The Fourth International Conference on Railway Technology
RAILWAYS 2018
3–7 September 2018
Sitges, Barcelona, Spain

Validation Methodology for Rail Vehicle Dynamics Models: From Theory to Practice

Oldrich Polach
Independent consultant, Switzerland

Gernoth Götz
DB Regio AG, Germany

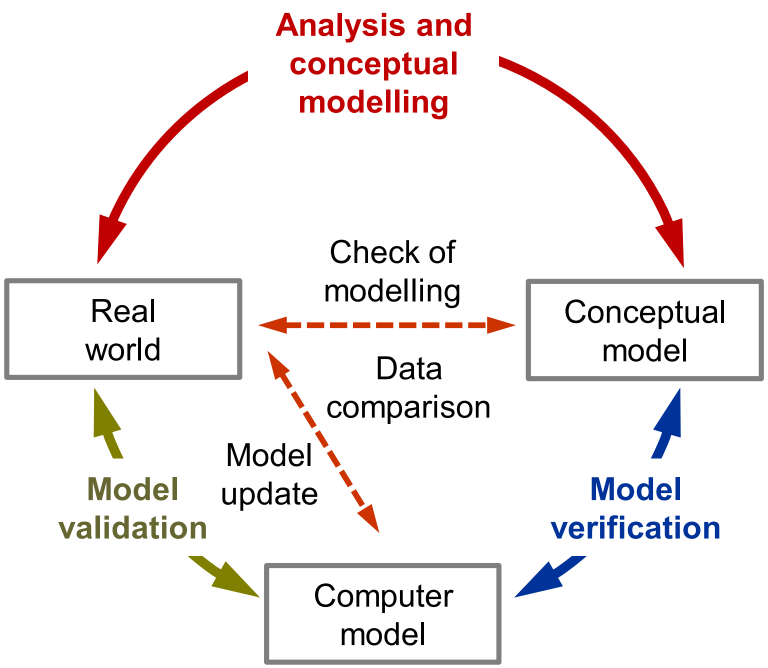
Contents

- Introduction: What is model validation?
- Peculiarities of model validation in rail vehicle dynamics
- Model validation methods according to standard EN 14363
- Validation according to Method 2 in EN 14363: New findings
- Summary and conclusions

What does the model validation mean?

- Methodology of Verification and Validation (V&V) of computer simulations is a research topic for more than four decades

Graphical representation of the fundamental meaning of V&V constructed by the Society for Computer Simulation

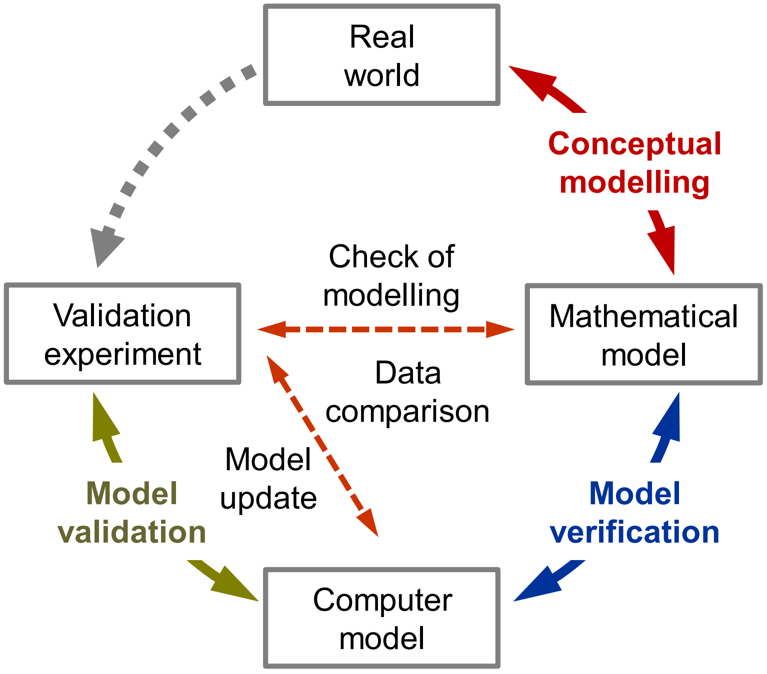


From (adapted): Schlesinger: Terminology for model credibility. Simulation, Vol. 32, Issue 3, 1979

What does the model validation mean?

- Methodology of Verification and Validation (V&V) of computer simulations is a research topic for more than four decades
- V&V is based on comparison with reality - but we do not know the reality - we only know the experiment results!

Graphical representation of the fundamental meaning of V&V

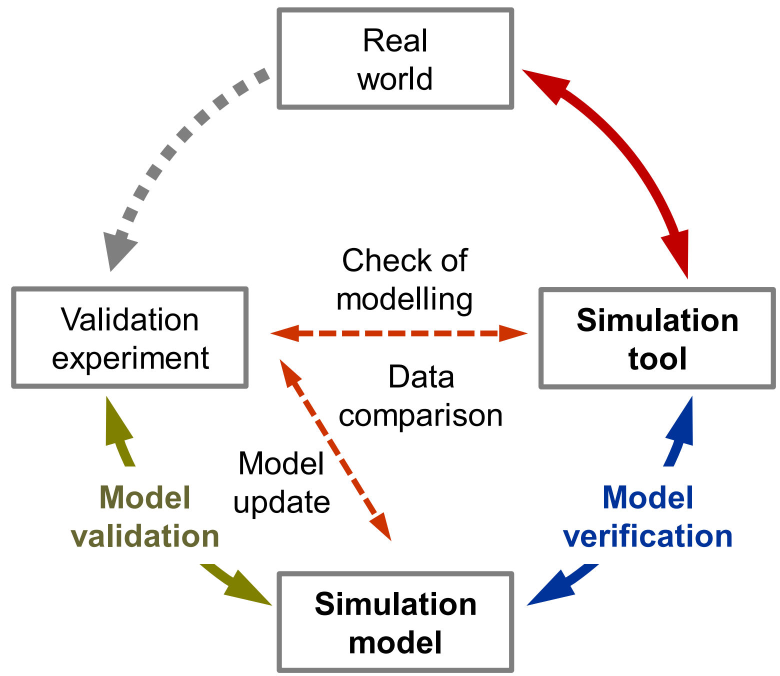


From (adapted): Kwasniewski, L., Bojanowski, C.: Principles of verification and validation. Proceedings of conference Application of Structural Fire Engineering, 19-20 April 2013, Prague, Czech Republic

What does the model validation mean?

