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Railway applications — Technical Report about the revision of EN 14363

National foreword

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der EN 14363

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European foreword

This document (CEN/TR 17039:2017) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

1 Scope

EN 14363 contains a lot of requirements which were modified during the last revision. The scope was also extended. It was found in the working group, that many decisions that were taken to formulate these modifications need to be documented to improve understanding and to allow a later further development if practice of applications shows the necessity. The work for the revision was organised in 8 subgroups. Many of these subgroups recorded the way to the proposals in reporting templates, which were used for the editing work. Afterwards discussion was ongoing in WG 10 and in the enquiry process. This available information needs to be summarised and presented in a common format in order to allow people not involved in the discussions to understand the background of the modifications.

2 Members of the different drafting groups for the revision of EN 14363

Bold X means group leader Normal X means group member	8.1 Editing	8.2 Test Conditions	8.3 Track Quality, Contact Conditions	8.4 Special vehicles	8.5 Stationary Tests	8.6 Simulation, Extension of acceptance	8.7 Track Loading	8.8 Ride Characteristics
HS (DE)	X	X		X	X		X	X
SZ (DE)	X	X				X		
MW (SE)		X	X	X		X		
BE (UK)			X			X		
PD (FR)		X	X	X			X	
AC (UK)	X	X			X	X		X
JS (AT)		X	X		X	X	X	
VB (FR)		X				X		
AB (FR)					X			
VB (DE)		X				X		
JC (FR)		X						
OC (FR)							X	
RD (FR)								X
HG (NO)		X	X				X	
AH (AT)		X	X				X	
TH (CZ)					X			X
M J (UK)				X				
AK (AT)						X		
TK (DE)		X	X		X			X
RK (DE)					X	X		X
NK (IT)			X			X		
DL (FR)		X			X		X	

Bold X means group leader Normal X means group member	8.1 Editing	8.2 Test Conditions	8.3 Track Quality, Contact Conditions	8.4 Special vehicles	8.5 Stationary Tests	8.6 Simulation, Extension of acceptance	8.7 Track Loading	8.8 Ride Characteristics
JÖ (SE)							X	
MO (UK)					X			X
OP (CH)		X	X		X	X		
UR (CH)		X					X	
AS (CH)		X						
RW (UK)		X		X				
MZ (DE)			X		X		X	

3 Changes to the scope

3.1 Scope extension

The standard was further developed from a pure collection of test specifications to a description of the process for assessment of running characteristics. In addition, it also contains specifications on an informative basis not necessarily to be used for the acceptance process.

The new process also includes the use of simulations. The requirements were further developed starting from the requirements specified in UIC 518:2009 and EN 15827 and refined in discussions inside WG 10 and its relating subgroups and in a second step by the DynoTRAIN research project.

The scope was extended to freight vehicles with nominal static vertical wheelset forces up to 250 kN (previously handled in EN 15687). Also the inclusion of vehicles intended for operation with cant deficiencies above 165 mm (previously handled in EN 15686) was covered by the new requirement to specify the combination of admissible speed and admissible cant deficiency. Additionally the loading conditions for the assessment have been defined more precisely.

Further a hint to a set of recommended values for admissible cant deficiencies to be chosen for broad international approval was included. It replaces the fixed requirements made for conventional vehicles in the previous version of the standard.

In order to close the open points in the Rolling Stock TSIs about track geometric quality and the achievability of the combination of the specified test conditions during on-track tests, the concept of defined target test conditions and the assessment of achieved test results against target test conditions was developed.

Further, it needed to be stated that the standard also contains quantities and dependencies that are not directly used for acceptance purposes, but for example for purposes of validation of simulation models or determination of operating conditions outside the reference conditions.

3.2 Limitation

In order to prevent misuse of the standard for non-railway and non-standard gauge vehicles, it was better described what needs to be considered when using it "by analogy" for such vehicles.

To clarify the limits of the scope, it was stated that the strength of the vehicle and mounted parts, passengers and train crew vibration exposure, comfort, load security and effects of cross wind are out of the scope of this standard – as well as the quantification of track deterioration or track fatigue.

3.3 Clarification

It was found that the old wording needed clarification: “Testing for acceptance of vehicles is based on some reference conditions of track. If these are not respected on certain lines, appropriate measures will be taken (speed modifications, additional tests, etc).”

The discussion in WG 10 showed that it was not possible to specify the underlying reference conditions by exact boundaries. The only way for clarification was to:

- state that all vehicles which were successfully assessed are able to be operated on tracks complying with EN 13803;
- describe the current state of the art in order to allow the EIM (European Infrastructure Managers) to continue to use their implemented process for operation under demanding track conditions in the future (for example on lines with curve radii below 250 m).

This includes two notes explaining why vehicles can also be operated safely outside the target test conditions. A third note clarifies that the methods of this standard may also be applied to determine operating rules under infrastructure conditions that are more severe than the target test conditions.

In this context, it was also stated that the document contains target test conditions for the geometric track quality, as they have been adjusted compared to the previous version of the standard.

As the target test conditions for stability testing were changed with respect of the target conditions of the TEN (Trans European Network), it was necessary to clarify, that the equivalent conicity to be included in the stability assessment might be higher in some national systems for the time being before the infrastructure target conditions are met. In this context, it was found necessary to state in a note that such national requirements do not necessarily have to include the maximum occurring values of equivalent conicity. This makes it possible to find practical test conditions and it reflects also testing at overspeed and that vehicles assessed as stable are in most cases far below the limit values.

3.4 Shifted to other sections

The allowances

- to deviate from the rules laid down if evidence can be furnished that safety is at least the equivalent to that ensured by complying with these rules and
- of variations from the defined conditions as specified by the article 7.1 of Directive 91/440 of EC which were stated in the scope of the 2005 version are now described more detailed in a separate clause (4). It is now stated that in case of deviations, these shall be reported, explained and taken into account when assessing the safety.

4 Fault modes

4.1 What was changed?

The explicit requirement on testing with deflated air springs was removed.

A new subclause 5.2.2 “Fault modes” and a new subclause in Annex T (Simulation of on-track tests), T.2.5 (Investigation of dynamic behaviour in case of fault modes) was introduced.

4.2 Why was it changed?

When testing with deflated air springs was introduced in UIC 518, air springs were a relative novelty in railway vehicles. Since then much experience has been gained and they are now very common and it was felt inappropriate to specify a test for the specific fault mode of deflated air springs, while many other possible fault modes were overlooked, such as faulty yaw dampers or failing active components.

In EN 14363:2005 faulty yaw dampers were also specifically mentioned in parallel to deflated air springs. A more open approach was also indicated in EN 14363:2005, this idea is further developed in the present revision of EN 14363.

