



# Technical Specification

**ISO/TS 18571**

## Road vehicles — Objective rating metric for non-ambiguous signals

*Véhicules routiers — Mesures pour l'évaluation objective de  
signaux non ambigus*

**Second edition  
2024-05**

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at [www.iso.org/patents](http://www.iso.org/patents). ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 36, *Safety and impact testing*.

This second edition cancels and replaces the first edition (ISO/TS 18571:2014), which has been technically revised.

The main changes are as follows:

- more descriptions about window size for dynamic time warping were provided. Ten percent of data length was used as window size;
- for slope score calculation, a modified algorithm was developed. In the new algorithm, a nine-point moving average method was used to keep data point symmetry and slope curve smooth;
- in original Annex data sets, some time intervals were not consistent with variations at thousandth digit. Now, data sets were cleaned up and time interval variations were eliminated. New rating results on Annex data sets were provided and all figures and tables were updated accordingly.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

Computer Aided Engineering (CAE) has become a vital tool for product development in the automobile industry. Various computer programs and models have been developed to simulate dynamic systems. To maximize the use of these models, the validity and predictive capabilities of these models are assessed quantitatively. Model validation is the process of comparing CAE model outputs with test measurements in order to assess the validity or predictive capabilities of the CAE model for its intended usage. The fundamental concepts and terminology of model validation have been established mainly by standard committees including the American Institute of Aeronautics and Astronautics (AIAA)<sup>[2]</sup>, the American Society of Mechanical Engineers (ASME) Standards Committees on verification and validation of Computational Solid Mechanics<sup>[3]</sup> and Computational Fluid Dynamics and Heat Transfer<sup>[4]</sup>, the Defense Modeling and Simulation Office (DMSO) of the U.S. Department of Defense (DoD)<sup>[5]</sup>, the United States Department of Energy (DOE)<sup>[6]</sup> and various other professional societies <sup>[19],[20]</sup>.

One of the critical tasks to achieve quantitative assessments of models is to develop a validation metric that has the desirable metric properties to quantify the discrepancy between functional or time history responses from both physical test and simulation result of a dynamic system<sup>[7],[16],[17]</sup>. Developing quantitative model validation methods has attracted considerable researchers' interest in recent years <sup>[11],[12],[13],[15],[17],[18],[23],[24],[26]</sup>. However, the primary consideration in the selection of an effective metric should be based on the application requirements. In general, the validation metric is a quantitative measurement of the degree of agreement between the physical test and simulation results.

This document is the essential excerpt of the ISO/TR 16250<sup>[1]</sup> which provides standardized calculations of the correlation between two signals of dynamic systems, and it is validated against multiple vehicle safety case studies.

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# Road vehicles — Objective rating metric for non-ambiguous signals

## 1 Scope

This document provides validation metrics and rating procedures to calculate the level of correlation between two non-ambiguous signals obtained from a physical test and a computational model and it is aimed at vehicle safety applications. The objective comparison of time-history signals of model and test is validated against various loading cases under different types of physical loads such as forces, moments and accelerations. However, other applications can be possible too, but are not within the scope of this document.

NOTE [Annex A](#) gives some examples of the application of this document.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

**3.1**  
**filtering** [standards.iteh.ai/catalog/standards/iso/c42e1ac3-e5d0-433b-9516-50cd7be3ac10/iso-ts-18571-2024](https://standards.iteh.ai/catalog/standards/iso/c42e1ac3-e5d0-433b-9516-50cd7be3ac10/iso-ts-18571-2024)  
smoothing of signals by using standardized algorithms

**3.2**  
**level of correlation**  
similarity of two signals

**3.3**  
**interval of evaluation**  
time domain that is used to calculate the correlation between two signals

**3.4**  
**rating**  
calculated value that represents a certain *level of correlation* ([3.2](#)) (objective rating)

**3.5**  
**sampling rate**  
recording frequency of a signal

**3.6**  
**time sample**  
pair values (e.g. time and amplitude) of a recorded signal

3.7

**time-history signal**

physical value recorded in a time domain

Note 1 to entry: Time-history signals are non-ambiguous.

