Model validation

Presented by Bridget Eickhoff
30 June 2015

Contents of presentation

- Uses of simulations
- European approval processes
  - UIC 518 / EN14363
- EU FP7 DynoTRAIN project
  - Model validation investigations
- Update of EN14363

Uses of Simulations

Uses of simulations in vehicle dynamics

- Suspension design
  - From first principles
  - Sensitivity studies
  - Variations from earlier designs
- Assessment
  - Component behaviour
  - Preparation for approvals process (‘no surprises’)
- Vehicle approvals
  - In association with testing
  - Alone (no testing)
- Investigations

Requirements for use of simulations for approvals

- The vehicle model is a good representation of the actual vehicle
- The software used is appropriate for the application
- The correct conditions have been covered
- The engineers undertaking the simulations are competent

- Key concern is the demonstration that the vehicle model correctly represents the actual vehicle over the range of conditions:
  - Speed, cant deficiency, track input, contact conditions etc
  - Quasi static / dynamic (range of frequencies)

UIC 518 & EN14363

UIC518:2009 & EN14363 revision

- UIC518:2009
  - First Europe-wide use of simulations as part of approval
  - Recognised the use of simulations in design (especially for passenger / locos)
  - Software packages accepted as state-of-the-art
  - Validation of vehicle models relied on independent review
  - Application after modification of vehicle or by comparison with previous approval.
- EN14363 revision
  - Built on the work of UIC
  - Concerned about subjective review
  - Desire for objective / numerate assessment of vehicle models
  - Use the results from DynoTRAIN project