It was therefore appropriate to further develop the writing in EN 14363:2005 and require a similar – more open – methodology for dynamics assessment. It is impossible in a standard like EN 14363 to foresee every possible relevant fault mode to assess since these will differ from vehicle to vehicle. Also, the technical development makes it necessary to adopt a methodology that can be used for future systems not known today.

It was not clear in EN 14363:2005 at what speed fault modes were to be tested, also not what test extent to apply. Therefore, a large variation of testing practice has evolved from country to country making it more difficult to follow a principle of testing in one country for acceptance in many.

With the introduction of simulations, it was also necessary to define under what conditions simulations can be used to assess fault modes.

Some important principles were clarified:

- Due to probability reasons, assessment of a fault mode is limited to running safety parameters, speed up to V_{adm} and cant deficiency up to I_{adm} .
- Independent fault modes shall be tested/ simulated independently, unless the analysis points out the combined fault is necessary to be assessed.
- The safety factor λ does not need to be derived for fault modes, see U.2.

4.3 Comments raised in the CRM process and how they were addressed

In the comment phase there were discussions, not on the principles but on the writing to make it clear yet open enough for its purpose.

The comments revealed concerns that the new approach would lead to requirements for additional testing which was not the intention. The intention was only to provide a framework to assess the relevant fault modes which may not be the same for each and every vehicle type.

To handle these concerns, modifications were made, where one of the most important changes was to clarify that potentially catastrophic failures of conventional mechanical parts are managed by the design and maintenance regime of the vehicle, and hence do not need to be additionally assessed.

5 Load conditions for testing

There were a number of different references to loading condition which were not consistent and clearly enough specified in the 2005 edition. It was concluded that for clarity, loading definitions used in EN 15663 would be the reference load cases, but where the loading conditions specified in EN 15663 are inappropriate then details for specific loading cases will be given where these apply. This is particularly the case with extreme loads. Testing in the context of EN 14363 does not relate to extreme cases, nor has it been used in the corresponding tests prior to the introduction of EN 14363 in European rail administrations. As a result, the test loading conditions to be used apply the relevant normal loading for the operation of the tested vehicle.

Another aspect was that extreme conditions could lead to outliers in the statistical sample that cannot be handled by the statistical approach of EN 14363.

Further it was agreed that the load cases to be used for stationary and on-track testing should be as consistent as possible and that for some tests not all of the load conditions need to be investigated.

For long distance and high speed trains without obligatory seat reservation it was found inadequate to test them only with occupied seats. Therefore, the load case "Design mass in working order" was adjusted by taking into account 2 P/m^2 in standing areas. It was found that this was already state of the art.

SNCF members of WG 10 explained, that vehicles for RER in Paris were always tested in a loaded condition taking into account up to 700 kg/m^2 in standing areas, referring to EN 15663:2009, 6.2. WG 10 decided that in future and if necessary, such a case should be handled as a notified national technical rule (NNTR). This will remove the possibility of uncertainty about when extreme loads are required to be considered and under which circumstances they are to be applied.

For handling the necessary fuel consumption during testing, some practical rules were specified, assuming that they will not be used to influence test results systematically. For locomotives, that normally have big fuel tanks, it was taken into account that measured values of track loading might vary too much if the full range of fuel consumption is used during testing. Therefore, the acceptable range was restricted to the upper third.

Another practical rule was created to specify the handling of loads that can be collected and/or distributed or spread along the railway track during operation.

The definitions of the load cases "empty" and "loaded" were concentrated in subclause 5.3.2 giving common rules for all tests described in EN 14363.

6 First stage assessment

6.1 General

In the 2005 edition, this topic was covered by Clause 4 'Stationary tests'. Concern was expressed that since some of the tests specified in the chapter were not in fact stationary but included movement of the test vehicle the title could therefore cause some confusion. As a result the title became the subject of much discussion, a suggestion to change the name to 'quasi-static tests' was rejected because this could also cause confusion since the term 'quasi-static' does not translate from English directly into other languages. As a result, the title of the clause was changed to 'first stage assessment' to reflect that generally the assessments that are identified in this chapter are carried out on a vehicle before the on-track testing is carried out.

The term assessment has been adopted to recognise that it is not always necessary to carry out physical tests to demonstrate the performance of a vehicle. In certain circumstances that are defined in the text of the clause, other means of demonstration of the performance is possible.

6.2 Safety against derailment on twisted track

Before the introduction of internationally accepted approval, the various approvals were carried out by each national authority. This process was generally carried out by the national railway. There was concern that a proper definition of the testing conditions did not exist, e.g. details such as tolerances on track gauge, track curvature etc. This was particularly so with the inclusion of additional institutions, who had not previously carried out these tests but were now permitted to perform the testing. A definition of the test conditions was therefore required. After inquiries with the railway test bodies, where they still existed, it became clear that there was no definitive definition of the test conditions that had historically been carried out, either arising from the UIC tests or for national requirements. In addition, the tests carried out in the past did not include records of the actual test conditions of the

track, such as track gauge, deviations from the 'nominal' values of track curvature or installed cant. As a result the current text does not define limits to be applied, but does require the track conditions to be recorded in the future. When sufficient data are available, it is the intention to specify limits that shall be applied that are both practical and relevant.

There was some confusion about the compatibility of the test conditions for each of the three test methods in the 2005 edition, the coefficient of friction was not consistent between the methods. The reason for the difference could not be determined although the three methods all derive from the original work carried out within the ERRI B55 project. As a result of the possible misinterpretation, it has been made clear that each method shall be considered separately.

As with the definition of track condition, investigations were carried out to determine the signal processing that had been applied to data recordings in the past. No information could be found about what processing was applied and so nothing could be specified with any confidence, again the processing that is applied in future test is required to be recorded with the intention that when sufficient data is available requirements will be formulated.

Method 1 as defined in the 2005 edition has caused some confusion. The requirements included a double requirement, with both the Y/Q limit and the flange climb wheel lift limit Δz , specified as acceptance criteria. This has been changed by removing the Y/Q limit with the Δz remaining as the acceptance requirement. However, the requirement is to record the Y/Q value during the tests, although this is not an acceptance criterion.

With current techniques it is not credible to analyse the interface conditions that influence the Δz value with certainty and so it is not permitted to carry out analysis of any changes to a vehicle that could affect Δz value. As a result any vehicle that differs from the tested vehicle shall be retested.

