

# AET Manual

24.08



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## 1. Introduction

The Acceleration Evaluation Tool – short AET – offers different functions for evaluation and analyzing measured driving parameter. Basic idea is that tire wear performance, which depends on the driving style, can be better rated. Therefore, several characteristic values are calculated within AET evaluation to detect differences. Nevertheless, in case of detected differences further analysis are needed.

AET evaluates only GPS based accelerations, that means measured accelerations are not considered, GPS information is required. The reliability of calculated values depends on the GPS receiver information quality and is not part of AET. A certain input quality is – of course – needed for reliable values.

Within AET, it is also implemented a sample rate detection for e.g., csv files. The expected frequency is between 1 Hz and 100 Hz, recommended frequency should be greater than 4 Hz otherwise the filter parameters are useless. Normally a sample rate of 10 Hz is used and sufficient.

## 2. How to install and start AET

After unpacking AET.zip-file, the tool can be started with **AET.exe**. This file can be found in the subfolder AET. Because this is generated tool with Matlab, there is a need for installing Matlab runtime.

The required Matlab runtime can be downloaded here:

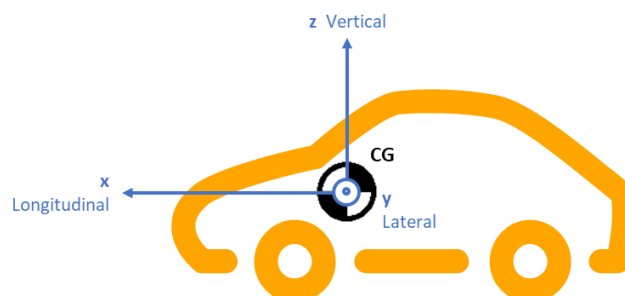
<https://de.mathworks.com/products/compiler/matlab-runtime.html>

For AET 24.08, **Matlab Runtime Version R2023a (9.14) for Windows** is required.

In case of an error or software bug, a file **err\_<date>.mat** will be generated and saved in AET folder. In this AET folder, there is also a folder named Data. Here will be saved the current user settings in **UserSettingAET.mat** and a default template **TestPreferences\_default.xlsx** is pre-defined and can be used for modifications.

## 3. Coordinate System Vehicle

Within AET following coordinate system is used:



## 4. Tool Functionalities

This tool has a tab structure. 5 main tabs appears after starting the program:

- **Data**
- **Parameter**
- **Evaluation** with inside tabs **All** and **Info**
- **Visualisation**
- **User Setting** with inside tabs **Pathway** and **Setting**

In following, all the tabs with their functions are described.

### 4.1. Data Tab

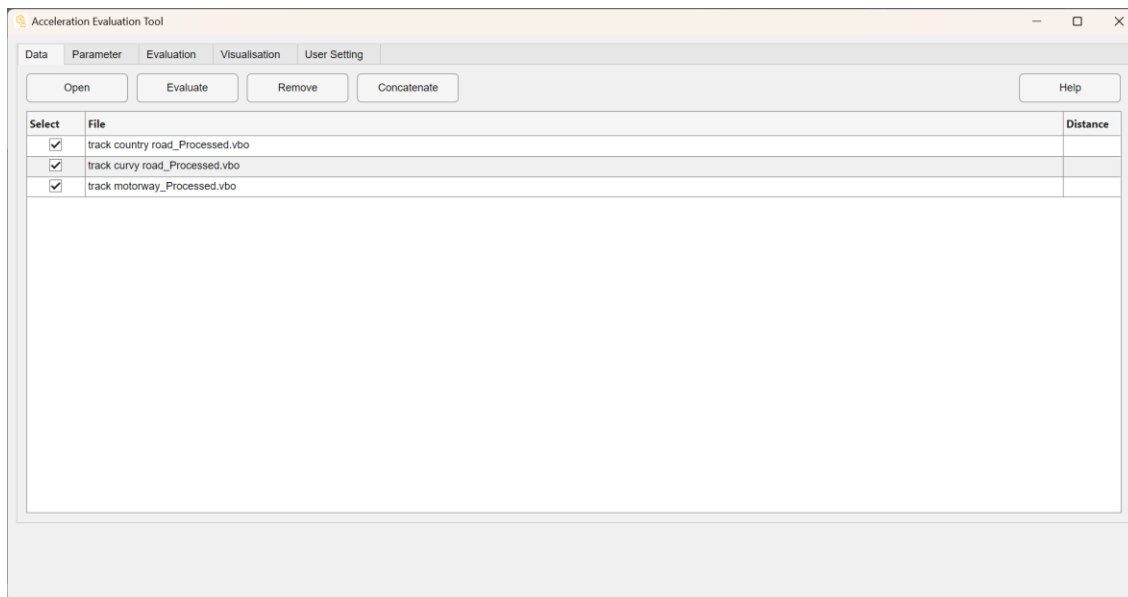
Data tab is used for importing the measured driving files. On the top, 5 function buttons are implemented:

- **Open** imports data files
- **Evaluate** makes a complete evaluation of all selected files
- **Remove** eliminates all selected files
- **Concatenate** combines all selected files to one file if all boundary conditions are fulfilled
- **Help** opens AET Manual