DynoTRAIN

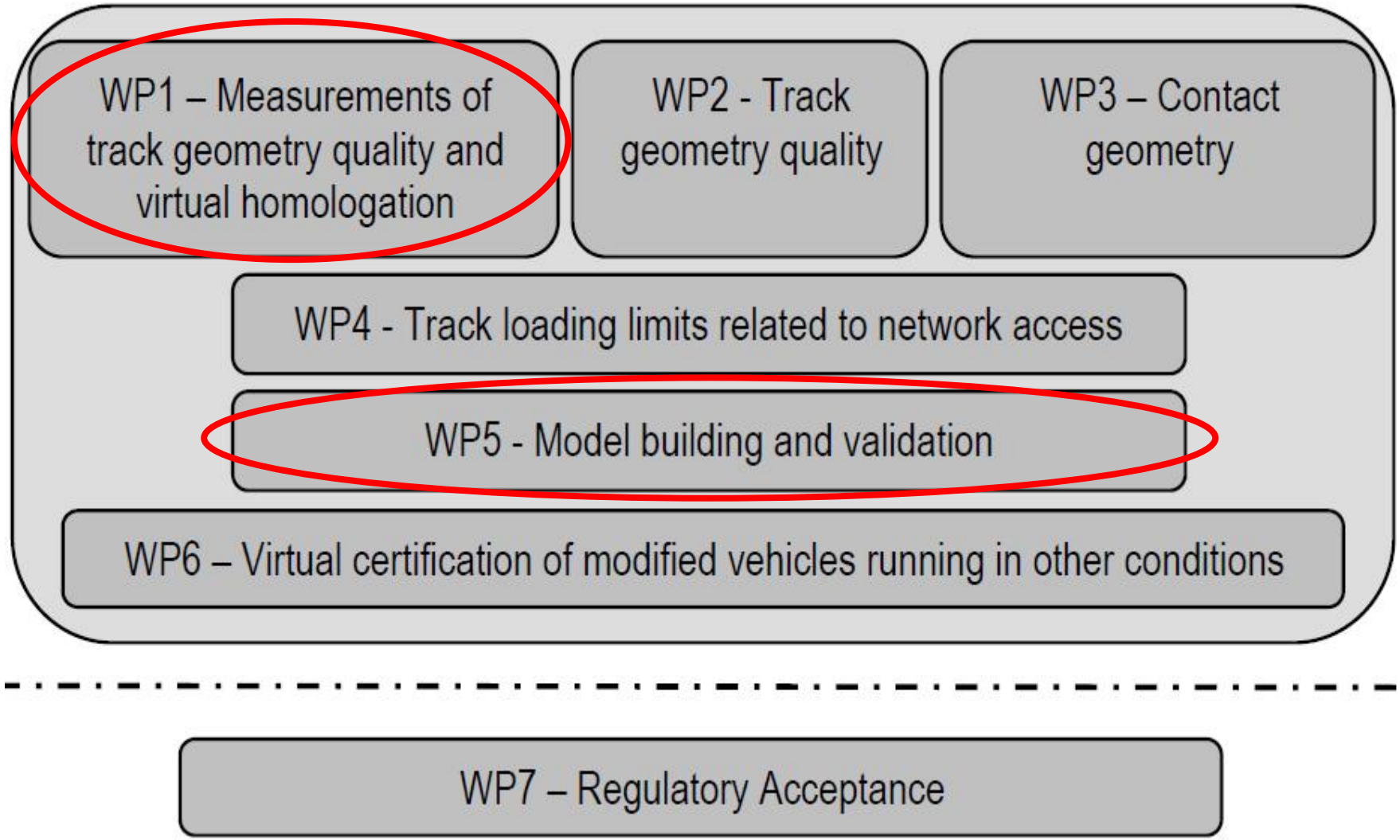
Background – DynoTRAIN

- Part of EU Framework 7 TrioTRAIN cluster of projects

DynoTRAIN

- Value €5.55m (EC funding €3.3m)
- Duration 4 years June 2009 to May 2013
  - Plus 4 month extension for reporting
- Project completed end Sept 2013
- Final event held in Frankfurt 26/27 September
- Special edition of Journal of Rail & Rapid Transit expected later 2015