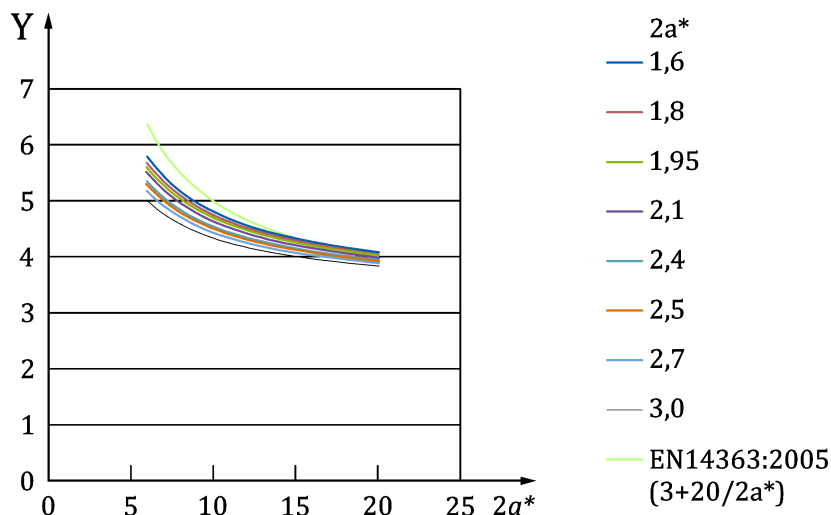
However, it is possible by using the recorded Y/Q values to analyse both the originally tested vehicle's performance and the performance of a vehicle that has undergone a change to the significant parameters of a vehicle using the method 2 criteria.

Method 2 now recognises that in the event of a change to a significant parameter of a vehicle (such as change in vertical stiffness) a vehicle type that has been previously accepted using method 2 can now be analysed to assess the effect of the change. The analysis can be made by comparing the performance of the original vehicle with that of the changed vehicle.

Method 3 In the 2005 edition, the twist criteria for the test was intended to be identical to that used in method 1, to maintain a consistent test condition. This resulted in a different test condition compared to the original criteria for method 3 which is defined in the GB RSSB document GM RT 2141.

A comment (GB 792) proposed to relax the bogie test twist of method 3 from 7 ‰ to 6,67 ‰ in order to be consistent with the origin of the requirement (GM/RT 2141, issue 3). A detailed analysis showed, that the original application of GM/RT 2141, issue 3, leads to a vehicle twist depending also on the bogie wheel base $2a^+$:

$$g_{GMRT}^* = 3,33\text{‰} + \frac{3,33\text{‰} \cdot (6m - 2a^+)}{2a^*}$$



Key

Y vehicle test twist in mm/m

$2a^*$ running gear distance in m

Figure 1 — Vehicle test twist as a function of vehicle dimensions

As this is lower than or roughly equal as the vehicle test twist specified in EN 14363:2005 (see Diagram) $g_{EN}^* = 3\text{‰} + 20\text{mm}/2a^*$, it was decided, to keep the vehicle test twist specification from EN 14363:2005 in combination with the slightly relaxed bogie test twist from GM/RT 2141 as it was proposed by the comment. Compared to the twist conditions of method 1 and method 2 this test condition remains roughly equal or more demanding, depending on the geometry of the vehicle to be tested.

To fit the two curves for bogie twist and vehicle twist, the limitation for the application of 6,67 ‰ needed to be increased from 5 m to 5,45 m.

6.3 Safety against derailment under longitudinal compressive forces in S-shaped curves

The tests referenced in this chapter, and detailed in EN 15839, reflect the requirements developed in the UIC leaflet 530-2. The reference has been changed from UIC 530-2 to EN 15839 and EN 14033-1 for special vehicles.

6.4 Evaluation of the torsional coefficient of a car body

This evaluation has been included since it is relevant to the tests for safety against derailment under longitudinal compressive forces in S-shaped curves and some of the tests for safety against derailment on twisted track. It was derived from ERRI B12/DT 135, Annex E and was refined in order to remove the influence of the roll moment from the results.

6.5 Determination of displacement characteristics

This chapter replaced the subclause 4.3 “Sway characteristics” in EN 14363:2005. This replacement and the inclusion of this evaluation has been made in conjunction with CEN/TC 256 WG 32, at their request. This evaluation is included because the tests described are generally performed when the other tests described in the First Stage Assessment are carried out. Only the tests are described, the data obtained is used in the processes of EN 15273. Details have been removed from the main text and placed in Annex D of the revised EN.

The term “flexibility coefficient” has replaced “roll coefficient” to relate directly to the EN 15273 series.

6.6 Loading of the diverging branch of a switch

For some railways the determination of a vehicle's performance is required when negotiating a diverging branch. The characteristics of the track at a diverging branch differ between countries and as a result it is not possible to define testing or acceptance criteria. Nevertheless, a methodology has been agreed for the process to be followed when there is a need to determine the performance when negotiating this track feature. Much of the work in developing the technique was carried out by DB but the limit values that were established during this work relates only to the DB situation. For other situations where the features of a diverging branch differ from the DB case, it would be necessary to carry out specific studies to determine specific limits for that case.

The following provides background about the work carried out by DB in determining the assessment of vehicles negotiating DB switches.

Switch Test (6.5 and Annex F)

A test which determines the loading on the turnout branch in switches was not specified in EN^o14363:2005. However, it was mentioned in the scope that this is an open point and a future inclusion of turnout runs in switches with $R \leq 190$ m in the normal and simplified measurement method is possible if test conditions will be fixed after further investigations.

In UIC 518:2009 test conditions have been specified in chapter 6.1.6 and Appendix N. These test conditions are adopted and incorporated in this revision, chapter 6.5 and Annex F. It has to be mentioned that no requirements for the assessment of the vehicle behaviour in switches and crossings are specified in this revision of EN 14363. Annex F is informative and presents a methodology for a consistent approach.

After an increase of rail failures in switch blades, see Figure 2, Deutsche Bahn carried out fatigue tests of switch blades in order to determine the fatigue limit at the most critical section (fixed end of the switch blade). With the help of Finite Element calculations the maximum permissible Y and Q forces were determined in order to respect the fatigue stress limit.



Key

- 1 broken switch blade causes a high risk of derailment

Figure 2 — Broken switch blade in a switch (diamond crossing) with $R = 190$ m

6.7 Running safety in curved crossings for vehicles with small wheels

There is no international requirement for the assessment of the passage of a vehicle with small wheels as defined in this revision of EN 14363. The methodology given in Annex E is derived from earlier work carried out by ERRI (see UIC 510-2) but is presented only as a possible means of carrying out an assessment.

Some clarifications of the methodology were done, clarifying e.g. that when measuring angle of attack and lateral force it is necessary to measure these before a possible hit of the crossing nose and also that the reference diameter is for the minimum wheel diameter (worn). In UIC 510-2 it was assumed that the lateral forces are measured using H-force measurements. Criteria have now been introduced also when using instrumented (load measuring) wheelsets. An option to replace a missing assessment quantity (angle of attack or lateral force) has been specified. A continuous formula instead of discrete values for flange height defining allowed dispensation from test has been introduced.