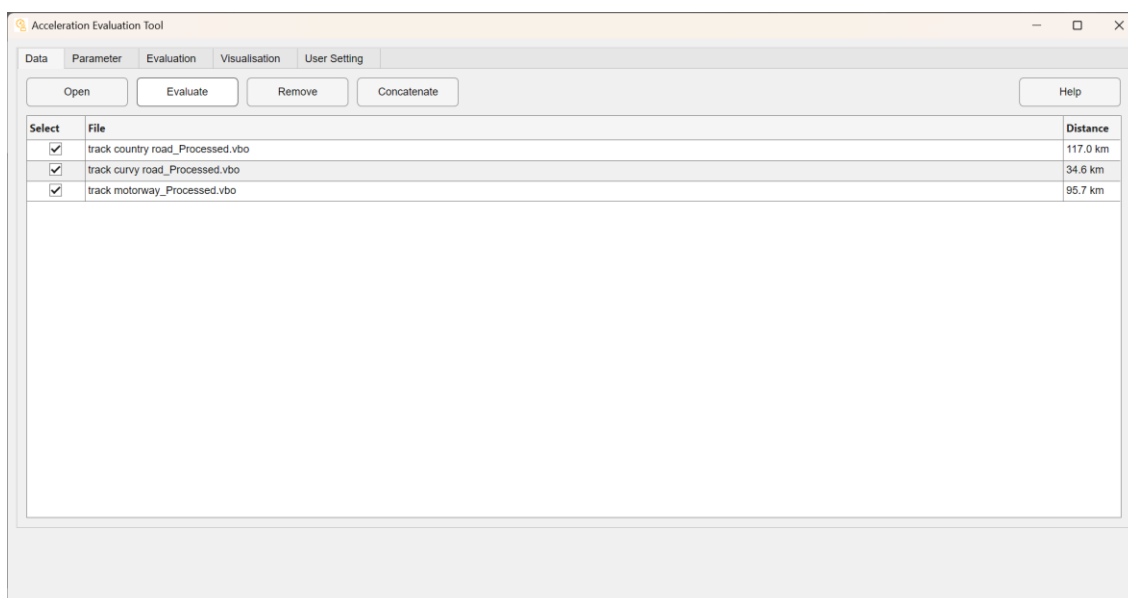
Currently there is the possibility to load following files:

- vbo-file (Racelogic)
- hex-file generated by Avisaro Logger
- mat-file with concatenated data created with AET
- csv-file, following syntax is necessary:
  - all values are separated with a comma
  - first line is the header with variable names
  - **t** in [s] (this timestamp is used for sample frequency detection)
  - **v** in [m/s]
  - **ax** for longitudinal acceleration [ $\text{m/s}^2$ ]
  - **ay** for lateral acceleration [ $\text{m/s}^2$ ]
  - example, here with a sample rate of 10 Hz:

```
t;v;ax;ay
479.1;29.68361111;0.309395543;0.278167458
479.2;29.73569444;0.136404651;0.127257195
479.3;29.78777778;0.181184793;0.175140467
479.4;29.85625;0.131349095;0.130351699
479.5;29.92472222;0.119612683;0.176478122
479.6;29.91430556;-0.02324284;0.242724505
```



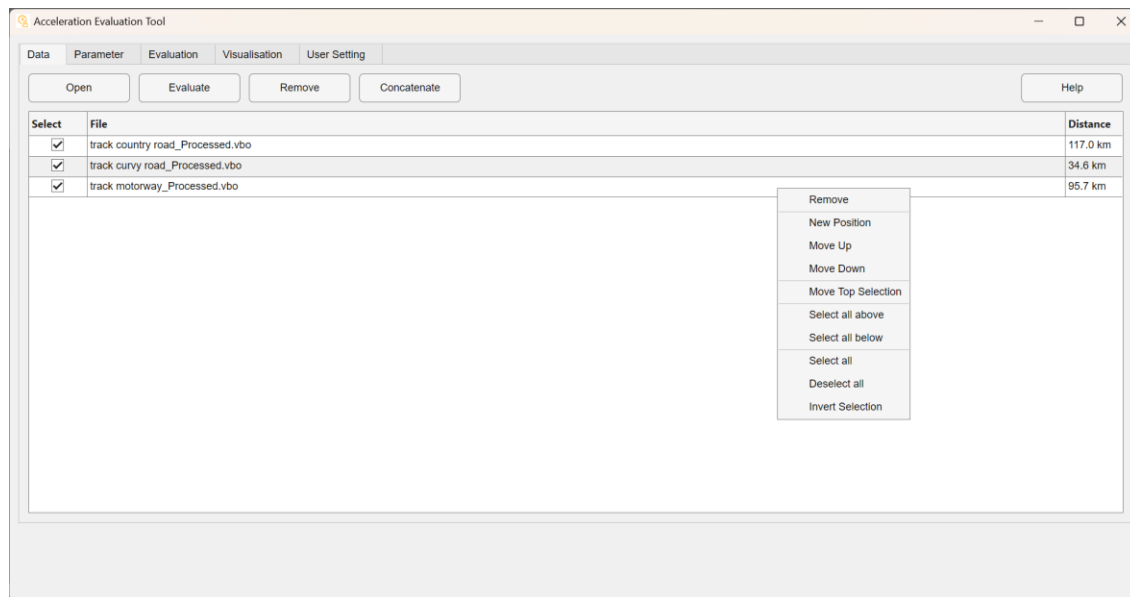
If a file is imported and not evaluated, the distance cell is empty. This information is available after a first evaluation of file. It gives feedback about evaluation status.



Other functions on this tab are - as mentioned - **Remove** and **Concatenate**. In case of using on on these buttons, all selected files are removed or – in case of concatenate – the selected files are combined to one file in the sequence defined by position.