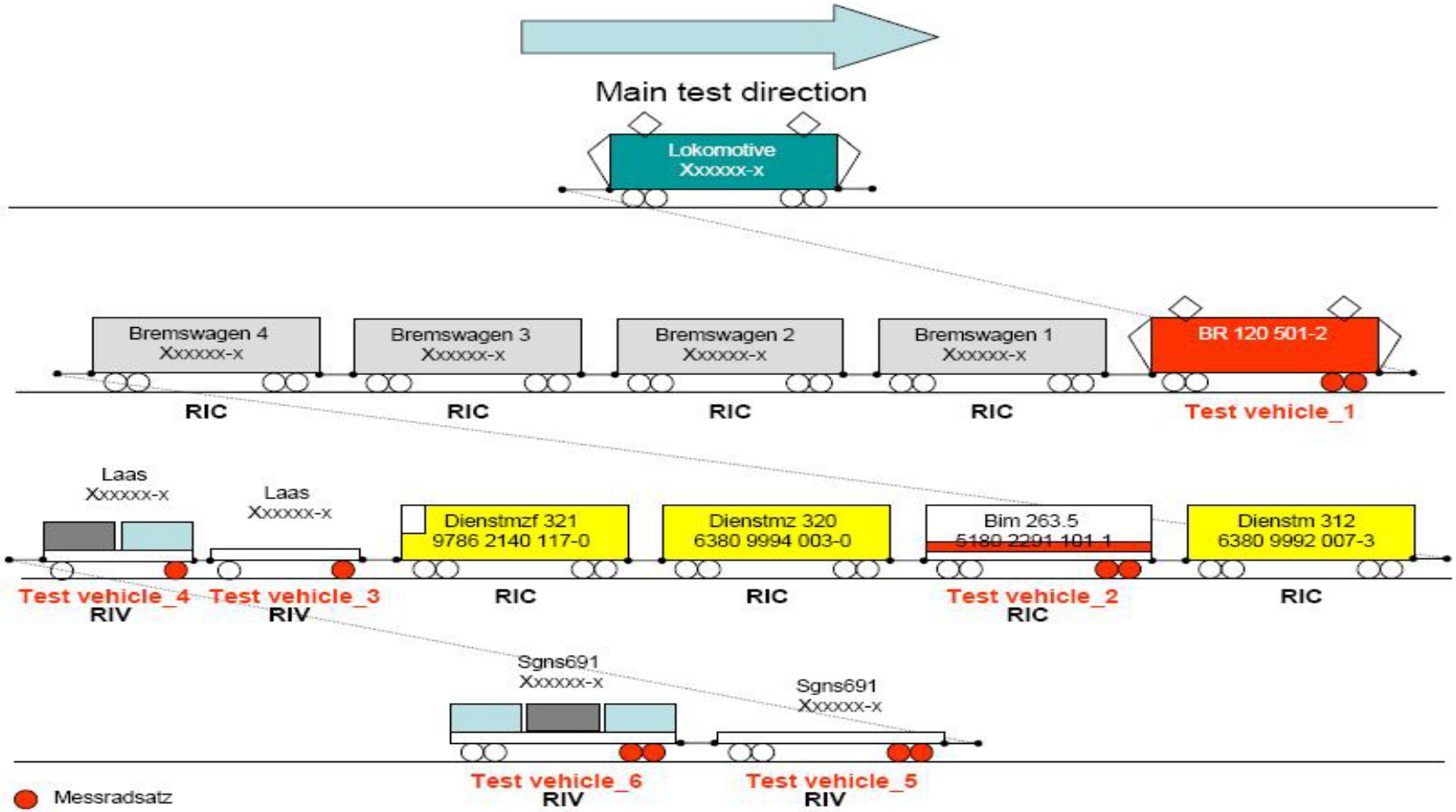
Work packages



WP1 Testing

- 4 countries
  - Germany, France, Italy, Switzerland
- 6 test vehicles
  - BR120 loco, passenger coach, 2-axle wagons, bogie wagons
- Synchronised measurements
  - Track geometry
  - Rail profiles, Wheel profiles
  - Wheel-rail forces
  - Vehicle accelerations and displacements
  - Video recordings
- Vehicle stationary tests

WP 1 : on track tests



WP1– task 1.2 – On-track tests

- On track tests completed 2010
- 7500 km test length in 4 weeks
- 6 test vehicles with 10 instrumented wheelsets
- 300 physical parameters measured
- 600 parameters evaluated
- 3,298,534,883,328 Byte of data
- Installation of :
  - 8,000 m cable length
  - 1,000 m fibre optic

WP5 - Model building and validation

Leader: Bombardier (Oldrich Polach)

Objectives:

- To review the state-of-the-art of building and validation of multi-body railway vehicle models;
- To test these models by comparisons between simulations and measurements, and
- To specify the requirements for agreed process of validation of vehicle models for virtual certification.

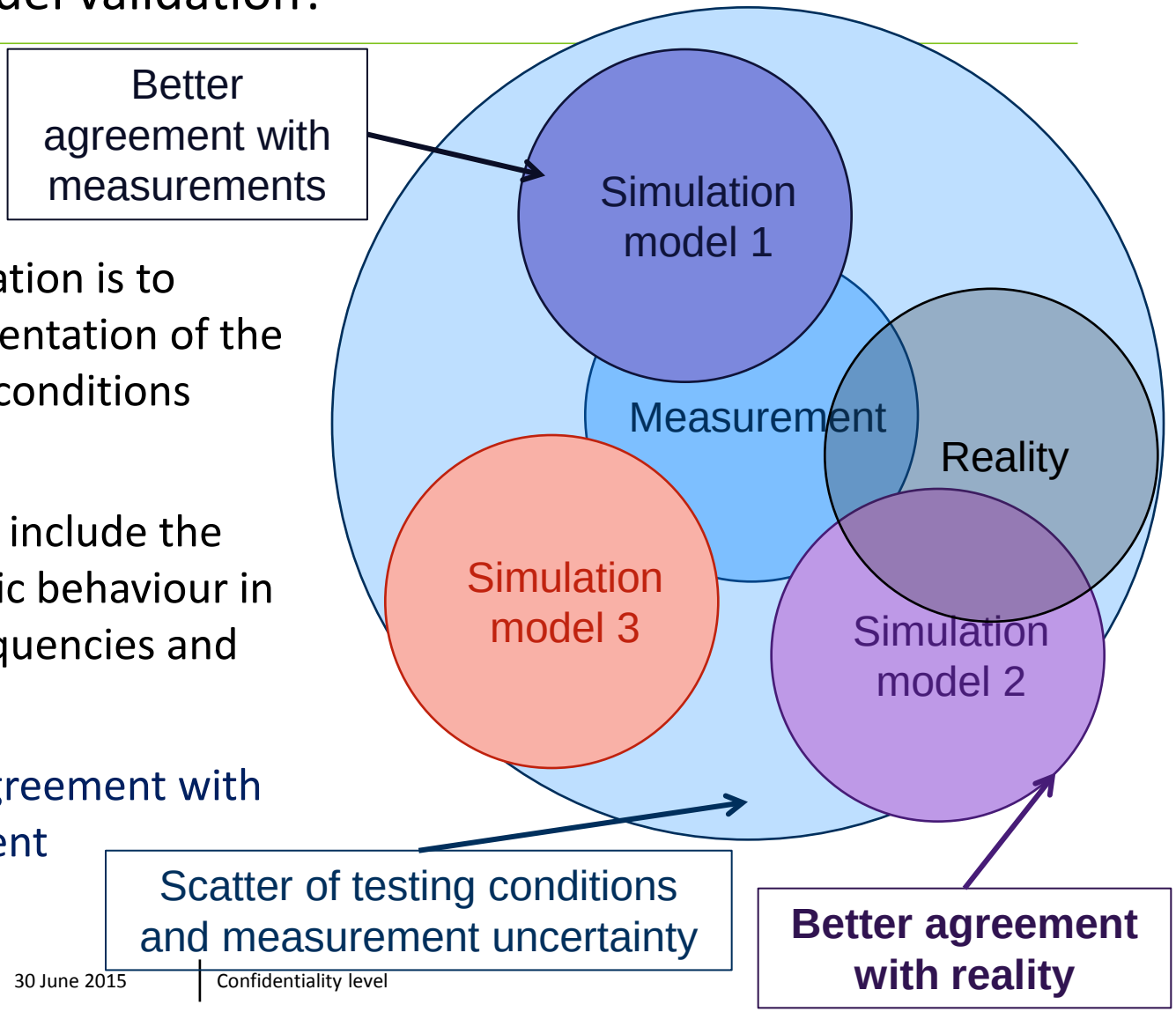
Results expected:

- Recommendations for vehicle modelling for virtual certification
- Comparison of vehicle tests and simulations
- Proposal for standardised model validation process

WP5 What is model validation?

- The aim of model validation is to achieve the best representation of the reality for the range of conditions considered
- The validation needs to include the quasi-static and dynamic behaviour in the range of typical frequencies and amplitudes

➢ May not be the best agreement with a particular measurement



Overview of simulation activity

- Objectives:
  - To test the models by comparisons between simulations and measurements
  - Set up a simulation plan which can provide the needed information for the definition of a validation process.
    - Identify the quantities to analyse
    - Evaluate the importance of modelling inputs.
- Simulations were carried out by 7 partners:
  - AB, BT, Alstom, Siemens, CAF, TUB, IFSTTAR.
  - Variety of software packages
- Vehicles tested:
  - 4 vehicle types tested in DynoTRAIN WP1
    - 7 models prepared by 5 partners.
  - 2 vehicle types tested outside DynoTRAIN project
    - 2 models prepared by 2 partners.

Simulation plan : validation exercises

The work is organised as an ordered sequence of validation exercises.

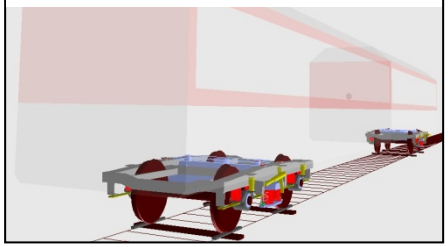
- A validation exercise is the comparison between the results of simulations and the results of on-track tests both referring to the same single part of track.

ON-TRACK TEST

Input data for simulations:

- **Rail profiles**
- **Track irregularities**
- **Track layout**

SIMULATION



Vehicle output values.

Vehicle output values.

Comparison of results

Simulation inputs : track layout

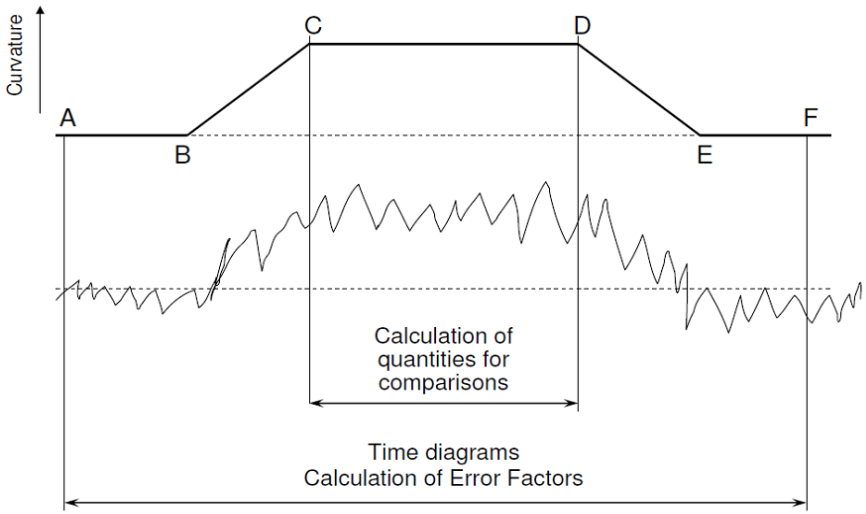
For each exercise the simulation has to be performed for a part of the track called "part of interest" (A-F).