7 Statistical analysis and multiple regression

7.1 Background

For the assessment of on-track test results EN 14363 uses a statistical approach. Tests are done on a small part of the future field of application and statistical methods are applied in order to estimate or predict the highest future values of the assessment quantities. These estimated maximum values are compared to the limit values.

7.2 Relationship of assessment parameters and input variables

Motivation and justification for this approach can be explained by Figure 3. It shows results from tests done with the loco 120 within DynoTRAIN. The 0,15 % or 99,85 % values (depending on the curve direction) of ΣY in curved track sections are plotted. The left diagram is the full sample of all constant radius curve sections, plotted against the sample number. The other diagrams indicate the influence of several input quantities. The expected main input parameters are speed, curvature, cant deficiency, track irregularities, contact geometry parameters and wheel-rail friction. In total, values from 2 274 sections are available, which all have different curve radii, track irregularities and have been operated with different uncompensated lateral accelerations. There are also differences in the wheel-rail contact conditions as well as in the wheel-rail friction. The relationship of ΣY to some of them is indicated in the other diagrams of Figure 3.

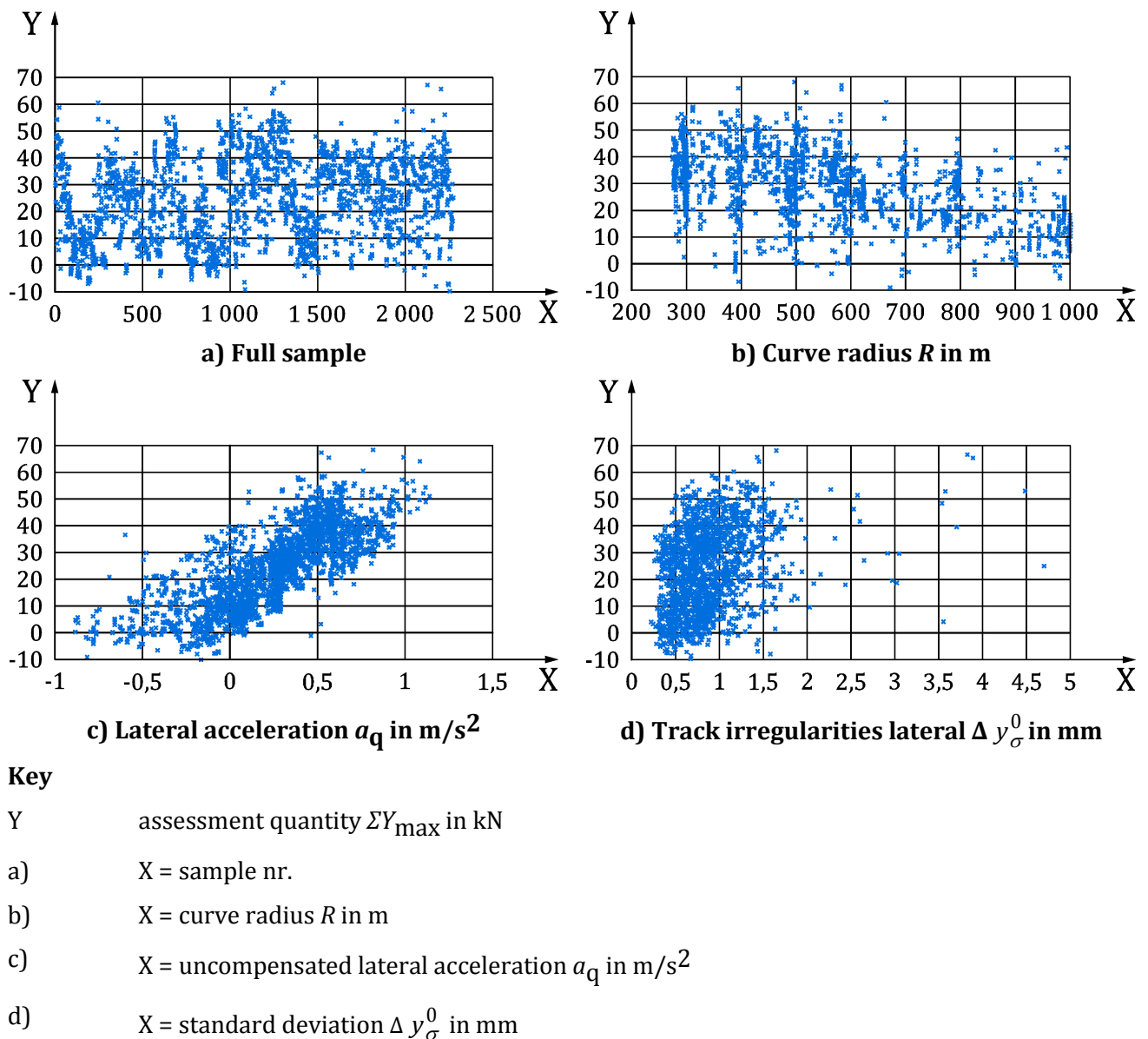


Figure 3 — Values of ΣY in curved sections, DynoTRAIN Loco 120, leading position

In the upper right one ΣY is plotted against curve radius in the respective section. There seems to be a clear tendency that forces decrease if curve radius increases. But it has to be kept in mind that this diagram shows not only the influence of the curve radius, but includes also the influence of the other influencing or input parameters. The influence of two others is shown in the two other diagrams, uncompensated acceleration in the lower left and track irregularities in the lower right one. As parameter for track geometry the standard deviation of the band-pass filtered alignment (outer rail) is used.

There seems to be a clear tendency that forces increase, if the uncompensated lateral acceleration increases. For track irregularities we see not that clear tendency, although forces seem to increase with increasing standard deviation of alignment.

Looking at these results (which are typical for most results from on-track tests), we conclude that the vehicle response consist of some parts which depend in a more or less deterministic way on input

parameters, such as curve radius or cant deficiency. The results include additional influences, which could depend on unknown or un-measurable parameters or are the consequence of the stochastic character of the vehicle response.

7.3 Assessment methods

The question is how to conclude, from the test results, the future behaviour of the vehicle in every condition of input parameters to be considered. There are a number of ways to do this.

One possibility is to measure the full network and assess the behaviour by comparing the values to limit values. De facto, this is an assessment of the highest value found. So assessment takes only one situation into account. If this situation changes, the result will change also, and the status of the network changes always, due to deterioration, maintenance, new lines, etc. The results contain an element of random behaviour and therefore, for a specific test run, the limit value may or may not be respected. For larger networks or interoperable rolling stock the approach of testing on the entire network is unachievable.