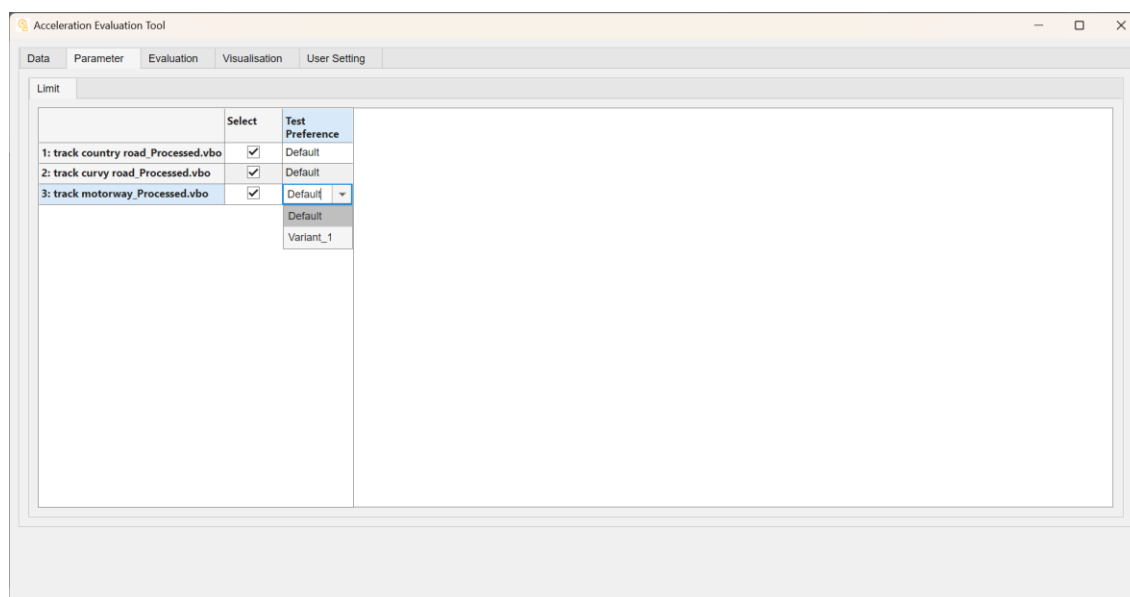
For **Concatenate** it is required that the files have the same sample rate as well as measured with the same logger type.

Additional to these buttons, a right click opens a context menu. A single file can be removed or the table position of files can be changed. Furthermore, functions for selection or deselection can be found here.



## 4.2. Parameter Tab

For the tabulated statistical values of each file, thresholds are checked and detected values are marked if the value is outside the defined range. Basis for these thresholds are the selected **Test Preference**. Further **Test Preferences** can be defined in **Test Preference File**, pathway to this file is defined in the tab **User Setting**. In case of defined more than one preference, the preference can be changed with the pull-down menu.



After modification of **Test Preference File** or choosing another **Test Preference File** in **User Setting**, a restart of AET is required, because this file is imported within AET startup function.

For further information concerning parameter definition, see chapter 6.3.

### 4.3. Evaluation Tab

After using **Evaluate**, the result appears in the Evaluation tab. This tab has two tabs inside:

- **All** is a tabulated overview about all calculated characteristic values.
- **Info** delivers information about e.g., used equipment, sample rate and data reliability.

Relevant statistical values are displayed on **All**. There is also a context menu with the option to export these values to a file. In case of export, both **All** and **Info** are saved. For saving, two modes are implemented: **Complete** and **Selected**. By choosing **Complete**, all data will be exported independent of user's selection. If there is a need to export only a part of the data, an export of only selected data is also possible.

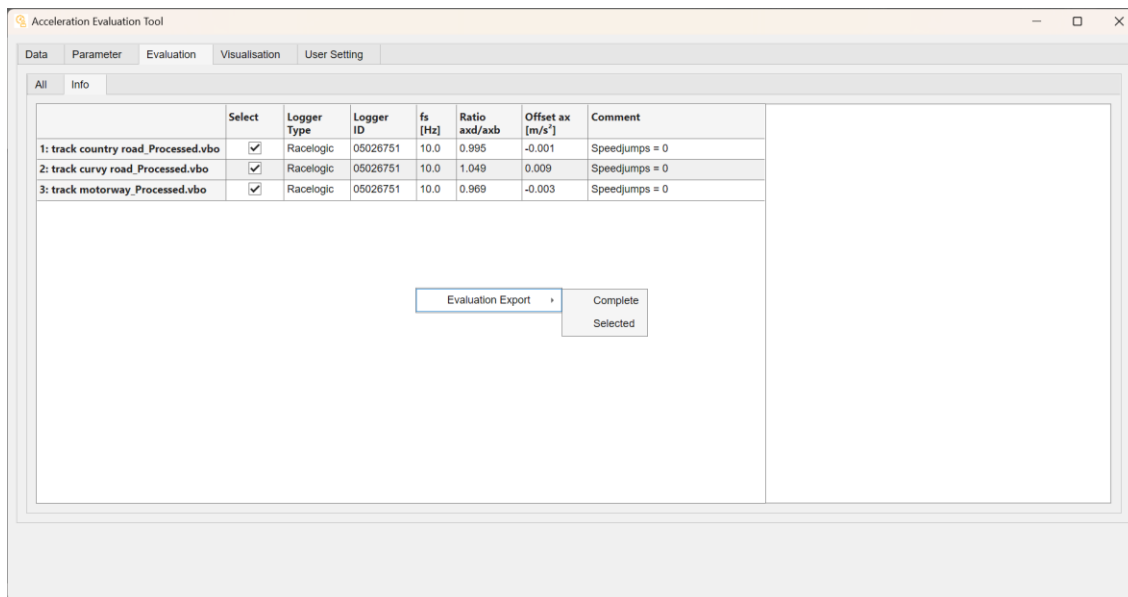
	Select	Distance [km]	Limit v1 [km/h]	Limit v2 [km/h]	<v1 [%]	[v1,v2] [%]	>v2 [%]	vmean [km/h]	vmax [km/h]	ā left [m/s²]	ā right [m/s²]	ā brake [m/s²]	ā drive [m/s²]	μ ax [m/s²]	μ ay [m/s²]	σ ax [m/s²]
1: track country road_Processed.vbo	<input checked="" type="checkbox"/>	117.0	60	90	40	38	22	61	105	4.42	-4.70	-4.09	4.11	0.001	-0.003	0.50
2: track curvy road_Processed.vbo	<input checked="" type="checkbox"/>	34.6	60	90	48	52	0	56	91	4.82	-4.67	-3.39	2.58	0.009	-0.029	0.54
3: track motorway_Processed.vbo	<input checked="" type="checkbox"/>	95.7	60	90	1	9	90	118	140	2.60	-3.33	-3.92	7.04	0.000	-0.011	0.31

