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Validation methodology for rail vehicle dynamics models: From theory to practice

O. Polach*[1], G. Götz[2]

[1]Self-Employed Consultant, Switzerland, [2]DB Regio AG, Germany

Introduction

Verification and validation (V&V) of computer simulations is a research topic for more than four decades. The development of V&V theory has been mainly promoted by applications in nuclear and aircraft industry and simulations of industrial and social processes. V&V activities in rail vehicle dynamics have been carried out mainly in the framework of the development and verification of multi-body simulation codes. Papers and articles mentioning the validation of rail vehicle dynamics models often present particular, project related examples comparing simulations with measurements. Publications dealing with generally applicable methodologies for model validation in rail vehicle dynamics, however, are very rare.

Rail vehicle dynamics simulations are increasingly being used not only for vehicle engineering but also as a substitute for physical testing. However, reliable application of simulation technique requires an objective, clearly specified validation of the simulation model. This contribution evaluates model validation methods in rail vehicle dynamics with a focus on the application in the vehicle acceptance process. Based on the theory of model validation in other disciplines, the peculiarities of testing and validation of rail vehicle dynamics are presented. The aim of this paper is to evaluate the methods of model validation as used today and to analyse the influence of the selected combination of comparisons on the validation result.

Validation methods

The validation methodology requires definitions of the validation and application domains, the quantities to be used for validation comparisons, the validation metrics and the limit values to be fulfilled for a successful validation. Peculiarities of vehicle testing and validation methods in the context of rail vehicle dynamics are presented and advantages and disadvantages of different metrics and criteria discussed.

The revision of standard EN 14363:2016 [1] specifies two model validation methods for simulations regarding the acceptance of running characteristics of railway vehicles. Based on theory of model validation, the advantages and disadvantages of both methods are shown and their application areas discussed. Although both methods are considered equivalent, only one of them provides a complete specification of the quantities to be evaluated, the metrics to be applied, the number of sections to compare, and the limits that must be met for successful validation. This procedure, called in EN 14363:2016 validation according to Method 2, was developed in the framework of research project DynoTRAIN [2]. This method requires an evaluation of mean values and standard deviations of differences between simulation and measurement for 12 quantities on a minimum of 12 track sections and their assessment against the specified validation limit values. This allows an unambiguous validation assessment for the selected combination of track sections. However, in a complete on-track test, there can be many possible combinations of track sections available for model validation. How does the selection of track sections used for validation comparisons influence the validation result? Can the fulfilment of validation criteria be achieved by selecting sections with “good results” only? New research studies have been carried out to answer these questions.

Results of new research

The evaluation of hundreds of thousands of possible compilations of track sections demonstrate that the minimum number of 3 track sections per test zone as specified in EN 14363:2016 [1] is a sufficient compromise between the costs and reliability of model validation. An example of scatter of normalised validation results evaluating 250,000 combinations of track sections is shown in Figure 1. The result “validated” is almost independent of the selected combination of track sections; only less than 2% of combinations provide a different assessment result.

As the number of track sections per test zone increases, the scattering decreases (Figure 2), but the choice of 3 track sections per test zone provides sufficient information at a reasonable effort. If a validation result of randomly selected track sections achieves for all evaluated quantities large margins to the corresponding validation limits, then the result is unambiguous because almost all of possible compilations of track sections would pass the validation.