**4 Abbreviated terms and symbols**

**4.1 Abbreviated terms**

CAE	Computer Aided Engineering
CORA	CORrelation and Analysis
DTW	Dynamic Time Warping
EEARTH	Enhanced Error Assessment of Response Time Histories
SME	Subject Matter Expert

**4.2 General**

$C, C(t)$	Analyzed signal (CAE signal)
$T, T(t)$	Reference signal (test signal)
$\Delta t$	Interval between two-time samples
$t$	Time signal (axis of abscissa)
$t_0$	Time zero of an event (e.g. test, crash, impact)
$t_{start}$	Starting time of the interval of evaluation
$t_{end}$	Ending time of the interval of evaluation
$N$	Total number of sample points (e.g. time steps) between the starting time $t_{start}$ and ending time $t_{end}$

**4.3 Corridor score**

$Z$	Corridor score
$Z(t)$	Corridor score at time $t$ (curve)
$k_Z$	Exponent factor for calculating the corridor score between the inner and outer corridors
$a_0$	Relative half width of the inner corridor
$b_0$	Relative half width of the outer corridor
$\delta_i$	Half width of the inner corridor
$\delta_o$	Half width of the outer corridor
$\delta_i(t)$	Lower/upper bounds of the inner corridor at time $t$ (curve)
$\delta_o(t)$	Lower/upper bounds of the outer corridor at time $t$ (curve)



$N_{>0}$	All natural numbers without zero
$T_{\text{norm}}$	Absolute maximum amplitude of the reference signal $T$

#### 4.4 Phase, magnitude and slope scores

##### 4.4.1 General

$C^{\text{ts}}, C^{\text{ts}}(i)$	Truncated and shifted CAE curve
$C^{\text{ts}+w}$	Warped CAE curve of $C^{\text{ts}}$
$C_0^{\text{ts}+d}$	Derivative CAE curve of $C^{\text{ts}}$
$C^{\text{ts}+d}$	Derivative CAE curve of $C^{\text{ts}}$ after averaging
$T^{\text{ts}}, T^{\text{ts}}(j)$	Truncated and shifted test curve
$T^{\text{ts}+w}$	Warped test curve of $T^{\text{ts}}$
$T_0^{\text{ts}+d}$	Derivative test curve of $T^{\text{ts}}$
$T^{\text{ts}+d}$	Derivative test curve of $T^{\text{ts}}$ after averaging

##### 4.4.2 Phase score

$E_p$	Phase score
$k_p$	Exponent factor for calculating the phase score $E_p$
$\varepsilon_p^*$	Maximum allowable percentage of time shift
$m$	Time steps moved to evaluate the phase error
$n_\varepsilon$	Number of time shifts to get $\rho_E$
$\rho_E$	Maximum cross correlation of all $\rho_L(m)$ and $\rho_R(m)$
$\rho_L(m)$	Cross correlation – signal is moved to the left
$\rho_R(m)$	Cross correlation – signal is moved to the right

##### 4.4.3 Magnitude score

$E_M$	Magnitude score
$k_M$	Exponent factor for calculating the magnitude score $E_M$
$\varepsilon_M^*$	Maximum allowable magnitude error
$\varepsilon_{\text{mag}}$	Magnitude error
$n$	Number of data samples of time shifted and truncated curves ( $C^{\text{ts}}$ and $T^{\text{ts}}$ )

## ISO/TS 18571:2024(en)

$d$	Local cost matrix to perform the dynamic time warping
$d(i, j)$	Local cost function to perform the dynamic time warping
$d_{\text{tw}} [i, j]$	Cumulative cost matrix
$D_{\text{TW}}$	Dynamic time warping distance
$D_{\text{TWopt}} (i, j)$	Cost of the optimal warping path
$i$	Index number of time shifted and truncated CAE curve $C^{\text{ts}}$
$i_l$	Index number of $l$ -th warping path of curve $C^{\text{ts}}$
$j$	Index number of time shifted and truncated test curve $T^{\text{ts}}$
$j_l$	Index number of $l$ -th warping path of curve $T^{\text{ts}}$
$k$	Index number of any warping path
$\tilde{k}$	Number of data samples of the optimal warping path
$w$	Optimal warping path
$w_l$	The $l$ -th warping path cell

### 4.4.4 Slope score

$E_S$	Slope (topology) score
$k_S$	Exponent factor for calculating the slope score $E_S$
$\varepsilon_S^*$	Maximum allowable slope error
$\varepsilon_{\text{slope}}$	Slope error

### 4.5 Overall ISO rating

$R$	Overall ISO rating
$w_Z$	Weighting factor of the corridor score $Z$
$w_P$	Weighting factor of the phase score $E_P$
$w_M$	Weighting factor of the magnitude score $E_M$
$w_S$	Weighting factor of the slope score $E_S$
$r$	Rank of the sliding scale of the ISO metric
$S_{\text{Clower}} (r)$	Lower threshold of rank $r$
$S_{\text{Cupper}} (r)$	Upper threshold of rank $r$

## 5 General data requirements

The metric described in this document requires non-ambiguous curves (e.g. time-history curves). Furthermore, it is required that the reference curve  $T(t)$  and the evaluated curve  $C(t)$  are both defined between starting time  $t_{start}$  and ending time  $t_{end}$ . Both curves shall have the same number of sample points  $N$  with a constant time interval  $\Delta t$  within the evaluation interval.