The context menu is also available on **Info**. In this tab, general information is displayed:

- **Logger Type** and **fs [Hz]** are relevant for concatenate files.
- **Ratio axd/axb**
  - axd is sum of all positive accelerations (drive)
  - axb is sum of all negative accelerations (brake)
  - Ratio  $\approx 1$  is expected in case of a driven circuit<sup>1</sup>
- **Offset ax [m/s²]**
  - Offset off longitudinal accelerations
  - Offset  $\approx 0$  is expected in case of a driven circuit<sup>1</sup>

Ratio axd/axb and offset ax describe the same circumstance and so these values are interdependent. Nevertheless, both values are valued and displayed.

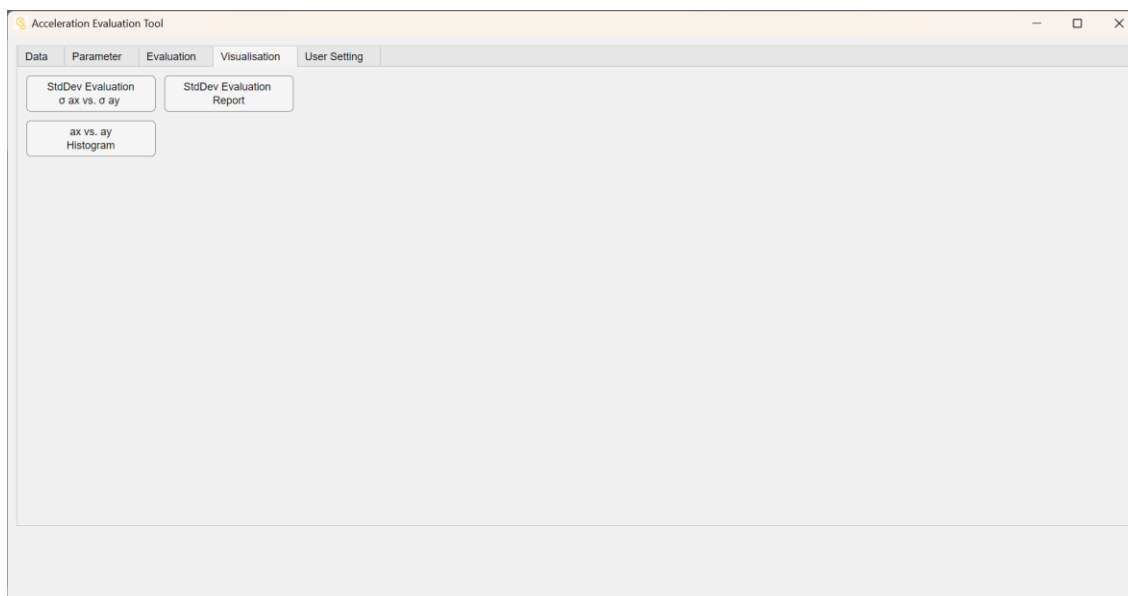
<sup>1</sup> Driven circuit means in this case that start and end point are on the same altitude level.