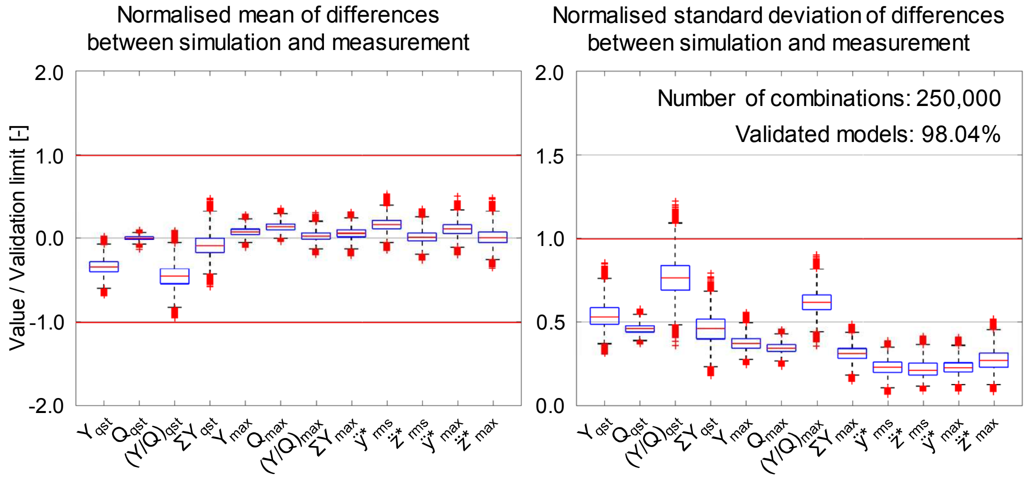

Figure 1: Scatter of validation results for different track section combinations with 3 sections per test zone

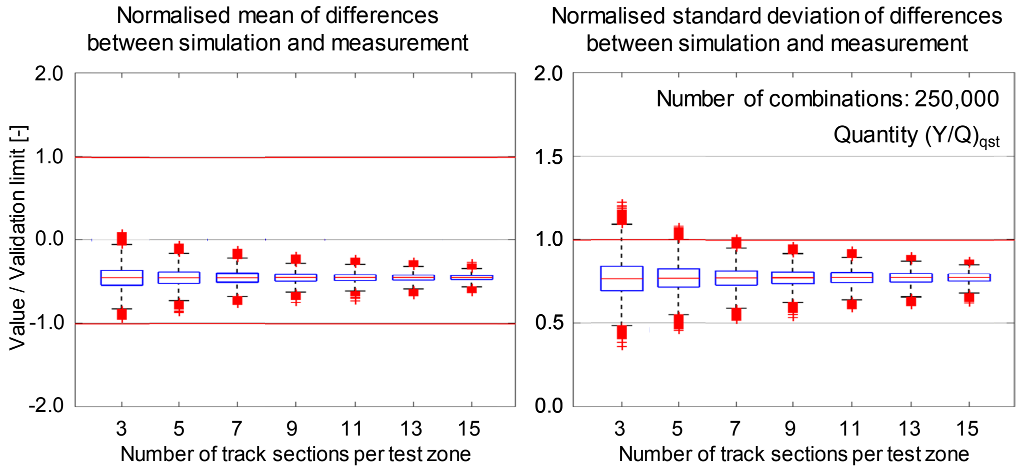

Figure 2: Effect of number of track sections on scatter of validation results on example of validation quantity $(Y/Q)_{qst}$

The present analyses identified a new important condition regarding the number of sections used for evaluation: It is necessary to use the same or at least similar number of sections from each test zone, even if there are more measurements available, because applying significantly different number of sections from different test zones could change the validation result and hide a model inaccuracy.

Furthermore, the evaluations showed repeatedly differing sensitivity of evaluated quantities to the corresponding validation limit values. Further investigations could possibly allow to reduce the number of evaluated quantities without reducing the quality of validation. Modifications of validation limits could on other hand improve the validation reliability.

Conclusions and outlook

An indispensable condition of applying the simulations to reduce the scope and cost of the on-track tests for the acceptance of running characteristics of rail vehicles is the development of an objective methodology for validation of simulation models in railway vehicle dynamics.

The revision of standard EN 14363:2016 specifies two model validation procedures for this purpose. Only one of them, the validation according to Method 2, represents an objective validation assessment.

Recent research regarding this validation methodology evaluated the effect of the selected combination of track sections on the validation results. The investigations lead to the following conclusions:

- Minimum of 3 track sections per test zone is a sufficient compromise between the costs and reliability of model validation;

- Number of track sections from each test zone must be equal or at least similar to avoid an unreliable validation;

- Validation result with a large 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.

Future investigations regarding the validation Method 2 in EN 14363:2016 should include a checking the need of the evaluated quantities, possible modifications of validation limit values, a modified validation methodology for use with simplified measurement method and development of validation methodology in frequency domain.

References

[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

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