- Methodology of Verification and Validation (V&V) of computer simulations is a research topic for more than four decades
- V&V is based on comparison with reality - but we do not know the reality - we only know the experiment results!
- Rail vehicle dynamics today:
  - Physical laws and relationships deeply understood
  - Multi-body commercial simulation tools developed, tested and compared in benchmarks
  - Simulation models are typically prepared using proven multi-body simulation programmes (tools) and represent a particular application of simulation tool on a certain vehicle and its state (empty/loaded etc.)
- Model validation method should contain a unique quantitative specification of:
  - Validation and application domains
  - Validation quantities
  - Validation metrics
  - Validation limit values
- Validation experiment and application domain considered in this presentation:
  - Testing for the acceptance of running characteristics according to EN 14363

Graphical representation of the fundamental meaning of V&V in railway vehicle dynamics

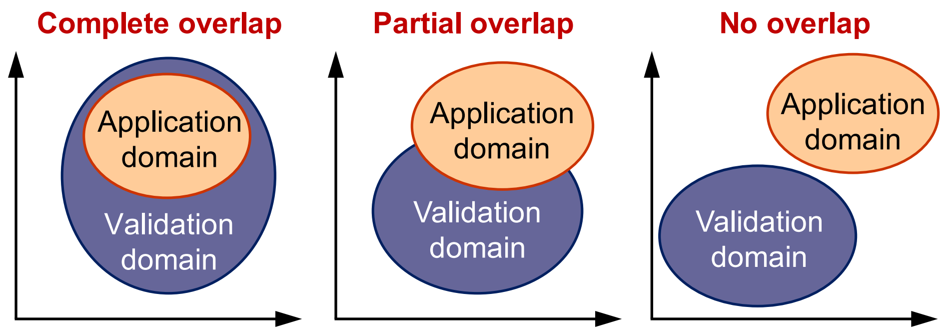


Contents

- Introduction: What is model validation?
- **Peculiarities of model validation in rail vehicle dynamics**
- Model validation methods according to standard EN 14363
- Validation according to Method 2 in EN 14363: New findings
- Summary and conclusions

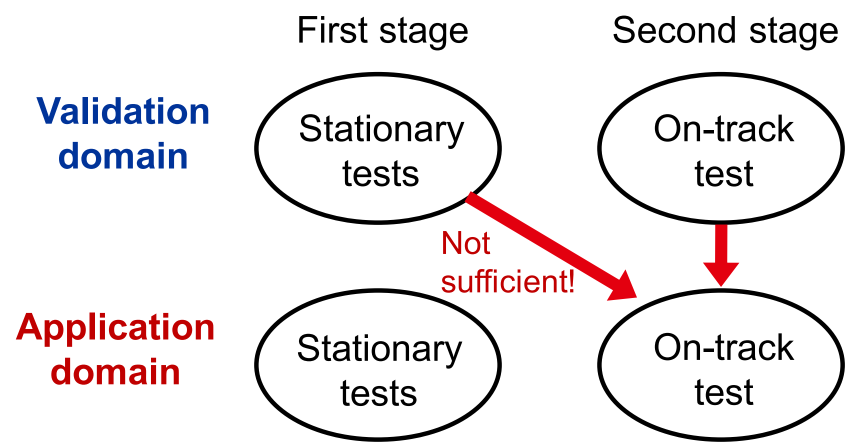
Validation and application domains

- Relationships between validation and application domain:
  - At least partial overlap required!



*From: Oberkampf, Trucano, Hirsch, 2004 * (adapted)*

- Testing for the acceptance of running characteristics acc. to EN 14363:
  - Stationary tests (First stage)
    - Test rigs
    - Slow speed tests in a short track sections
  - On-track test (Second stage)

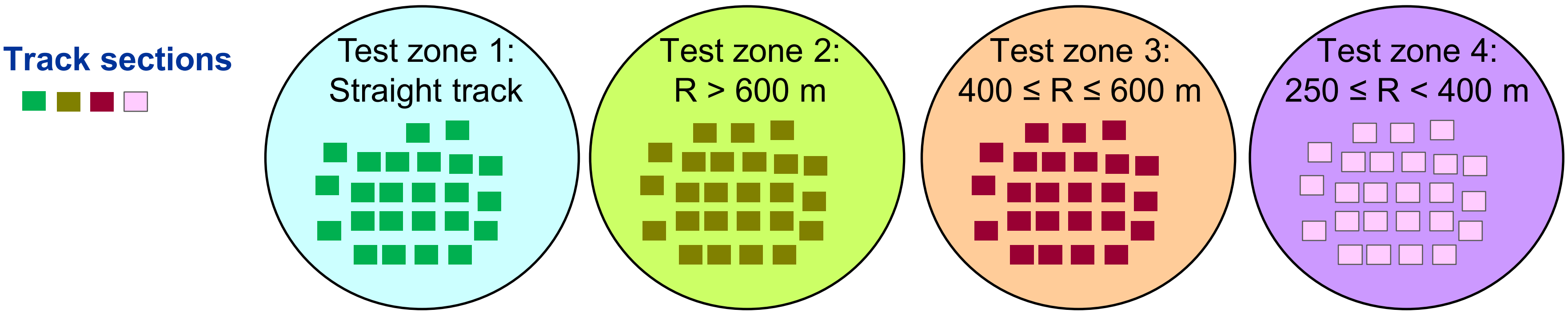


- In following we concentrate on the application domain of on-track tests
- This application requires validation using on-track test

