NND

Submarining Evaluator

1 Simulation data

Select simulation type: ☐ One Simulation Run ☒ Multiple Simulation Runs
Select the parent directory in which each simulation run is saved as a subfolder:

Submarining_Evaluation_Tool_v2.0.0\02_example-files

Select directory

adds a "number_" prefix to the folder names.

Simulation indices (e.g. '1', '1.4.5' or '3-10'):

1-2

Confirm

Confirm is only needed if you want to enter true labels manually (a table appears below). Otherwise just start the evaluation.

2 Key file

Are the key files the same? ☒ Yes ☐ No
Select the key file in which the lap belt nodes and both ASIS nodes are tracked via *DATABASE_HISTORY_NODE(SET) keywords. This can either be your include file or the file generated in the first step with the Preprocessor GUI (recommended).

Submarining_Evaluation_Tool_v2.0.0\02_example-files\1\evaluation_file_for_GUI.key

Select key file

3 Time window

All times below are entered in ms. Max time can be equal to or shorter than the time available in the binout, but not longer.
Max time [ms]

120

 Time unit in the binout

ms

Evaluate from [ms] (optional)

0

Evaluate from: default 0 = the whole curve is evaluated. Enter e.g. 30 to ignore the first 30 ms. The curves are still plotted completely.

Optional settings and additional evaluations (e.g. for ATDs)

4 Detection box around the ASIS node

Box around the ASIS node: x reaches from the ASIS in negative x direction (in front of the ASIS), y and z extend plus/minus around it. If no belt node is found in the box any more, the output value is automatically set to the fixed value -10. Defaults are recommended.
x length [mm]

100

 y +/- [mm]

3

 z +/- [mm]

100

Orientation of your model: x axis points to the ☒ rear (against driving direction, default) ☐ front (driving direction)
z axis points ☒ up / superior (default) ☐ down / inferior
☒ zmax (default): lowest belt node in the box
☐ zmin: belt node closest below the ASIS (more conservative, but more prone to false classification)

5 Optional additional evaluation, especially for ATD applications

6 True labels (optional)

7 Save results

The results are saved in a new subfolder "submarining_evaluation_<timestamp>" of this directory. It is filled in automatically with the directory of your simulation runs and can be changed. A directory that does not exist yet (e.g. type a new name) is created.

Submarining_Evaluation_Tool_v2.0.0\02_example-files

Select directory

Files: submarining_evaluation_<timestamp>_superplot_*.png (3), _scatter_*.png (2), .xlsx and CSV files

Start evaluation

Start evaluation

Ready.

Results

Superplot: resultant

Scatter: minimum

Scatter: time until submarining

Further results

Superplot: delta x

Superplot: delta z

Excel overview

After clicking “Start evaluation”, three new tabs open including a superplot and two scatterplots.

NND Superplot resultant Scatter minimum Scatter time until subm.

Fit to tab 100 % Zoom + Zoom - submarining_evaluation_20261009_172655_superplot_resultant.png

Resultant

Simulation 1

Simulation 2

Resultant of x and z distance [r n]

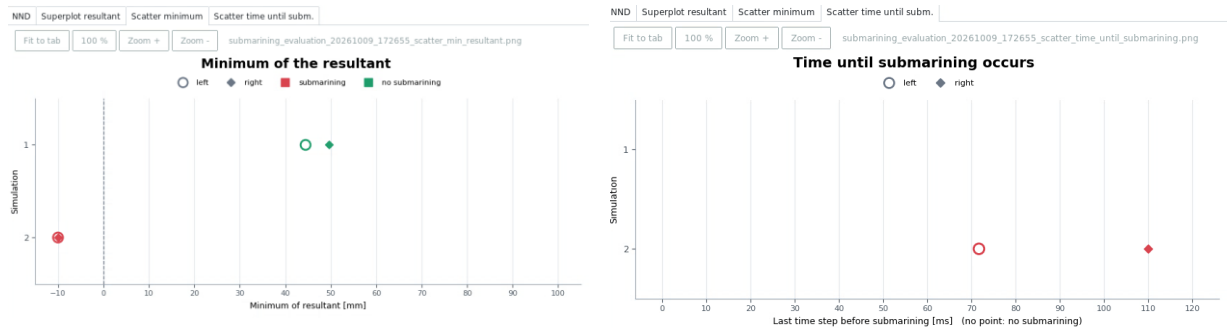
Time [ms]

Box x/y/z: 100 / 3 / 100 mm | selection: zmax | evaluated from 0 ms | max time 120 ms

— left — right ■ submarining ■ no submarining

- Run 1: both sides without submarining; the minimum of the resultant is about 45 mm on the left and 50 mm on the right side with the default settings.
- Run 2: both sides do submarine. Left side earlier at around 70ms and right side later at 110 ms.