Another possibility is to identify the critical situations and measure the vehicle response there. This may be done on a specially built test track (as e.g. the test ring in Pueblo, USA from AAR/TTCI), or some selected pieces of service track. This approach requires to identify and quantify the desired critical situations and to build and maintain these features in the test track. Another main disadvantage is, that it depends very much on the vehicle design, which situations (e.g. speed, cant deficiency, curvature, track irregularities and their combinations) are critical for a vehicle and which are not. As the assessment is usually done by comparing the measured values with limit values, there is also the problem of the random nature of the vehicle response. Experience in the USA was in some cases, that vehicles passed the tests and derailed in situations, where the conditions were assumed to be significantly less critical than those in the tests.

EN 14363 uses a different approach: Because of the random nature of the vehicle reactions and in order to limit the amount of tests, statistical methods are used.

7.4 Assessment by statistical methods in EN 14363

7.4.1 General

The principle is to model the measured parameters and use this statistical model to predict the range of future values. The upper range of the predicted values is then assessed against the limit value.

In EN 14363:2005 two statistical methods are mentioned:

- one-dimensional method;
- two dimensional method (or simple regression).

In the new version additionally the multiple regression method has been introduced.

Mathematically spoken, all three methods are regression methods, where the data are modelled using no input parameter (one-dimensional method), one input parameter (two-dimensional method with cant deficiency as input parameter) or more input parameters (multiple regression).

7.4.2 One-dimensional method

EN 14363:2005 gives a formula for calculating the estimated maximum of the assessment parameters for running safety:

$$Y(PA)_{\max} = \bar{y} + ks_y \quad (1)$$

with $\bar{y}$ as the mean value of the sample, s_y as the standard deviation and

$k=3$ for running safety parameters;

$k = 2,2$ for other parameters.

This is a simplification of the formula resulting from regression model with no input parameter ("intercept only model") as [1]

$$Y(PA)_{\max} = \bar{y} + t(PA, f) \left(1 + \frac{1}{N} \right) s_y \quad (2)$$

with N as the sample size (number of sections, $f = N - 1$ as the degree of freedom, PA the significance level of the Student t-distribution (confidence level), which is 99 % for running safety parameters and 95 % for the other parameters.

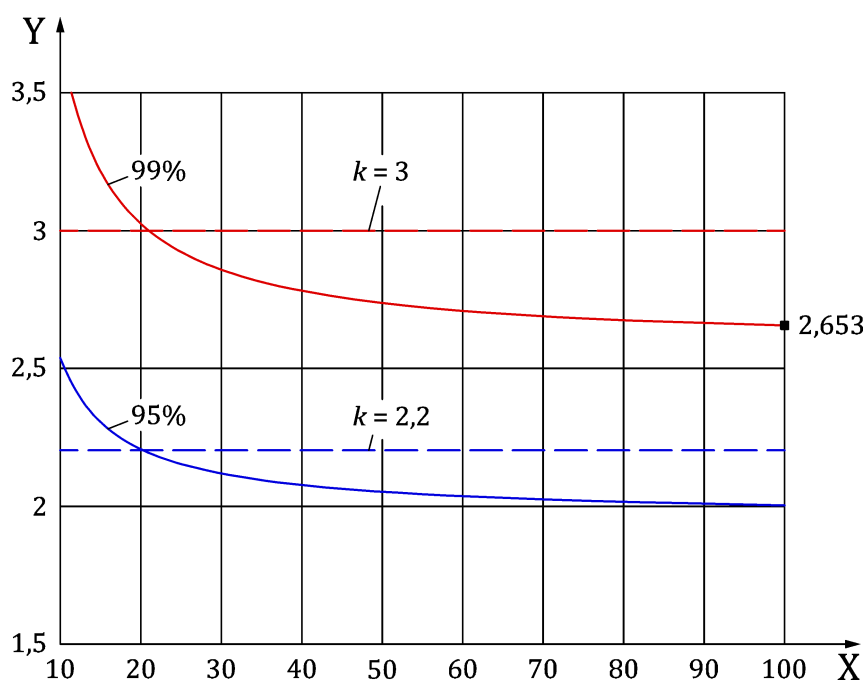
This can be derived assuming that

$$y_i = \beta_0 + e_i = \bar{y} + e_i \quad (3)$$

with e_i as difference to the regression, here the mean. e_i is called residuum or statistical error. s_y^2 is an estimation of the variance of the errors.

As Formula (1) is a simplification of the exact Formula (2) we can compare. In Figure 4 the coefficients k from Formula (1) are compared with those from Formula (2). Below a sample size $N = 20$ the values from the simplified formula are lower than those from the exact formula. This is not relevant because the minimum sample size is 25. At a sample size of 25 the exact formula gives 2,908 8 instead of 3,0 (confidence level 99 %). At a sample size of $N = 100$ the result is 2,65 and the value converges to 2,575 8 at very large samples.

In the revised EN 14363 the exact formula has been introduced.



Key

- X number of samples
- Y $t(PA, f) * (1 + 1/N)$ or k

Figure 4 — Comparison of simplified formula for one-dimensional method in EN 14363 and the exact formula

EN 14363:2005 required a minimum number of sections of $N \geq 25$ (50 for test zone 3). UIC 518:2009 allows also the use of a smaller number of sections between 15 and 24 (49). In these cases UIC 518:2009 uses Figure 4 by defining a higher value of the student factor $t(PA)$.

Studies within DynoTRAIN showed that the latter approach may lead to unreliable results, because with a small number of sections the regression assumptions are unlikely to be respected. Other changes implemented in EN 14363:2016 make it easier to reach the required number of sections. Therefore the scale factors from UIC 518:2009 have not been adopted.

The one-dimensional method has a number of limitations. If the output variable includes a deterministic dependency to an input, this variation is modelled as a statistical error. This can be demonstrated by the following example: Here a sample has been created, with varying cant deficiency a_q , which is normal distributed. A deterministic relationship between the output ΣY and the input a_q is assumed as

$$\Sigma Y / \Sigma Y_{lim} = -0,31667 + 0,83333a_q \quad (4)$$

The uncompensated lateral acceleration a_q has been varied, assuming normal distribution with a mean value