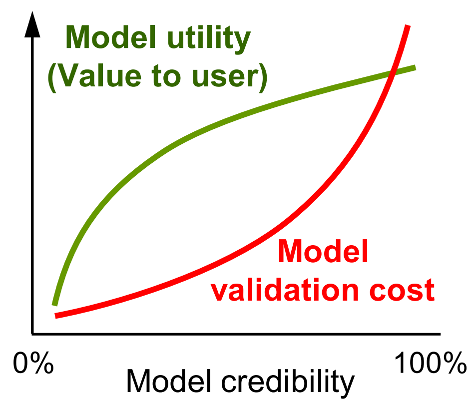
** Oberkampf, W.L., Trucano, T.G., Hirsch, Ch.: Verification, validation, and predictive capability in computational engineering and physics. Appl Mech Rev vol 57 (2004), no 5, pp. 345-384*

Validation experiment: On-track test
Validation runs, quantities, metrics

- On-track test according to EN 14363:
  - Experiment not designed for validation



- Measured quantities:
  - Accelerations (simplified measuring method)
  - Accelerations and wheel/rail forces (normal measuring method)
- Statistical evaluation of measurements:
  - Evaluation per section (maximum, median, rms-value)
  - Statistical evaluation of sections per test zone to determine the estimated values representative of the target test conditions
- What are the validation requirements and validation limits?
- Validation cost versus credibility of simulation model:
  - Too expensive validation creates a barrier in application of simulations!



*From: Sargent, 1988 * (adapted)*

** Sargent, G.: A tutorial on verification and validation of simulation models. Proc. of the 1988 Winter Simulation Conference, pp. 33-39*

Contents

- Introduction: What is model validation?
- Peculiarities of model validation in rail vehicle dynamics
- Model validation methods according to standard EN 14363
- Validation according to Method 2 in EN 14363: New findings
- Summary and conclusions

Model validation methods according to EN 14363:2016* Method 1

- This method is based on the validation method in UIC 518:2009
- Validation domain:
  - Stationary as well as on-track test
- Application domain:
  - Complete or partial on-track test
- Validation quantities:
  - List of suggested quantities which can be used for validation
- Validation metrics:
  - Various metrics suggested which can be used for validation
- Validation limits:
  - Validation limit values specified only for a small number of quantities
  - No requirement regarding the number of comparisons between simulation and measurement
  - No clear requirement what has to be demonstrated for successful validation
- Judgement of validation results by an independent reviewer required
- Examples of suitable application:
  - Test results from partial on-track test or simplified measuring method
  - Application domain where one can estimate the impact on dynamic behaviour well, e.g. comparison of tested and modified design solution

Method 1

** EN 14363:2016 Railway applications — Testing and simulation for the acceptance of running characteristics of railway vehicles — Running behaviour and stationary tests. CEN, Brussels, March 2016*

Model validation methods according to EN 14363:2016* Method 2

- This method is one of the results of EU research project Dynotrain (2009 – 2013)
- Validation domain:
  - Complete on-track test using normal measuring method

Method 2

- Application domain:
  - On-track test
- Validation quantities:
  - Quantities to be compared are described
- Validation metric:
  - Metrics to be used are described
- Validation limits:
  - Number of comparisons and limit values to be met for successful validation are specified
- No reviewer required
- Examples of suitable application:
  - Complete on-track test data using normal measuring method available
  - Application domain not restricted, deviations regarding to running dynamics between tested and simulated vehicle not easy to assess, simulation of complete on-track test (e.g. new vehicle similar to already tested and accepted vehicle)

** EN 14363:2016 Railway applications — Testing and simulation for the acceptance of running characteristics of railway vehicles — Running behaviour and stationary tests. CEN, Brussels, March 2016*

Validation Method 2 according to EN 14363:2016

- Validation is based on comparisons between simulation and measurement for 12 quantities, filtered and processed by analogy with EN 14363
- Each quantity is evaluated using at least two signals, e.g. acceleration above leading and trailing bogie
- Simulation and measurement results have to be compared for each quantity for at least 3 track sections per test zone (i.e. minimum of 12 track sections), so that at least 24 simulated values are compared with measured values for each quantity

Track sections

Quantities

Y_{qst} Y_{max}

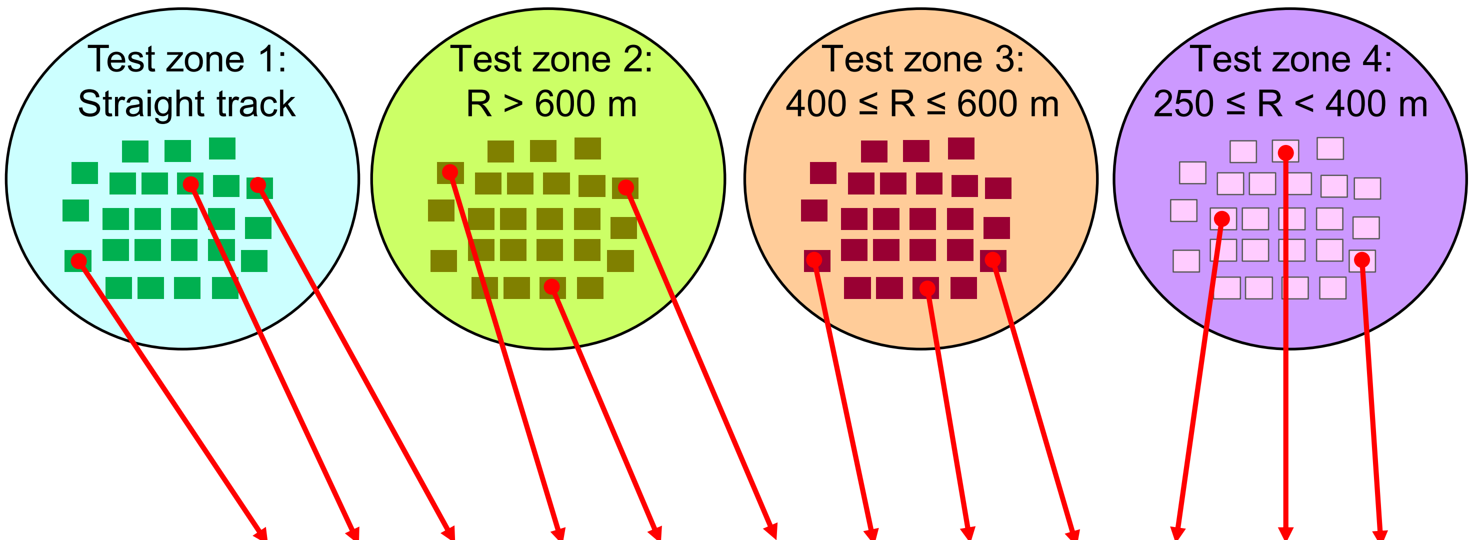
Q_{qst} Q_{max}

(Y/Q_{qst}) (Y/Q_{max})