- The signal which refers to the "part of interest" is used for the comparison of diagrams and evaluation of metrics.

In addition a "part with constant radius" (C-D) is specified

- The signal which refers to the "part with constant radius" is used to calculate the output quantities used in the numerical comparison between measurements and simulations

Exercise number	Part of interest A-F (km-km)	Part with constant radius C-D (km-km)
1	km63.18-63.92	km63.38-63.78
2	km65.08-65.36	km65.14-65.28
3	km69.94-71.02	km70.23-70.55
4	km 76.62 to 75.75	km 76.40 to 75.91
5	km85.83 - 84.7	km85.56 - 84.88
6	km59.25 - 58.50	km59.05-58.69
7	km67.19 - 66.50	km66.94-66.75
8	km 58.52 - 56.75	km 58.52 - 56.76
9	km281.8-278.5	km281.5-278.856
10	km 21.3 - 18.1	km 21.3 - 18.1
11	km 14.9 - 11.7	km 14.9 - 11.7
12	km22.25-21.746	km21.936-21.826
13	km21.746-20.778	km21.666-20.895
14	km 102.820-102.396	km 102.775-102.495
15	km 111.480-111.096	km 111.383-111.191
16	km292.57-293.08	km292.70-292.95
17	km288.08-288.731	km288.190-288.616



How to evaluate the validation limits?

Simulation results:

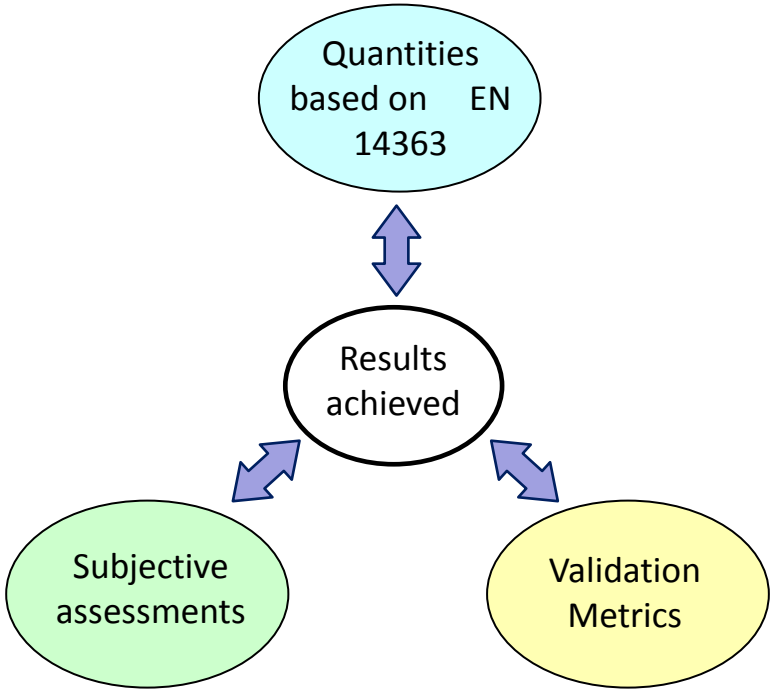
- 9 vehicle models
- 78 model configurations
- > 1 000 simulations of validation exercises

Comparisons simulation - measurement:

- > 60 000 values based on EN 14363
- > 21 000 time (distance) plots

Subjective assessments:

- 6 800 plots assessed by WP5 partners
  -> 55 000 plot assessments
- 120 plots assessed by experts and project partners
  -> 3 000 plot assessments



How to evaluate the limits for a successful validation?