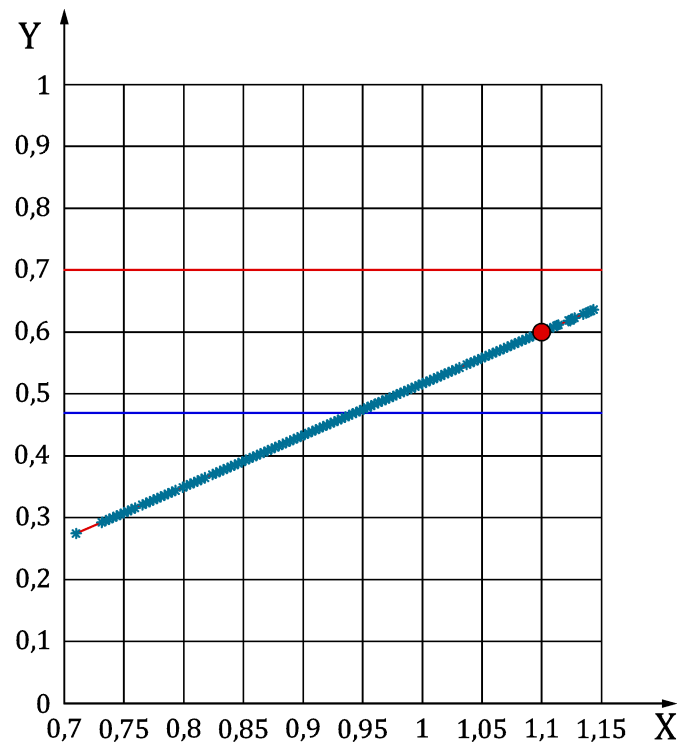
$$\text{mean}(a_q) = 0,945$$

and a standard deviation

$$\text{std}(a_q) = 0,1.$$

The values are then limited to the range between $0,7 \text{ m/s}^2$ and $1,15 \text{ m/s}^2$, as defined in EN 14363.

In Figure 5 the sample is plotted against the cant deficiency. The estimated maximum value using Formula (1) is $0,697$ and is plotted as a red line, the blue line is the mean value. The estimated maximum value is higher than all “measured” values, and significantly higher than the values resulting from the two-dimensional method, which is $0,6$ (indicated by the red circle).



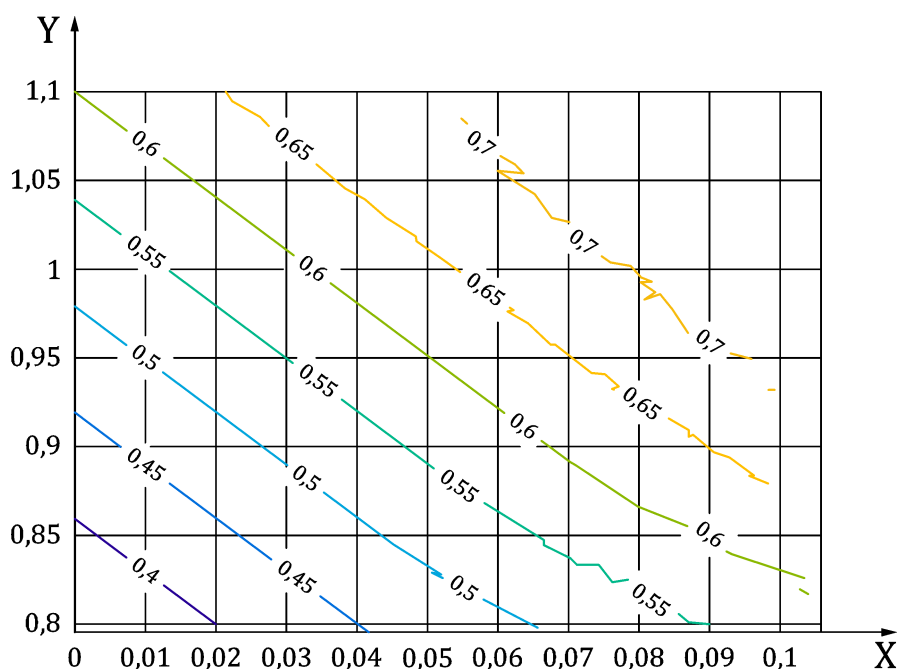
Key

X lateral uncompensated acceleration $a_{q,\text{mean}}$ in m/s^2

Y quotient $\Sigma Y / \Sigma Y_{\text{lim}}$

Figure 5 — Estimated maximum value using one-dimensional method on a purely deterministic sample

The next limitation is that the result depends on the “design” of the sample. This applies especially if there are strong dependencies on input variables. If for instance the response increases strongly with cant deficiency, then a higher estimated maximum value will result, if the cant deficiencies in the sample are higher. This can also be demonstrated with the example using Formula (4). The mean and the standard deviation of the uncompensated acceleration a_q has been varied and normal distributed samples of a_q have been calculated. The uncompensated lateral acceleration has been restricted to the range $0,7 \dots 1,15 \text{ m/s}^2$, therefore the distribution at higher means and standard deviations diverges slightly from the normal distribution.