ΣY_{qst} ΣY_{max}

$\ddot{y}^*_{rms}$ $\ddot{y}^*_{max}$

$\ddot{z}^*_{rms}$ $\ddot{z}^*_{max}$



Exercise number		1	2	3	4	5	6	7	8	9	10	11	12
Nomenclature	Unit												
z"*lm	m/s^2	0.300	-0.327	0.087	0.270	0.709	-0.306	0.352	0.274	-0.322	0.677	2.413	-0.137
z"*llm	m/s^2	0.181	-0.136	0.047	0.379	0.907	-0.187	0.296	0.488	-0.175	0.390	0.546	0.484

Set of differences simulation – measurement for $\ddot{z}^*_{max}$

Validation Method 2 according to EN 14363:2016

- Mean value and standard deviation of differences between simulation and measurement per each quantity are calculated and then normalized by the specified validation limits
- For successful validation, the standard deviation and the mean of the differences between the simulation values and the measurement values for all quantities must not exceed their validation limits

Evaluation of single quantity

Set of differences simulation – measurement for $\ddot{z}^*_{max}$

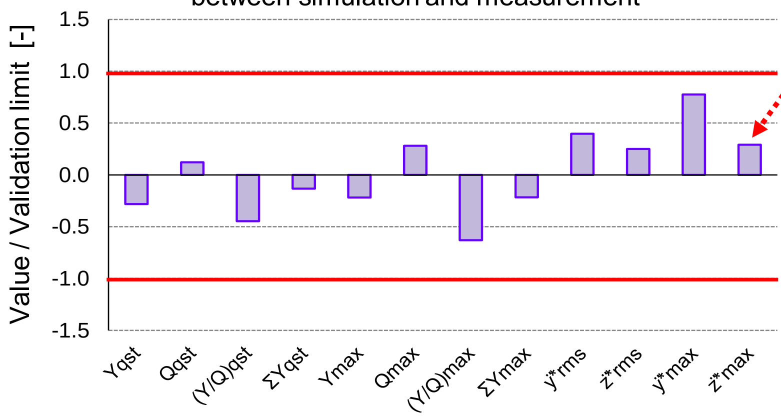
Exercise number		1	2	3	4	5	6	7	8	9	10	11	12
Nomenclature	Unit												
z"*Im	m/s^2	0.300	-0.327	0.087	0.270	0.709	-0.306	0.352	0.274	-0.322	0.677	2.413	-0.137
z"*IIm	m/s^2	0.181	-0.136	0.047	0.379	0.907	-0.187	0.296	0.488	-0.175	0.390	0.546	0.484

Mean value: 0.075 m/s^2
Validation limit: 0.267 m/s^2
Normalised mean value: **0.28**

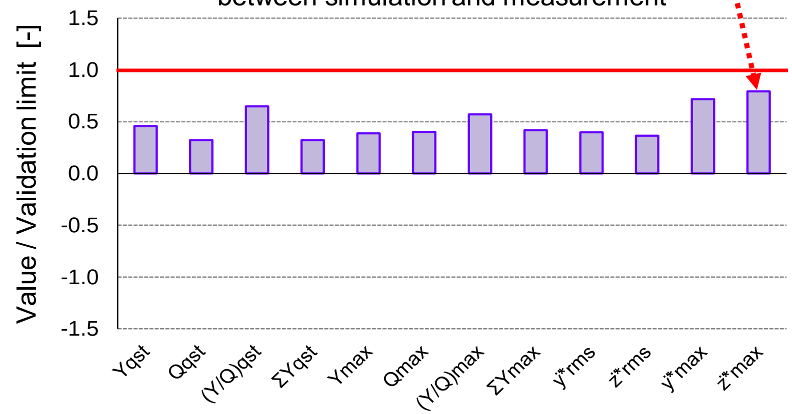
Standard deviation: 0.321 m/s^2
Validation limit: 0.400 m/s^2
Normalised standard deviation: **0.80**