## 6 ISO metric

### 6.1 General

The approach of this document is to combine different types of algorithms to get reliable and robust assessments of the correlation of two signals. The calculated score provides fair assessment for poor and for good correlations of two signals. The two most promising metrics are identified in Reference [1], they are the CORA corridor method and EEARTH. A combined metric based on the improved CORA corridor method and EEARTH is then proposed for this document which has been fully validated using responses from multiple vehicle passive safety applications.

Figure 6.1 shows the structure of the overall ISO metric. While the corridor method calculates the deviation between curves with the help of automatically generated corridors, the EEARTH method analyses specific curve characteristics such as phase shift, magnitude and shape. Hence, the ISO metric consists of the two best available algorithms.

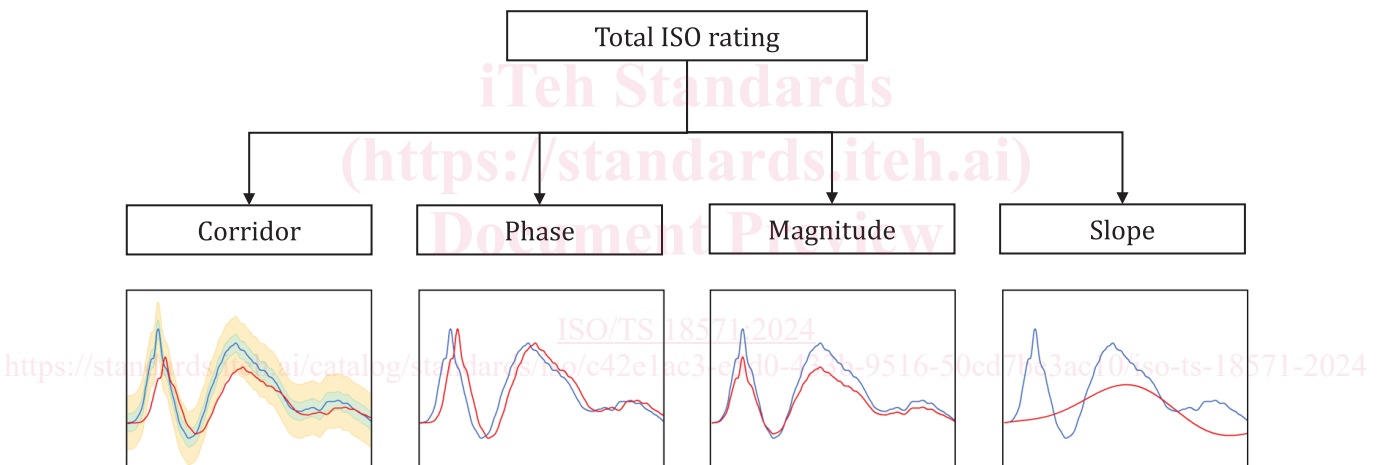


Figure 6.1 — ISO metric structure

### 6.2 Calculation of the overall ISO rating

The combination of the four metric ratings (corridor, phase, magnitude and slope) will provide a single number  $R$  for the correlation of the analysed signals which represents the final overall objective rating. The overall objective rating  $R$  is calculated by combining the separate sub-ratings of corridor ( $Z$ ), phase ( $E_P$ ), magnitude ( $E_M$ ) and slope ( $E_S$ ). Four individual weighting factors are defining the influence of each metric on the overall rating [see Formulae (6.1) and (6.2)]. The corresponding weighting factors are shown in Table 6.1.