#### 4.4. Visualisation Tab

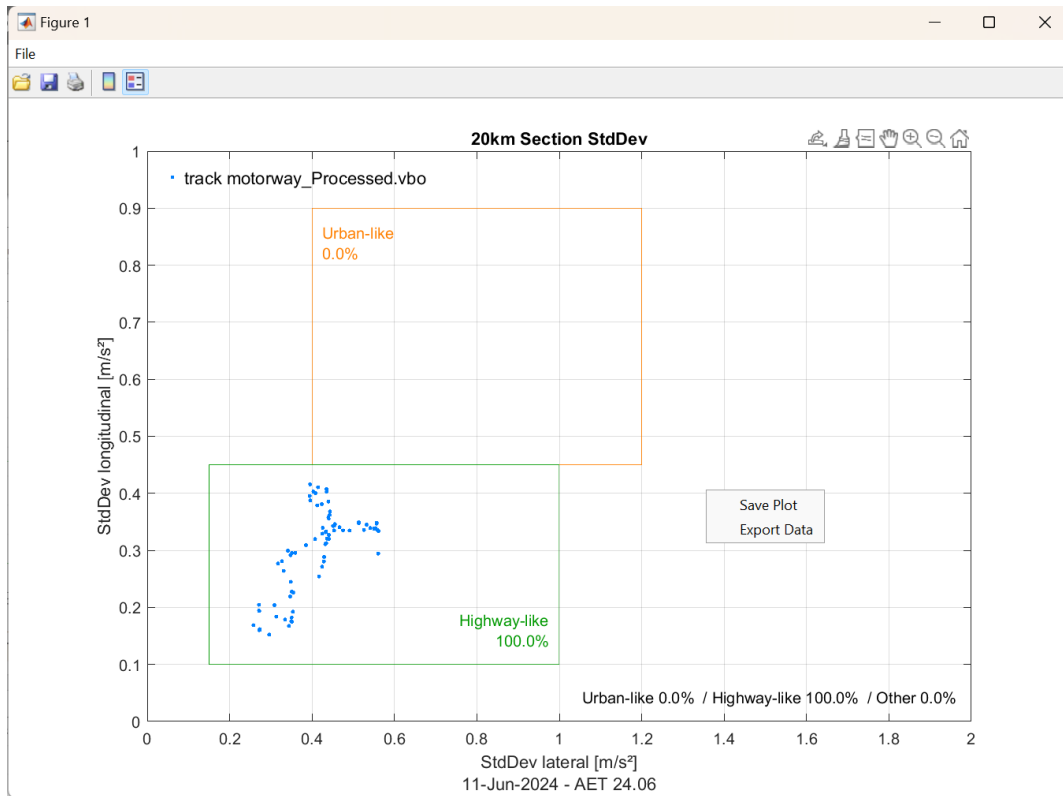
For visualisation, different function buttons are placed in this tab:

- **StdDev Evaluation  $\sigma$  ax vs.  $\sigma$  ay** plots the calculated values in separate figures for each selected file.
- **StdDev Evaluation Report** displays the calculated values in one table.
- **ax vs. ay Histogram** creates 3D histograms in separate plots for each selected file.

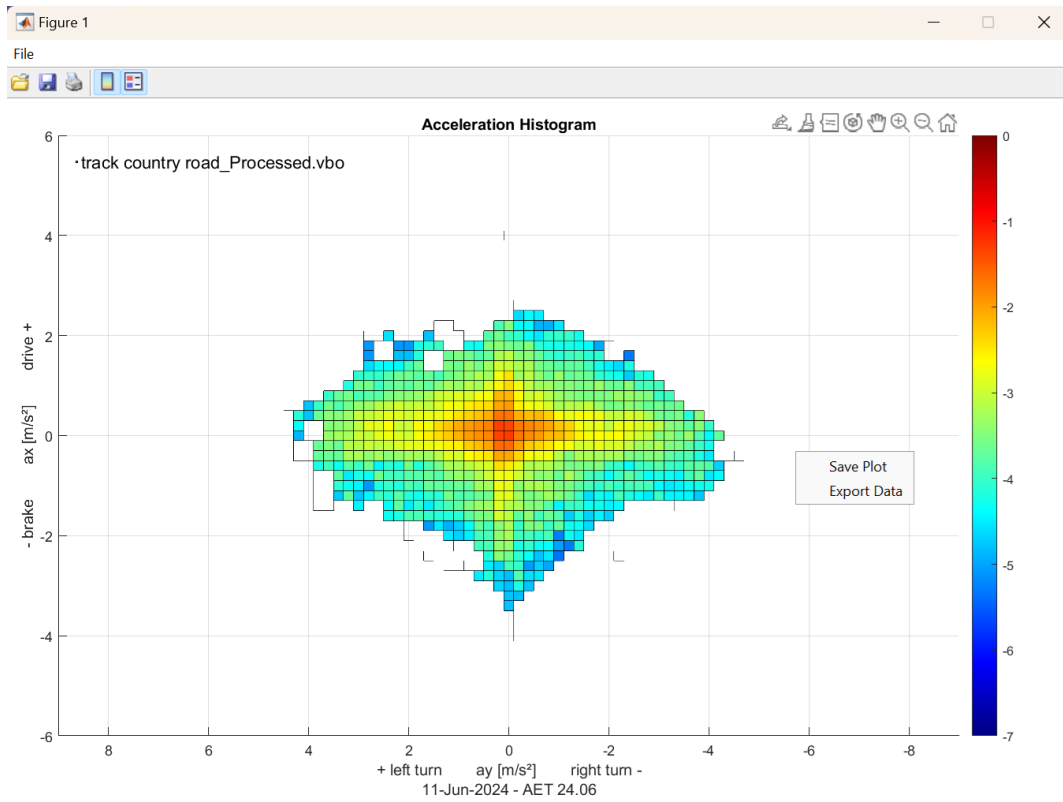


Also, a context menu is implemented. In case of **StdDev Evaluation  $\sigma$  ax vs.  $\sigma$  ay**, it is possible to save the plot or to export the plot data.