Validation result

Normalised mean of differences between simulation and measurement



Normalised standard deviation of differences between simulation and measurement

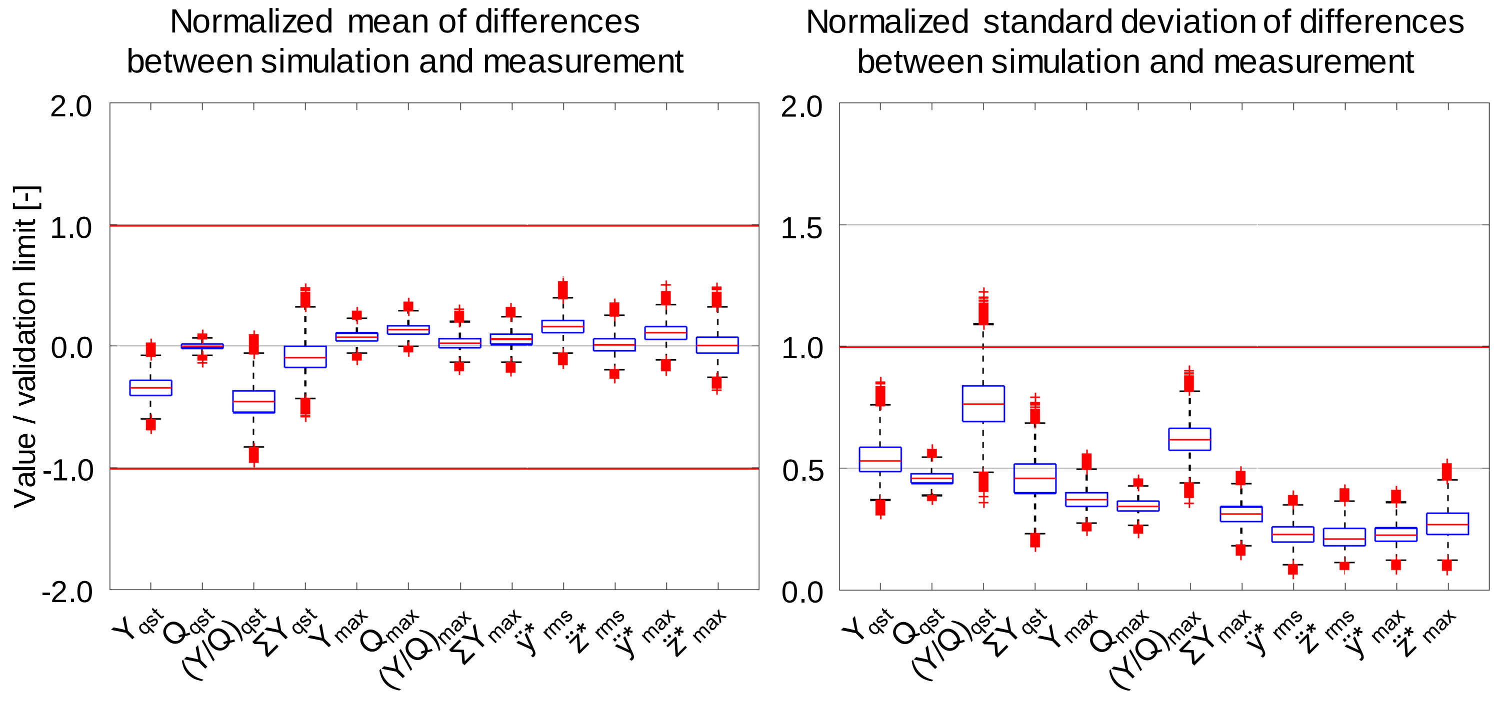


Contents

- Introduction: What is model validation?
- Peculiarities of model validation in rail vehicle dynamics
- Model validation methods according to standard EN 14363
- Validation according to Method 2 in EN 14363: New findings
- Summary and conclusions

Sensitivity of model validation according to Method 2 to the selection of track sections

- Variation of the result depending on the selection of track sections used for validation
  - 27,984,100,000,000 possible validation results!
  - Scatter of validation results presented in box-plot diagrams

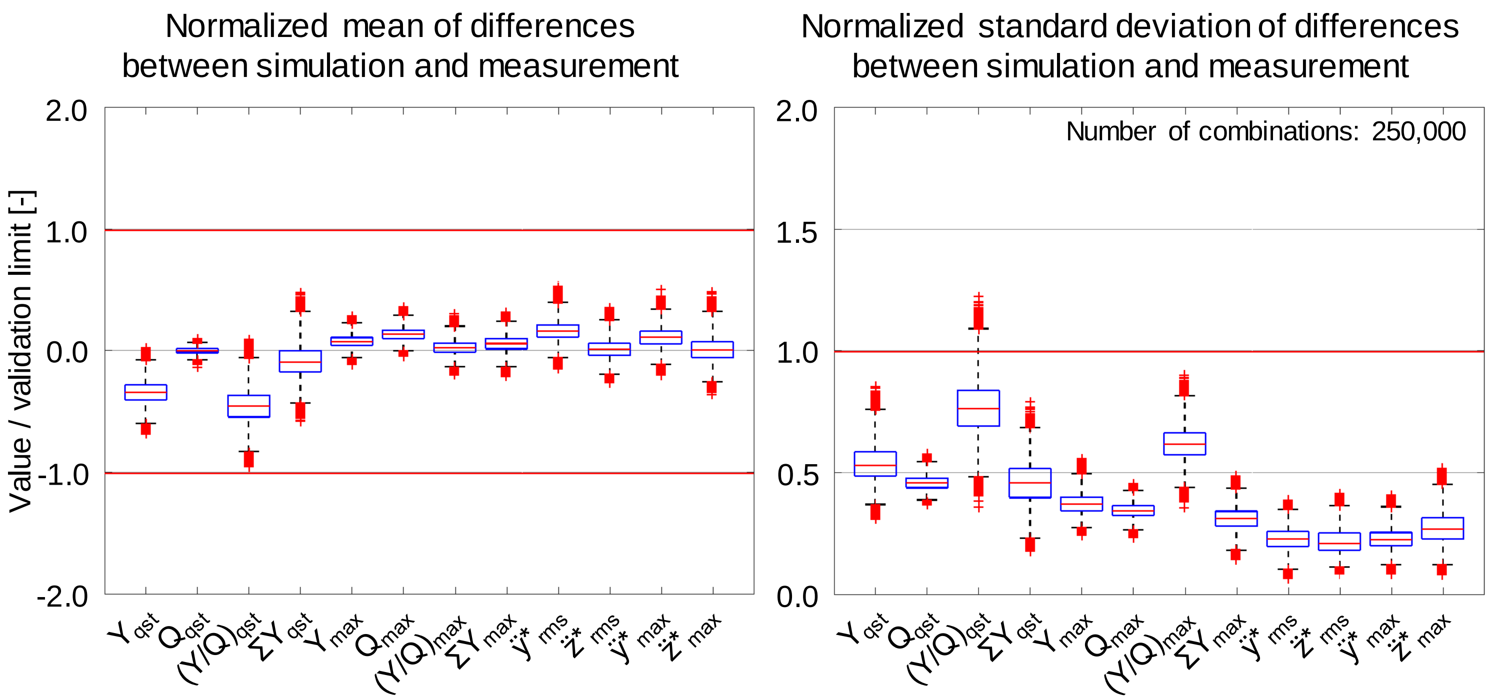


Götz, G.: Modellvalidierung in der Schienenfahrzeugdynamik für die fahrtechnische Zulassung. Thesis, TU Berlin 2018