WP5 Process to agreement on validation

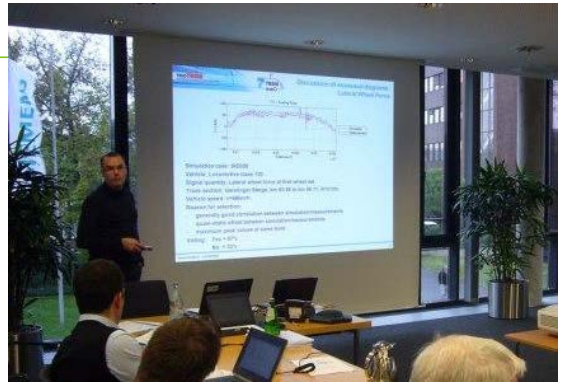
Three parallel paths to an agreement on conditions for successful validation

Simulations of on-track tests and calculation of differences simulation - measurement

Subjective assessment by WP5 partners	Subjective assessment by experts	Comparison of achievable differences for all vehicles and all WP5 validation exercises
All results	**Selected examples**	**All results**
Homework for all WP5 partners	**WORKSHOP 7. 11. 2012** **Discussion and agreement**	**Discussions and agreements in WP5 meetings**

Agreement about the conditions for successful validation by all WP5 partners

WP5 Workshop, Krefeld Nov 7, 2012



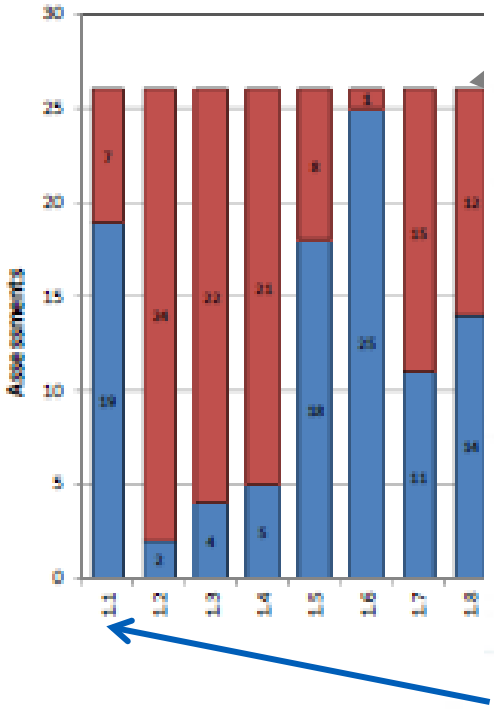
Total 29 attendees; including 12 invited experts