$$R = w_Z \cdot Z + w_P \cdot E_P + w_M \cdot E_M + w_S \cdot E_S \quad (6.1)$$

$$w_Z + w_P + w_M + w_S = 1 \quad (6.2)$$

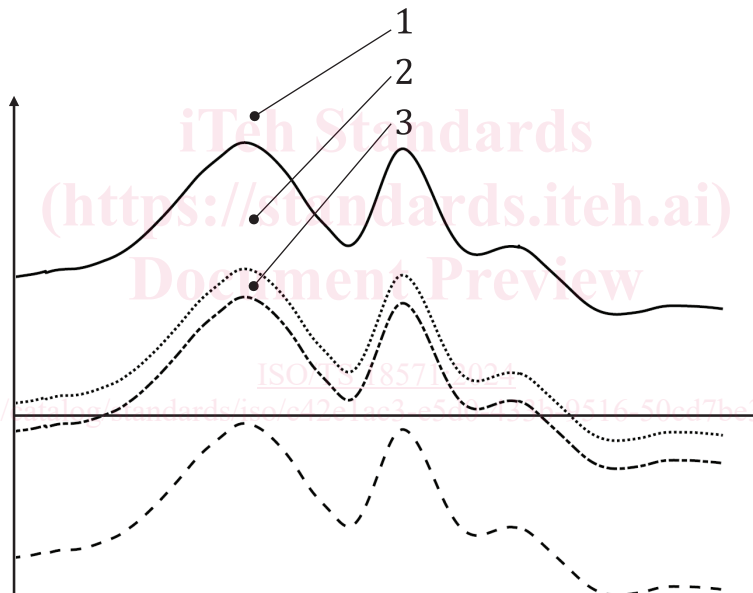
Table 6.1 — Weighting factors of the ISO sub-ratings

Parameter	Value	Description
$w_Z$	0,4	Weighting factor of the corridor score
$w_P$	0,2	Weighting factor of the phase score
$w_M$	0,2	Weighting factor of the magnitude score
$w_S$	0,2	Weighting factor of the slope score

### 6.3 Corridor score

#### 6.3.1 General

The corridor metric calculates the deviation between two signals by means of corridor fitting. The two sets of corridors, the inner and the outer corridors, are defined along the mean curve. If the evaluated curve  $C$  is within the inner corridor bounds, a score of “1” is given and if it is outside the outer corridors bounds, the score is set to “0”. The assessment declines from “1” to “0” between the bounds of inner and outer corridors resulting in three different rating zones as shown in Figure 6.2. The compliance with the corridors is calculated at each specific time  $t$  and the final corridor score  $Z$  of a signal is the average of all scores  $Z(t)$  at specific times  $t$ .



**Key**

- 1 rating = 0
- 2  $0 < \text{rating} < 1$
- 3 rating = 1

Figure 6.2 — Rating zones of the corridor metric (corridors of constant width)<sup>[9]</sup>

The philosophy of the ISO approach is to use a narrow inner corridor and a wide outer corridor<sup>[14]</sup>. It limits the number of “1” ratings to only good correlations and gives the opportunity to distinguish between poor and fair correlations. If the outer corridor is too narrow, too many curves of a fair or moderate correlation would get the same poor rating of “0”, like signals of almost no correlation with the reference. Basically, the width of the corridors can be adjusted in order to reflect the specific signal characteristic. The width can be constant for the whole duration of the dynamic responses or vary at the different time intervals. This document applies the most common approach of using constant corridor widths for the whole duration of the dynamic response<sup>[1],[25]</sup>.

### 6.3.2 Calculation

The parameters  $a_0$  and  $b_0$  define the relative half widths of the inner and the outer corridors. Both shall be between “0” and “1”, and  $a_0$  shall be less than  $b_0$ . The absolute half widths of both corridors are defined as the product of relative half width and the absolute maximum amplitude  $T_{\text{norm}}$  of the reference signal  $T$ . [Formula \(6.3\)](#) shows the calculation of  $T_{\text{norm}}$  and it is calculated within the interval of evaluation.

$$T_{\text{norm}} = \max\{|\min(T)|, |\max(T)|\} \quad (6.3)$$

The absolute half width of the inner corridor (absolute distance from the reference signal to the outer bounds of the inner corridor) is defined by [Formula \(6.4\)](#). The calculation of the absolute half width of the outer corridors [see [Formula \(6.5\)](#)] is similar to that of the inner corridors.

$$\delta_i = a_0 \cdot T_{\text{norm}} \quad 0 \leq a_0 \leq 1 \quad (6.4)$$

$$\delta_o = b_0 \cdot T_{\text{norm}} \quad 0 \leq b_0 \leq 1 \quad \text{and} \quad a_0 < b_0 \quad (6.5)$$

Based on these definitions the lower and upper bounds of the inner corridor are defined by [Formula \(6.6\)](#) and the lower and upper bounds of the outer corridor are defined by [Formula \(6.7\)](#).