Effect of number of track sections per test zone using symmetric distribution

- **3** track sections per test zone

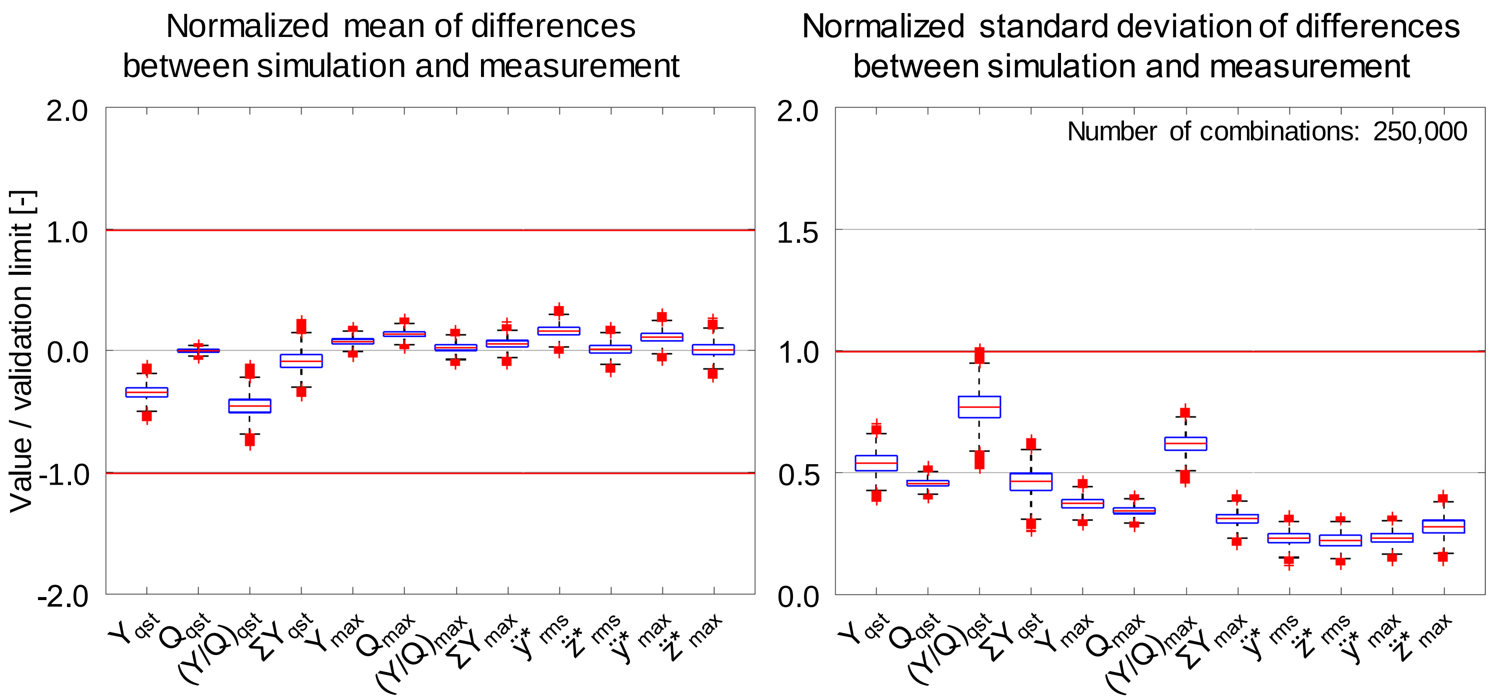
Validation requirements fulfilled: **98.0%**



Effect of number of track sections per test zone using symmetric distribution

- **7** track sections per test zone

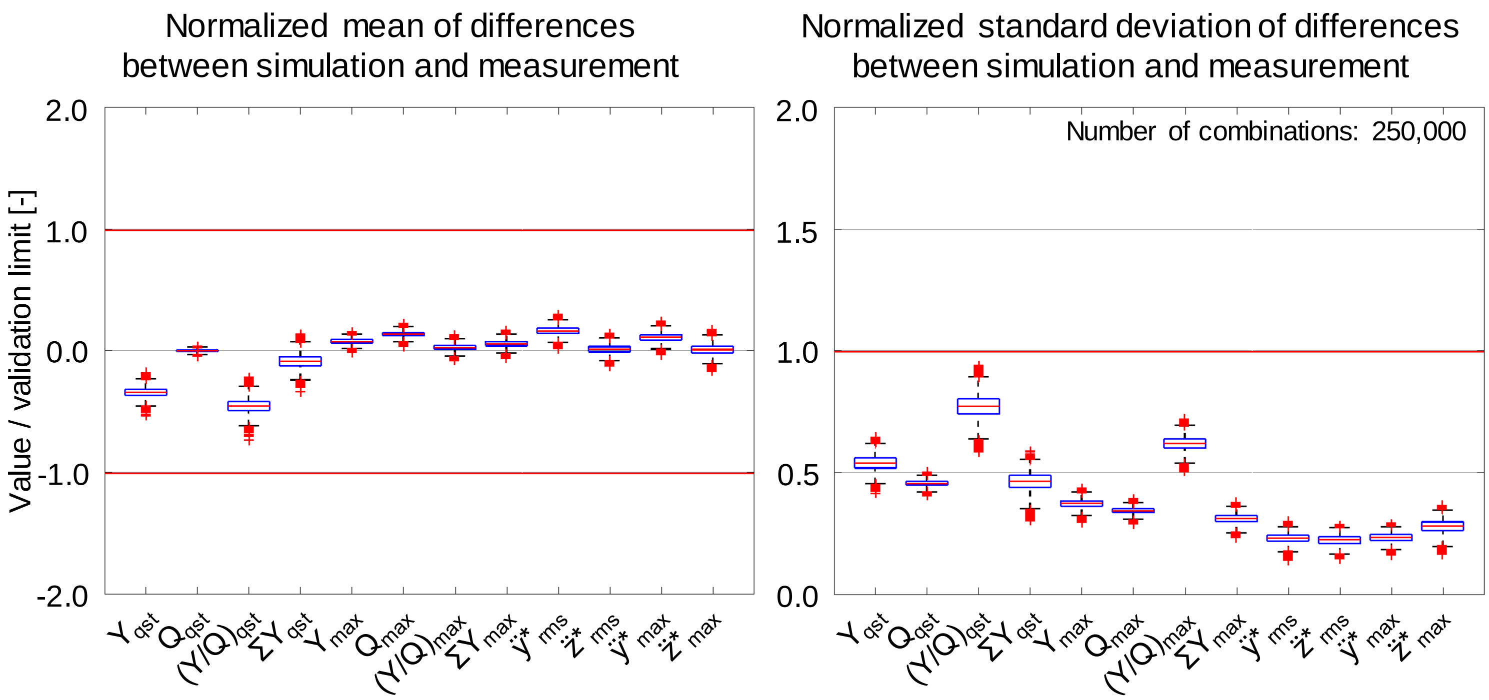
Validation requirements fulfilled: **100.0%**