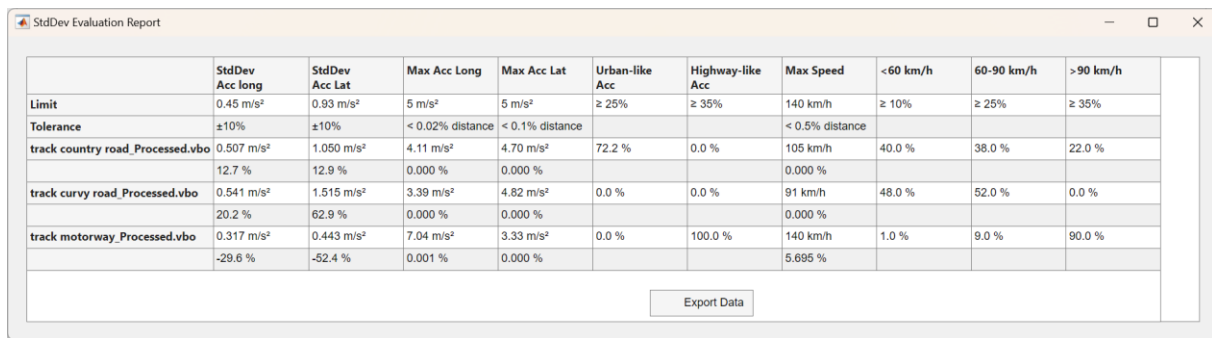


Same context menu is implemented for **ax vs. ay Histogram**.



On the right side, a legend is included. The histogram values are logarithmic. That means that the 0 means 100%, -1 stands for 10%, -2 represent 1% and so on.

If a **StdDev Evaluation Report** is created, data export is possible with right-click.



	StdDev Acc long	StdDev Acc Lat	Max Acc Long	Max Acc Lat	Urban-like Acc	Highway-like Acc	Max Speed	<60 km/h	60-90 km/h	>90 km/h
<b>Limit</b>	0.45 m/s²	0.93 m/s²	5 m/s²	5 m/s²	≥ 25%	≥ 35%	140 km/h	≥ 10%	≥ 25%	≥ 35%
<b>Tolerance</b>	±10%	±10%	< 0.02% distance	< 0.1% distance			< 0.5% distance			
track country road_Processed.vbo	0.507 m/s²	1.050 m/s²	4.11 m/s²	4.70 m/s²	72.2 %	0.0 %	105 km/h	40.0 %	38.0 %	22.0 %
	12.7 %	12.9 %	0.000 %	0.000 %			0.000 %			
track curvy road_Processed.vbo	0.541 m/s²	1.515 m/s²	3.39 m/s²	4.82 m/s²	0.0 %	0.0 %	91 km/h	48.0 %	52.0 %	0.0 %
	20.2 %	62.9 %	0.000 %	0.000 %			0.000 %			
track motorway_Processed.vbo	0.317 m/s²	0.443 m/s²	7.04 m/s²	3.33 m/s²	0.0 %	100.0 %	140 km/h	1.0 %	9.0 %	90.0 %
	-29.6 %	-52.4 %	0.001 %	0.000 %			5.695 %			

Export Data

## 4.5. User Setting Tab

**User Setting** has two tabs inside:

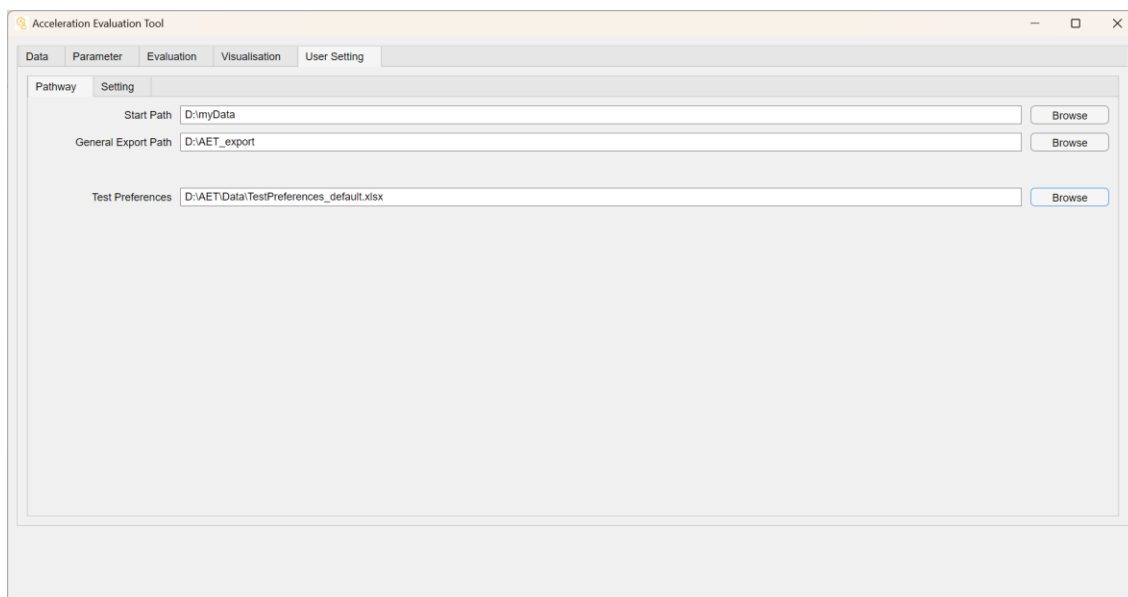
- **Pathway** defines **Start Path**, **General Export Path**, and **Test Preferences**.
- **Setting** for evaluation parameter.