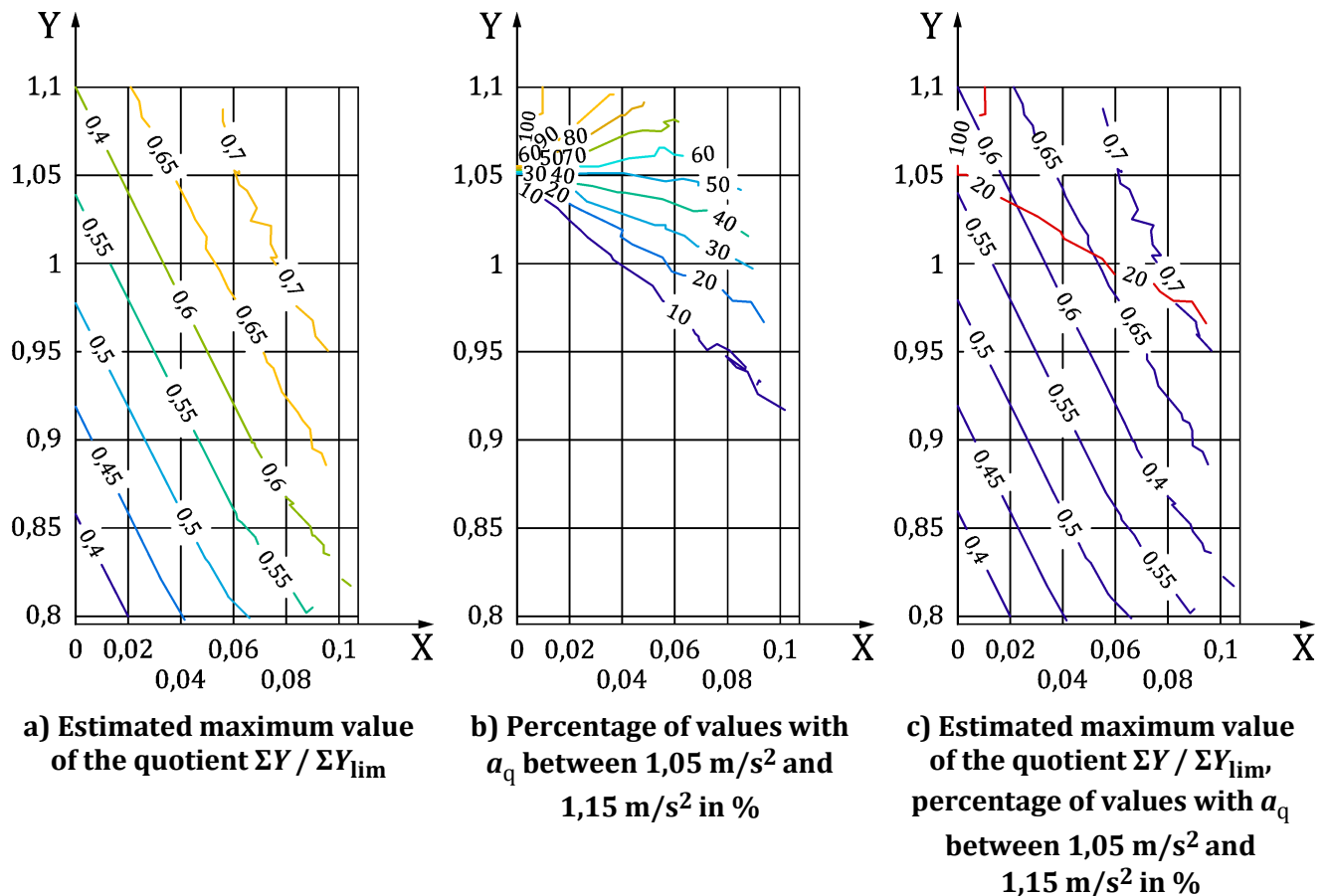
Key

- X standard deviation of uncompensated lateral acceleration a_q in m/s^2
Y mean value of uncompensated lateral acceleration a_q in m/s^2

Figure 6 — Maximum estimated values of the quotient $\Sigma Y / \Sigma Y_{\text{lim}}$ depending on mean and standard deviation of the input

Figure 6 shows the resulting estimated maximum values with varying mean and standard deviation of the input a_q . If the sample of the input parameters is at lower values, the estimated maximum value is significantly lower than the “correct” value of 0,6 from the two-dimensional method. If the mean is at 1,1 (which is the value where the two-dimensional method determines the estimated maximum value) the results depends on the variance of the input. With no variance we get 0,6, with increasing variance the estimated maximum values increases as discussed above in the context of Figure 5.

EN 14363 handles this problem by requiring that more than 20 % of the sections shall have an uncompensated lateral acceleration between 1,05 and 1,15 m/s^2 . In Figure 7 the percentage in this range is shown in the middle diagram and together with the estimated maximum values in the right diagram. Now the estimated maximum values are mostly higher than 0,6 and the result is quite well controlled.



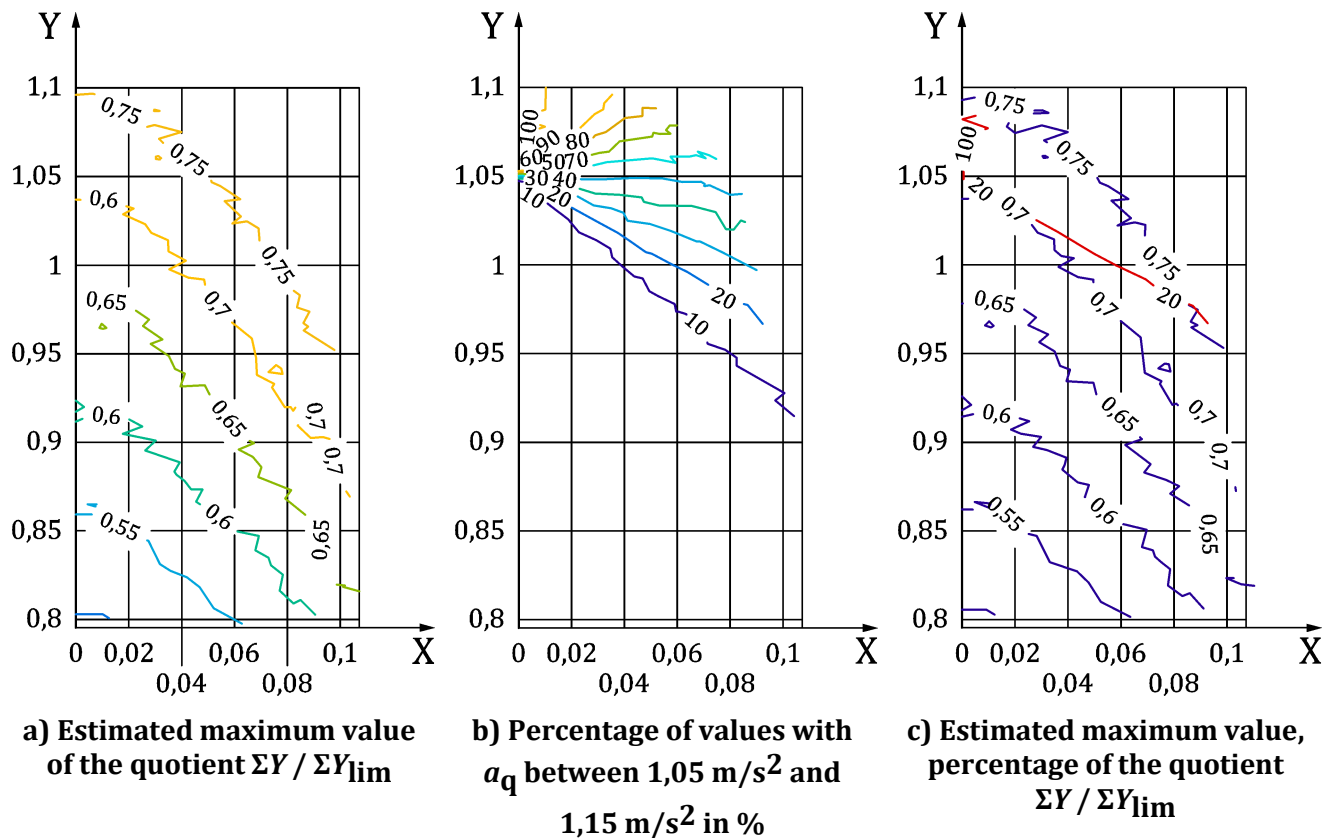
Key

X standard deviation of uncompensated lateral acceleration a_q in m/s²

Y mean value of uncompensated lateral acceleration a_q in m/s²

Figure 7 — Maximum estimated values depending on mean and standard deviation of the input and percentage of values with uncompensated lateral acceleration between 1,05 m/s² and 1,15 m/s²

If a random statistical error is introduced in Formula (4) the relations change. Figure 8 shows the result if a normal distributed statistical error with a mean equal to zero, a standard deviation of 0,01 is included.