Effect of number of track sections per test zone using symmetric distribution

- **11** track sections per test zone

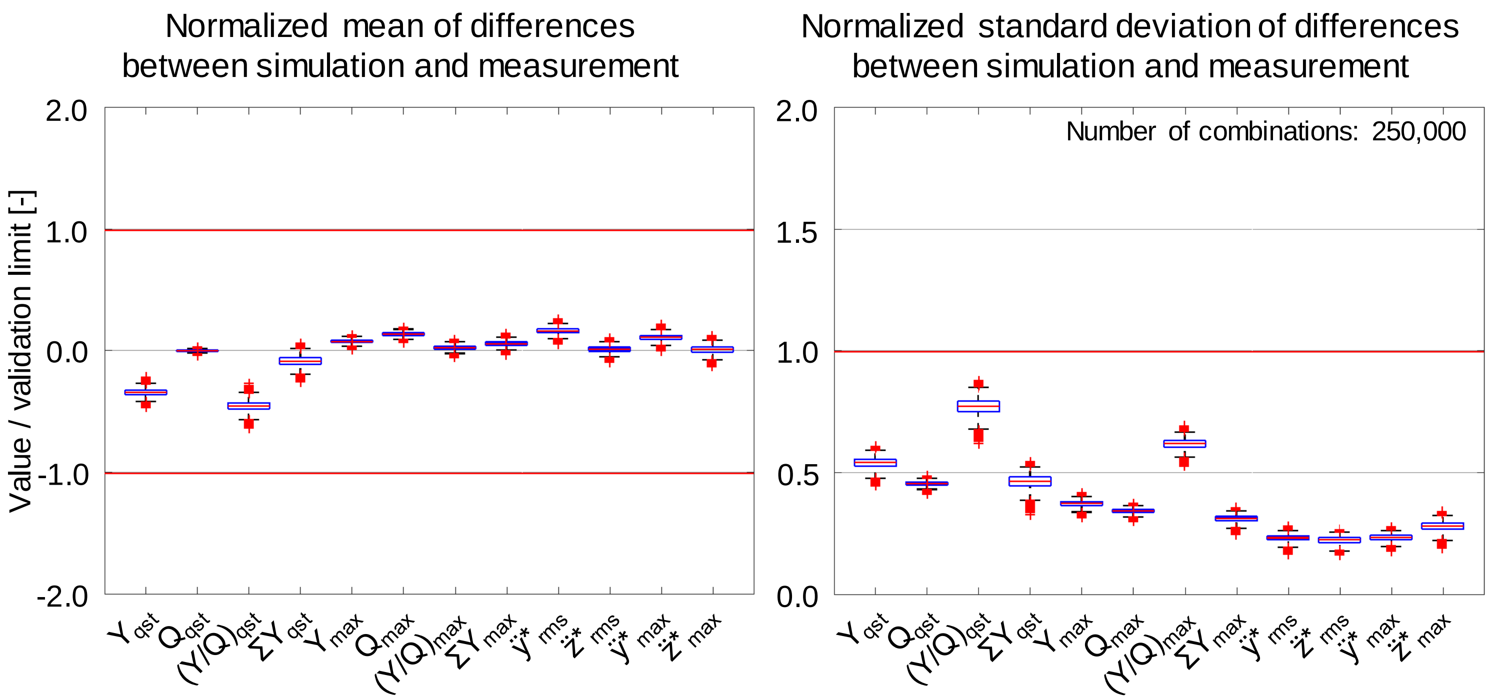
Validation requirements fulfilled: **100.0%**



Effect of number of track sections per test zone using symmetric distribution

- **15** track sections per test zone

Validation requirements fulfilled: **100.0%**



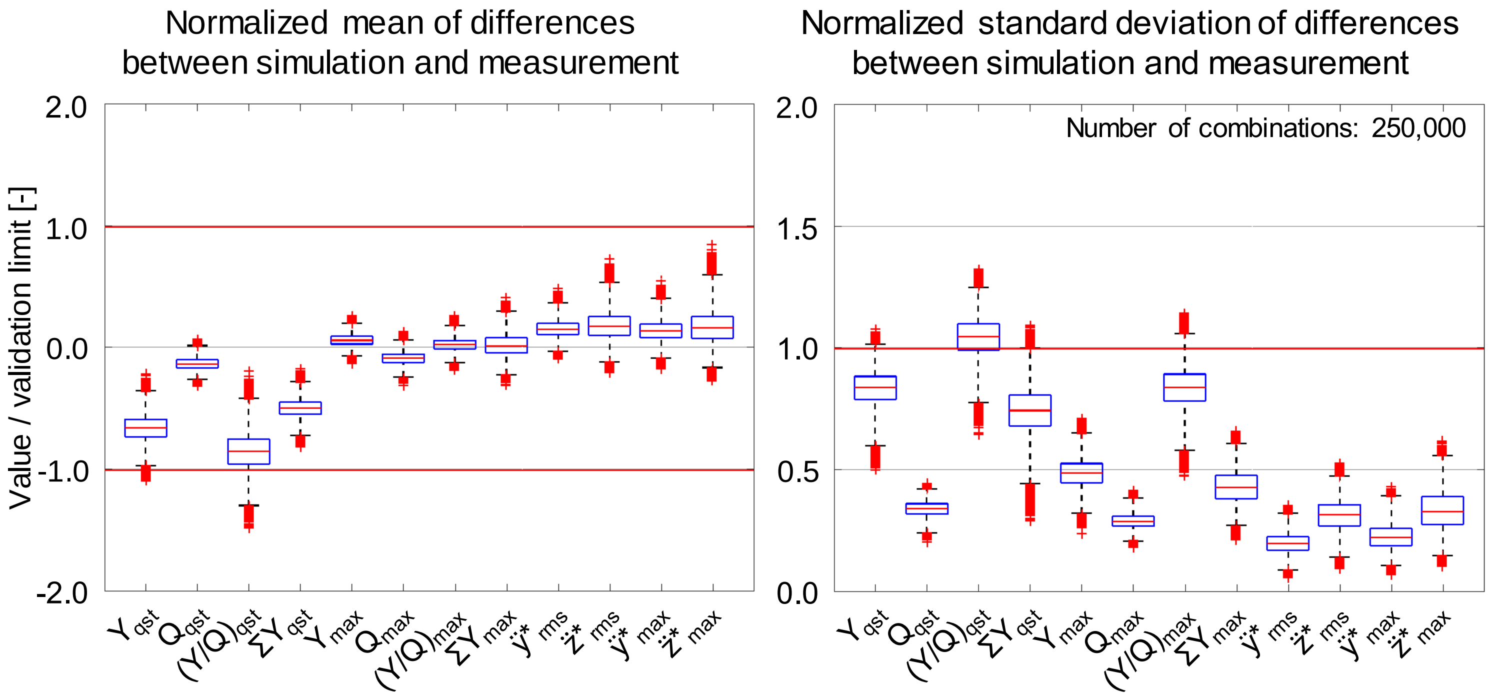
- Minimum of 3 track sections per test zone is confirmed as sufficient for reliable validation