The user has the possibility to define his own folders with **Pathway**:

- **Start Path** is the start folder in case of choosing **Open**
- **General Export Path** is the start folder in case of exporting data, saving plots or reports
- **Test Preferences** define the path to xlsx file with the defined limits. As default is a file created, which can be used also for added own limits.

For each imported file, the test preference defined in column C of Sheet Test Preference Data is used as default value.

After modification of **Test Preference File** (e.g., using Excel) or choosing another **Test Preference File** in **User Setting**, a restart of AET is required, because this file is imported within AET startup function.



Acceleration Evaluation Tool

Data Parameter Evaluation Visualisation User Setting

Pathway Setting

Start Path D:\myData Browse

General Export Path D:\AET\_export Browse

Test Preferences D:\AET\Data\TestPreferences\_default.xlsx Browse

The inside tab **Setting** is planned for evaluation parameters and settings, which are used within calculation.

Currently 2 parameters are changeable by user:

- **Step Size [km]** is used for section calculation.
- **Section Size [km]** defines the length of single section.

As default it is defined 1 km for step size and 20 km for section size. That means that first interval starts at 0 km and ends at 20 km, the second one from 1 km to 21 km, the third one from 2 km to 22 km and so on.



## 5. Calculated Values

Following table shows an overview about the main calculated characteristic values displayed in Result table.

Name	Description	Unit
distance	distance of evaluated track	[km]
limit $v_1$	velocity threshold for share calculation	[km/h]
limit $v_2$	velocity threshold for share calculation	[km/h]
$<v_1$	share of driven distance with low velocity, threshold defined by test	[%]
$[v_1, v_2]$	share of driven distance with medium velocity, threshold defined by test	[%]
$>v_2$	share of driven distance with high velocity, threshold defined by test	[%]
$v_{\text{mean}}$	mean value of vehicle velocity	[km/h]
$v_{\text{max}}$	maximum value of vehicle velocity	[km/h]
$\hat{a}_{\text{left}}$	maximum value of lateral acceleration "left turn", positive value	[m/s <sup>2</sup> ]
$\hat{a}_{\text{right}}$	maximum value of lateral acceleration "right turn", negative value	[m/s <sup>2</sup> ]
$\hat{a}_{\text{brake}}$	maximum value of braking acceleration, negative value	[m/s <sup>2</sup> ]
$\hat{a}_{\text{acc}}$	maximum value of driving acceleration, positive value	[m/s <sup>2</sup> ]
$\mu_{\text{ax}}$	mean value of longitudinal acceleration	[m/s <sup>2</sup> ]
$\mu_{\text{ay}}$	mean value of lateral acceleration	[m/s <sup>2</sup> ]
$\sigma_{\text{ax}}$	standard deviation of longitudinal acceleration	[m/s <sup>2</sup> ]
$\sigma_{\text{ay}}$	standard deviation of lateral acceleration	[m/s <sup>2</sup> ]
$\notin [v]$	values outside defined speed range	[%]
$\notin [a_x]$	values outside defined longitudinal acceleration range	[%]
$\notin [a_{\text{xd}}]$	values higher than defined longitudinal acceleration range, "drive"	[%]
$\notin [a_{\text{xb}}]$	values lower than defined longitudinal acceleration range, "brake"	[%]
$\notin [a_y]$	values outside defined lateral acceleration range	[%]
$\hat{1} \notin [v]$	maximum continuous distance outside speed limit	[m]
$\hat{1} \notin [a_x]$	maximum continuous distance outside longitudinal acceleration limit	[m]
$\hat{1} \notin [a_{\text{xd}}]$	maximum continuous distance outside longitudinal acceleration limit "drive"	[m]
$\hat{1} \notin [a_{\text{xb}}]$	maximum continuous distance outside longitudinal acceleration limit "brake"	[m]
$\hat{1} \notin [a_y]$	maximum continuous distance outside lateral acceleration limit	[m]
DSN	driving severity number	[-]
$\text{DSN}_{\text{brake}}$	driving severity number in longitudinal direction due to braking	[-]
$\text{DSN}_{\text{drive}}$	driving severity number in longitudinal direction due to driving	[-]
$\text{DSN}_{\text{lat}}$	driving severity number in lateral direction	[-]
$\text{DSN}_{\text{long}}$	driving severity number in longitudinal direction	[-]

## 6. Tool Calculations & Formulas

In this tool a lot of calculations are implemented. In this chapter an overview of all used formulas is described for a better understanding. Following grouping is chosen:

1. Descriptors used for driving behavior
2. Statistical values for driving behavior
3. Descriptors used for test limit check and speed distribution

The input values for all formulas are filtered. Following table shows the filtering of the relevant values:

Input	1 <sup>st</sup> Filter "Lowpass"	2 <sup>nd</sup> Filter "Smooth"
Speed <sub>GPS</sub>	Butterworth: order = 2, $f_{\text{cutoff}} = 1\text{Hz}$	Moving Average: 2 sec
Acceleration <sub>GPS,longitudinal</sub>	Butterworth: order = 2, $f_{\text{cutoff}} = 1\text{Hz}$	Moving Average: 1 sec
Acceleration <sub>GPS,lateral</sub>	Butterworth: order = 2, $f_{\text{cutoff}} = 1\text{Hz}$	Moving Average: 2 sec

For the calculation, only values for velocities greater than **MinimumSpeed4Evaluation** are considered (defined with test preferences selection on parameter tab , see chapter 6.3).