Key

- X standard deviation of uncompensated lateral acceleration a_q in m/s^2
- Y mean value of uncompensated lateral acceleration a_q in m/s^2

Figure 8 — Maximum estimated values of the quotient $\Sigma Y / \Sigma Y_{\text{lim}}$ depending on mean and standard deviation of the input and percentage of values with uncompensated lateral acceleration between $1,05 \text{ m/s}^2$ and $1,15 \text{ m/s}^2$, model including a statistical error

So we may sum up that the one-dimensional method only gives correct results, if the input parameters (or parameters influencing the assessment quantities) have a small spread and are centred around the value where the highest response parameters occur. In EN 14363 this is ensured by limitations of the test conditions.

The main input parameters are speed, curvature, cant deficiency, track irregularities, contact geometry parameters and wheel-rail friction. EN 14363:2005 includes requirements on all these parameters.

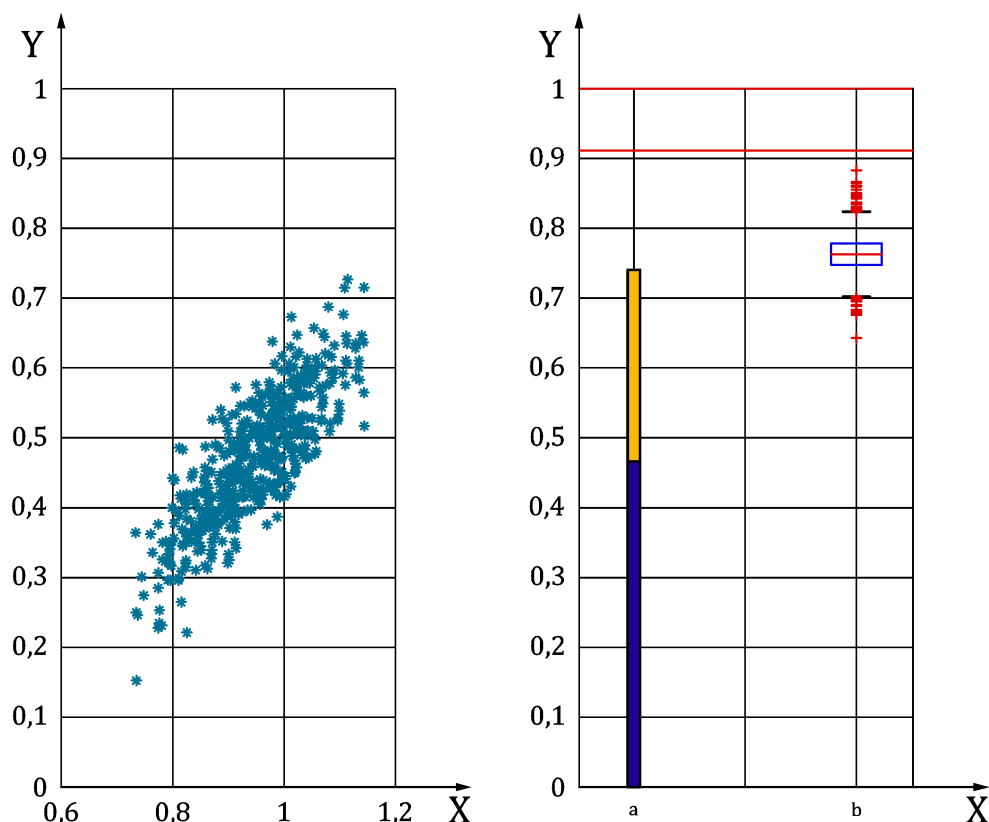
- Speed, which is a relevant parameter for test zone 1 (straight track) is limited to a small range $1,1V_{\text{adm}} \pm 5 \text{ km/h}$.
- Cant deficiency, which is a relevant parameter in curved tracks is limited to the range $(0,7 \dots 1,15)cd_{\text{adm}}$ with the additional requirement that a defined percentage ($> 20\%$ for one-dimensional method) of test sections have to be in the range $(1,05 \dots 1,15)cd_{\text{adm}}$.
- The influence of curvature is covered by separating the analysis into three zones: Zone 4 with radii between 250 m and 400 m, zone 3 with radii between 400 m and 600 m and zone 2, those sections

in curves where speed is in the range $(0,95 \cdots 1,15)V_{adm}$ and cant deficiency is in the $(0,7 \cdots 1,15)cd_{adm}$. The according curve radii depend on the admissible speed V_{adm} . Within test zone 3 and 4 the mean radius of all sections has to be within a defined range.

- Track irregularities are controlled by requiring a defined distribution for the standard deviations of alignment and longitudinal level ($50 \% \leq QN1, 10 \% > QN2$).
- Contact geometry is controlled by requiring tests on tracks with 1:20 and with 1:40 rail inclination and a limitation of equivalent conicity in case of unstable behaviour.
- Spread and influence of friction is controlled by requiring tests to be done only on dry rails.

This approach is correct and gives at first valuable results, if the underlying regression assumptions are respected. To derive Formula (2) one has to assume that the statistical errors are normal distributed [1]. One problem of restricting the sample by rigid conditions on the input parameters is that often a lot of sections have to be eliminated and samples become small. Such samples are very sensitive to deviations from normal distribution, which may distort the result. And there is no control of this necessary selection or elimination process.

The problem is demonstrated also with the synthetic data used above. A sample is created using a mean of 0,9 and a standard deviation of 0,1 for the a_q -sample. The scatter of the output is plotted in Figure 9 against the cant deficiency. In the right diagram the estimated maximum value of this sample is plotted as bar. From the sample 65 observations are in the range between 1,05 m/s² and 1,15 m/s². This is 13 %, which is less than the required 20 %. So some sections have to be removed, it is also allowed to use less sections. It is only required to use 25 sections in minimum. If this is done randomly, different estimated maximum values are calculated, which are plotted in the boxplot.



Key

- X lateral uncompensated acceleration a_q in m/s^2
- Y quotient $\Sigma Y / \Sigma Y_{lim}$
- a full sample
- b all samples

Figure 9 — Output (quotient $\Sigma Y / \Sigma Y_{lim}$) versus uncompensated lateral acceleration and estimated maximum values from one-dimensional analysis

7.4.3 Two-dimensional method

The two-dimensional method models the influence of cant deficiency using a linear regression. The following formula applies:

$$y_i = \beta_0 + \beta_1 a_{qi} + e_i \quad (5)$$

Here three parameters have to be estimated, the intercept β_0 , the regression coefficient β_1 and the errors e_i . In difference to the one-dimensional method, a certain variation or spread of the input parameter cant deficiency is needed in order to achieve a good estimation of the dependency.

In the “synthetic example” discussed above (created with Formula (4)), the result of the two-dimensional method is also shown in Figure 5. As this example is fully deterministic there is no statistical error in this model and the result is the exact deterministic value. In the following figure this is studied further. In the upper row data are analysed, where only the influence of the uncompensated lateral acceleration is considered according to Formula (4). Estimated maximum values are calculated with the one-dimensional and the two-dimensional method and plotted against the portion of sections