$$\delta_i(t) = T(t) \pm \delta_i \quad (6.6)$$

$$\delta_o(t) = T(t) \pm \delta_o \quad (6.7)$$

[Formula \(6.8\)](#) shows the calculation of the corridor score for the correlation between the reference signal  $T$  and the analysed signal  $C$  at each evaluation time  $t$ . If the absolute difference between the signals  $T$  and  $C$  is less than the half width of the inner corridor ( $\delta_i$ ), then the score is set to “1”. The score is calculated by [Formula \(6.8\)](#) when the absolute difference between both signals is in between  $\delta_i \leq |T(t) - C(t)| \leq \delta_o$ . If the absolute difference between both signals is greater than the half width of the outer corridor ( $\delta_o$ ), then the score is set to “0”. The parameter  $k_z$  assesses the location of the analysed signal within the outer corridor, and it applies the appropriate penalty on the score. A linear ( $k_z = 1$ ), quadratic ( $k_z = 2$ ), cubical ( $k_z = 3$ ) or any other regression relationship can be defined accordingly.

$$Z(t) = \begin{cases} 1 & \text{if } |T(t) - C(t)| < \delta_i \\ \left( \frac{\delta_o - |T(t) - C(t)|}{\delta_o - \delta_i} \right)^{k_z} & \text{if } \delta_i \leq |T(t) - C(t)| \leq \delta_o \\ 0 & \text{if } |T(t) - C(t)| > \delta_o \end{cases} \quad k_z \in N_{>0} \quad (6.8)$$

The final corridor score  $Z$  is calculated by averaging all single time step score  $Z(t)$  as shown in [Formula \(6.9\)](#). The parameter  $N$  represents the total number of sample points (e.g. time steps) between starting and ending times of the interval of evaluation.

$$Z = \frac{\sum_{t=t_{\text{start}}}^{t_{\text{end}}} Z(t)}{N} \quad (6.9)$$

One of the advantages of the corridor metric is the simplicity and the clearness of the algorithm. It reflects criteria which are used intuitively in engineering judgment. Sometimes this simplicity may be the disadvantage of the method. For example, a small distortion of the phase can lead to a very undesirable rating<sup>[1]</sup>.

Based on a sensitivity study of CORA<sup>[14]</sup> and as described in Reference <sup>[1]</sup>, fixed width corridors are employed and the most appropriate metric parameters are identified as shown in [Table 6.2](#).

Table 6.2 — Parameters of the corridor metric

Parameter	Value	Description
$a_0$	0,05	Relative half width of the inner corridor
$b_0$	0,50	Relative half width of the outer corridor
$k_Z$	2	Transition between ratings of “1” and “0” (progression)

### 6.3.3 Step by step procedure

First, the signals shall be pre-processed as described in [Clause 8](#). After preparing the signals for the analysis and defining the interval of evaluation, the maximum absolute amplitude  $T_{\text{norm}}$  of the reference signal  $T$  shall be determined within this interval. It is used to calculate the inner and outer corridors. The actual corridor assessment shall be executed within this defined interval. The total score ranges between “0” and “1”. A score of “1” does not mean that both signals are identical. Solely their correlation is mathematically perfect within the defined tolerances.

To summarize, the following step-by-step procedures shall be followed to calculate corridor score:

- Pre-process both signals according to [Clause 8](#).
- Calculate  $T_{\text{norm}}$  within the interval of evaluation by using the reference signal.
- Calculate the inner and the outer corridors.
- Calculate the corridor score  $Z(t)$  at every specific time  $t$  within the interval of evaluation.
- Calculate the total corridor score  $Z$  based on  $Z(t)$  and the number  $N$  of time sample points.

### 6.4 Phase, magnitude and slope scores

Phase, magnitude and slope (or so-called topology) error assessments between the time history curves  $T$  and  $C$  are used as objective rating metrics<sup>[23] [27]</sup> in addition to the corridor metric described before. The enhanced error assessment of response time histories (EEARTH) metric combines these three assessments to the global response error<sup>[27]</sup>. It is defined as the error associated with the complete time history with equal weight on each point. Quantifying the errors associated with these features of phase, magnitude and slope (topology) separately is challenging because there are strong interactions among them. For example, to quantify the error associated with magnitude, the presence of a phase difference between the time histories may result in a misleading measurement. A unique feature dynamic time warping (DTW)<sup>[22]</sup> is used to separate the interaction of phase, magnitude and slope (topology) errors. It aligns peaks and valleys as much as possible by expanding and compressing the time axis according to a given cost (distance) function<sup>[9]</sup>.

The ranges of the three errors are quite different and there is no single rating that can provide a quantitative assessment alone. Therefore, a numerical optimization method is employed to identify the appropriate parameters so that the resulted phase, magnitude and slope sub-ratings can match with SME’s ratings closely<sup>[8],[21]</sup>. [Figure 6.3](#) shows the workflow of the procedures and the details of the algorithms are described in the following subsections.