### 6.1. Descriptor used for the Driving Behavior

Input for DSN calculation are longitudinal and lateral accelerations. With these values one value representing the DSN is calculated:

$$DSN = \frac{\sum_{k=1}^N (factor_{DSN} \cdot a_{longitudinal,k}^2 + a_{lateral,k}^2) \cdot v_k}{\sum_{k=1}^N v_k}$$

DSN can be divided in longitudinal as well as lateral direction:

$$DSN_{longitudinal} = \frac{\sum_{k=1}^N a_{longitudinal,k}^2 \cdot v_k}{\sum_{k=1}^N v_k}$$

$$DSN_{lateral} = \frac{\sum_{k=1}^N a_{lateral,k}^2 \cdot v_k}{\sum_{k=1}^N v_k}$$

With these two values can be calculated also the DSN:

$$DSN = factor_{DSN} \cdot DSN_{longitudinal} + DSN_{lateral}$$

In this AET version,  $factor_{DSN}$  is not changeable and is defined with 0.4. This factor is used to consider the different influence of lateral and longitudinal accelerations on wear for the driven axle.

To get a hint concerning braking ( $a_{longitudinal} < 0$ ) and driving ( $a_{longitudinal} > 0$ ) behavior of the driver, 2 further numbers are defined:

$$DSN_{brake} = \frac{\sum_{k=1}^N a_{longitudinal,k}^2 \cdot v_k \cdot \left( \frac{-a_{longitudinal,k}}{2 \cdot |a_{longitudinal,k}|} + \frac{1}{2} \right)}{\sum_{k=1}^N v_k}$$

$$DSN_{drive} = \frac{\sum_{k=1}^N a_{longitudinal,k}^2 \cdot v_k \cdot \left( \frac{a_{longitudinal,k}}{2 \cdot |a_{longitudinal,k}|} + \frac{1}{2} \right)}{\sum_{k=1}^N v_k}$$

The bracketed terms in the formulas are necessary to consider only the relevant accelerations: in one case the negative accelerations representing a braking situation, for  $DSN_{drive}$  only the positive accelerations. Therefore,  $DSN_{longitudinal}$  can be calculated also with these two values.

$$DSN_{longitudinal} = DSN_{brake} + DSN_{drive}$$

## 6.2. Statistical Values used for Driving Behavior

The driven accelerations are evaluated and summarized in statistical values. The calculated statistical values are distance based mean value and standard deviation. Accelerations are time based and are interpolated for every meter by using speed information for distance calculation.

The standard deviations in lateral and longitudinal direction are comparable with  $DSN_{lateral}$  and  $DSN_{longitudinal}$  and delivers similar information. Because the calculations are different, small differences are observable, but if a normal distribution with mean value of 0 are measured, then following formulars are valid:

$$DSN_{longitudinal} = \sigma_{longitudinal}^2$$

$$DSN_{lateral} = \sigma_{lateral}^2$$

The advantage of standard deviation is, that an offset does not influence the result. The advantage of DSN values is that the driving behavior is described more detailed, but an offset influences the calculated DSN values.

## 6.3. Descriptors for Test Limit Check & Speed Distribution

The user has the possibility to define limits for different tests (see chapter 4.2).

Following limits can be defined:

- **AllowedMaxSpeed** for maximum speed [km/h]
- **TimeLimit4Speed** for allowed time outside speed limit without coloring maximum value [s]
- **AllowedMaxLateralAcc** for maximum allowed lateral acceleration [ $m/s^2$ ]
- **TimeLimit4LateralAcc** for allowed time outside lateral acceleration limit without coloring maximum value [s]
- **AllowedMaxSpeedUp** for allowed speed up acceleration [ $m/s^3$ ]
- **TimeLimit4SpeedUp** for allowed time outside acceleration limit without coloring maximum value [s]
- **Deceleration** for maximum deceleration [ $m/s^2$ ]
- **AllowedMaxBraking** for allowed time outside deceleration limit without coloring maximum value [s]
- **TimeLimit4Braking** for allowed time outside acceleration limit without coloring maximum value [s]
- **SpeedRangeThreshold1** for speed threshold 1 for percentage calculation [km/h]
- **SpeedRangeThreshold2** for speed threshold 2 for percentage calculation [km/h]
- **MinimumSpeed4Evaluation** as required speed threshold for evaluation [km/h]

Different limit parameters can be defined and added. For further definitions, additional test preferences are added by creating an extra column in the *xlsx*-file with all test preferences.

	A	B	C	D	E	F
1	<b>Parameter</b>	<b>Unit</b>	<b>Default</b>	<b>Variant_1</b>		
2	AllowedMaxSpeed	km/h	250	140		
3	TimeLimit4Speed	s	60	60		
4	AllowedMaxLateralAcc	m/s <sup>2</sup>	10	10		
5	TimeLimit4LateralAcc	s	10	10		
6	AllowedMaxSpeedUp	m/s <sup>2</sup>	9	9		
7	TimeLimit4SpeedUp	s	10	10		
8	AllowedMaxBraking	m/s <sup>2</sup>	-9	-9		
9	TimeLimit4Braking	s	10	10		
10	SpeedRangeThreshold1	km/h	60	55		
11	SpeedRangeThreshold2	km/h	90	110		
12	MinimumSpeed4Evaluation	km/h	7	7		
13						

A selection of the desired parameters is possible with *Test Preferences* (Parameter tab: Limit). For each imported file, the test preference defined in column C of sheet Test Preference Data is used as initial value for imported data.

All statistical values concerning test limit check are based on user's selection.