Just the minima of these four curves (2 per simulation) and the timing of the minima are given in two additional scatterplots:



With unfavourable initial belt routing or positioning (and missing or late pretensioning) the belt can lie above the ASIS at the start (negative Δz). With z_{max} this does not cause a false -10. With z_{min} it does; use “Evaluate from” then.

4. Description of the NND indicator

(More details in the referenced IRCOBI paper, Rees et al. 2025.) The Nearest Node Dynamic (NND) indicator describes the position of the lap belt relative to the ASIS over time. It is evaluated separately for the left and right body side. The method spans a box around the ASIS, selects the representative belt node inside this box and measures its distance to the ASIS. If no belt node is left in the box, submarining is indicated.

Notation per time step t :

$$\begin{aligned}\Delta x_i &= x_{\text{ASIS}} - x_i & \Delta y_i &= |y_i - y_{\text{ASIS}}| \\ \Delta z_i &= z_{\text{ASIS}} - z_i\end{aligned}$$

for lap-belt node i (z points upwards, x points to the rear of the occupant).

Step 1 – Detection box

$$B(t) = \{ i \mid 0 \leq \Delta x_i \leq L_x, \Delta y_i \leq L_y, |\Delta z_i| \leq L_z \}$$

with $L_x = 100$ mm, $L_y = 3$ mm and $L_z = 100$ mm as default. Only belt nodes in front of the ASIS ($\Delta x \geq 0$) and close to it in y and z belong to the box. The number of nodes $|B(t)|$ is saved for every time step.

Step 2 – Selection of the representative node

$$\text{zmax: } i^*(t) = \arg \max_{i \in B(t)} \Delta z_i$$

$$\text{zmin: } i^*(t) = \arg \min_{i \in B(t), \Delta z_i \geq 0} \Delta z_i$$

zmax selects the lowest belt node in the box (largest Δz ; the value can be negative if all nodes lie above the ASIS). zmin selects the node closest to the ASIS below it. Ties are decided by the lower node index.

Step 3 – Output

If a representative node $i^*(t)$ exists:

$$\begin{aligned}\Delta x^*(t) &= \Delta x_{i^*(t)} & \Delta z^*(t) &= \Delta z_{i^*(t)} \\ r(t) &= \sqrt{(\Delta x^*(t))^2 + (\Delta z^*(t))^2}\end{aligned}$$

The resultant $r(t)$ is the remaining distance between ASIS and belt in the sagittal plane. It cannot be negative; therefore the fixed value -10 is used as a flag for “no belt node in the box any more”. The separate curves of Δx and Δz show in which direction the margin is smaller. If no representative node exists:

$$\Delta x^*(t) = \Delta z^*(t) = r(t) = -10$$

Submarining flag

$$\text{Submarining} = \text{yes} \Leftrightarrow \exists t \in [t_{\text{start}}, t_{\text{max}}] : r(t) = -10$$

The depth of negative values is irrelevant. The flag is the input of the true-label comparison (TP, TN, FP, FN, precision, recall).

Key figures (per simulation and side, evaluated on $r(t)$)

Key figure	Definition
t before crossing	Last time step before the first -10 (empty without submarining; “error” if the first -10 is the first evaluated time step).
Minimum of r	Minimum of $r(t)$ in the evaluation window; -10 counts.
Time below / above 0	Duration (ms and % of the window) with $r < 0$ (the -10 phase) and $r \geq 0$.
r at 45 ... 95 ms	Value at the nearest time step (the earlier one on a tie), no interpolation,

Key figure	Definition
	empty if the time is behind the end; independent of “Evaluate from”.
Slope to minimum	A = first time step with -10 (submarining) or the minimum of the curve, B = time step nearest to 40 ms before A (not before the window start): slope = $(r_A - r_B) / (t_A - t_B)$ in mm/ms. With submarining it contains the jump to -10. “n/a” if A is the first evaluated step.
Slope 45 to 95 ms	$(r_{95} - r_{45}) / (t_{95} - t_{45})$ in mm/ms at the nearest time steps; also available without submarining. A -10 value is used as it is. Empty if 95 ms is behind the end.

Remarks

- Because the representative node can change from one time step to the next, the curves can show steps.
- The box width in y (± 3 mm) must contain at least one column of belt nodes. If your mesh is coarser, check “n_box per time step” in the Excel file; many zeros without real submarining indicate a too small box.
- The method is called “nearest node” for consistency; it does not select the geometrically nearest node in all directions.
- Notch tolerance (optional): with $x_{back} > 0$ the box is extended by belt nodes with $-x_{back} \leq \Delta x < 0$ and $\Delta z \geq 0$, i.e. nodes slightly behind but at or below the ASIS. Nodes behind and above the ASIS are not counted, so submarining is still detected. In this case Δx of the selected node can be negative, while the resultant stays positive.

Further details: Rees et al. (IRCOBI, 2025). A more comprehensive description will be available in his PhD dissertation.