Effect of asymmetry of section distribution
Symmetric number of sections per test zone

- Test zone 1: 3 sections
- Test zone 2: 3 sections
- Test zone 3: 3 sections
- Test zone 4: 3 sections

Validation requirements fulfilled:

25.6%



- Majority of results failed – this model is not suitable for simulation of on-track test

Effect of asymmetry of section distribution
Asymmetric number of sections per test zone

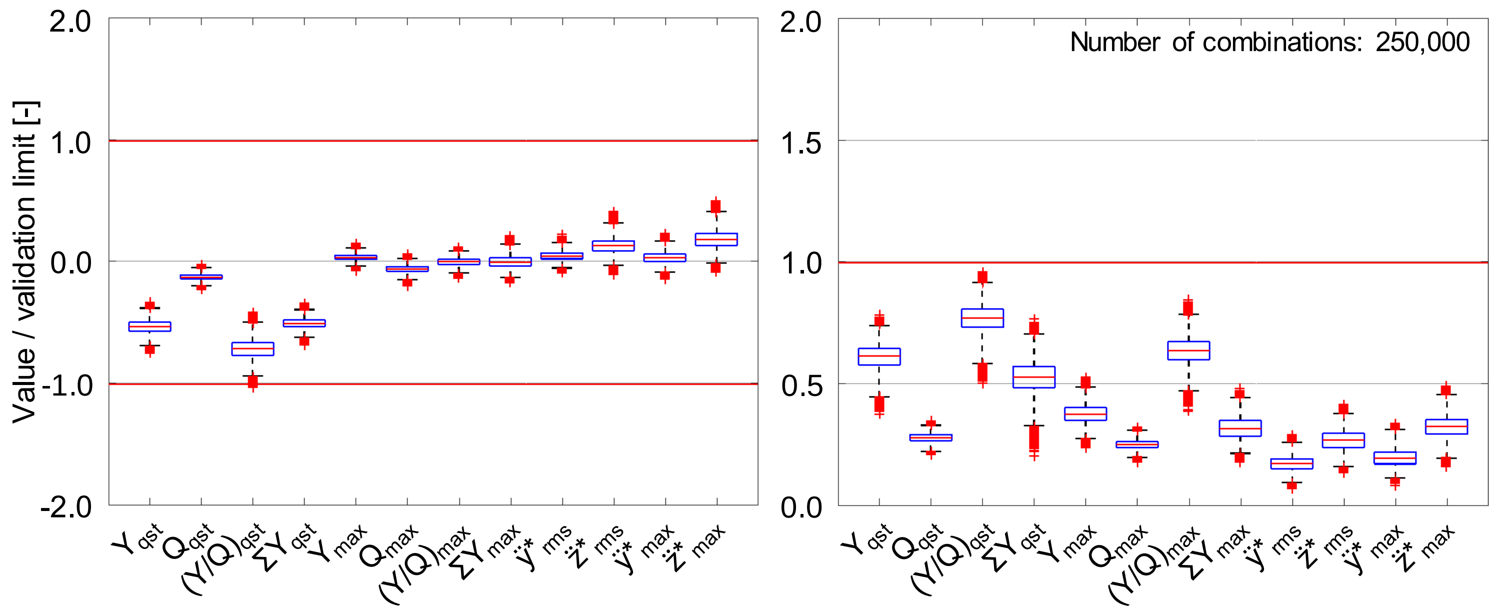
- Test zone 1: **15 sections**
- Test zone 2: 3 sections
- Test zone 3: 3 sections
- Test zone 4: 3 sections

Validation requirements fulfilled:

100.0%

Normalized mean of differences between simulation and measurement

Normalized standard deviation of differences between simulation and measurement



- Large number of track sections from test zone 1 has hidden the weakness of this model
- Equal number of track sections from test zones is required to ensure correct assessment!

Contents

- Introduction: What is model validation?
- Peculiarities of model validation in rail vehicle dynamics
- Model validation methods according to standard EN 14363
- Validation according to Method 2 in EN 14363: New findings
- **Summary and conclusions**

Summary and conclusions

- An indispensable condition for use of vehicle dynamics simulations to reduce the amount of on-track tests is a reliable and objective methodology for validation of simulation models
- Revision of standard EN 14363:2016 specifies two equivalent model validation procedures:
  - Subjective assessment by model builder, to be checked by an independent reviewer (Method 1)
  - Objective assessment of a set of quantities against the specified quantitative criteria (Method 2)
- Presented investigations using validation according to Method 2 lead to the following conclusions regarding the effect of selected track sections on the validation result:
  - The minimum number of 3 track sections per test zone is a sufficient compromise between the costs and reliability of model validation
  - The number of track sections from each test zone must be equal or at least similar to avoid an unreliable validation
  - Validation result with margin to the validation limit values can be considered as unambiguous because it is almost independent of the selected combination of track sections used for validation
- Exchange of experience with model validation and further development of the validation methods will significantly increase the confidence in simulations of the railway vehicle dynamics

Thank you for your attention

www.oldrich.polach.ch