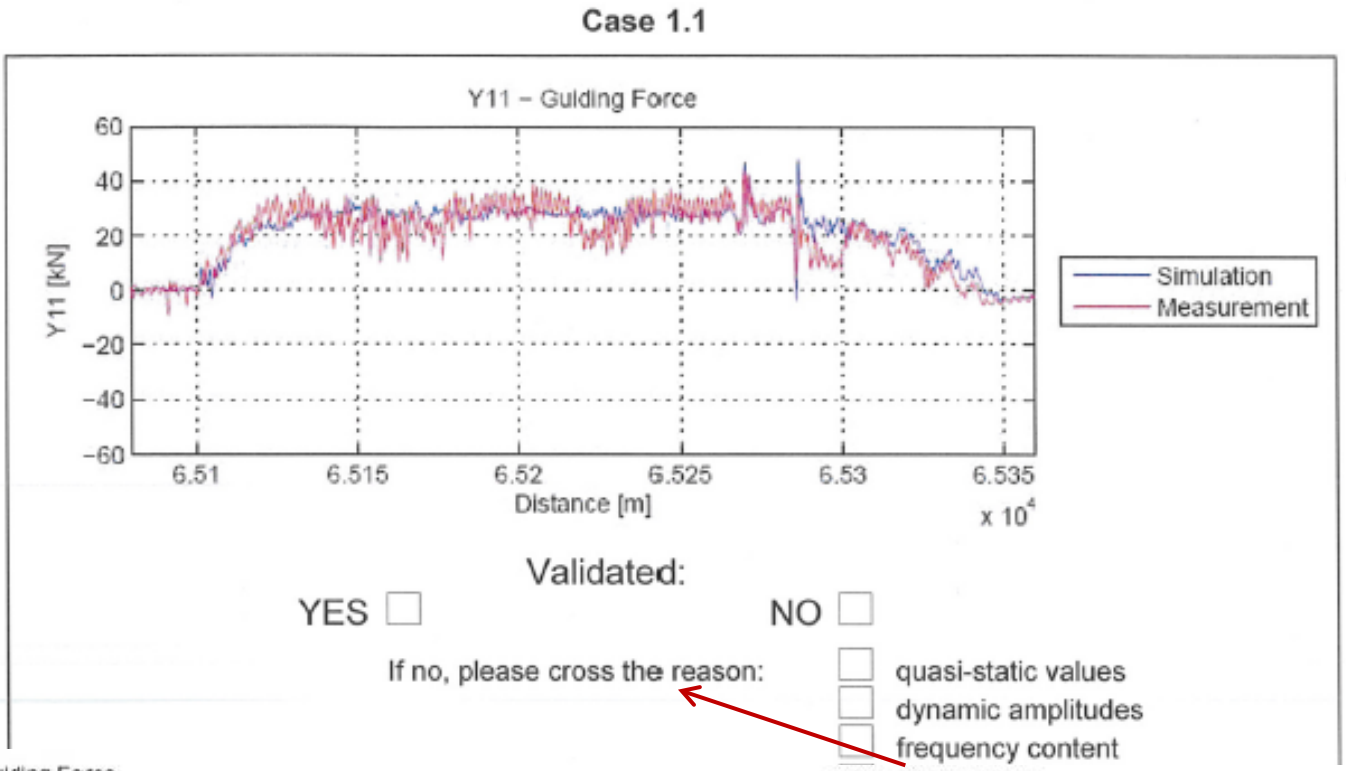
26 participants answered questionnaires

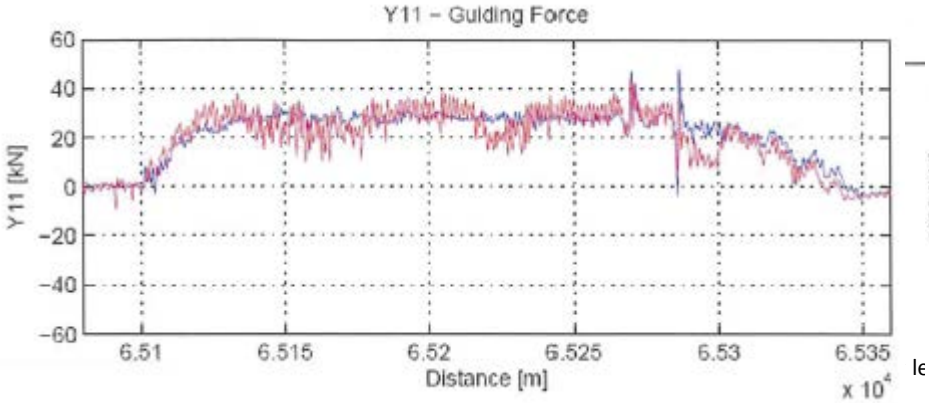
6 sets of plots assessed:

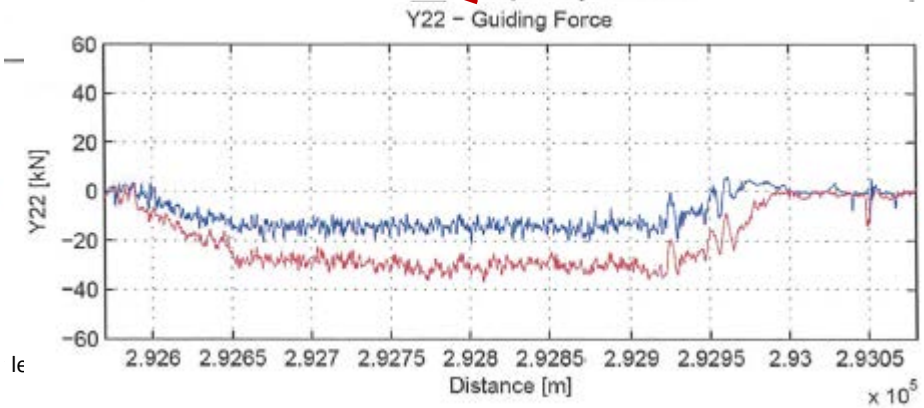
- Set 1: Lateral wheel-rail force (Y-force) 22 plots
- Set 2: Vertical wheel-rail force (Q-force) 22 plots
- Set 3: Quotient Y/Q 22 plots
- Set 4: Lateral bogie frame acceleration 22 plots
- Set 5: Lateral and vertical vehicle body acceleration 22 plots
- Set 6: Power spectral density of accelerations 10 plots

WP5 Example of workshop plots & results



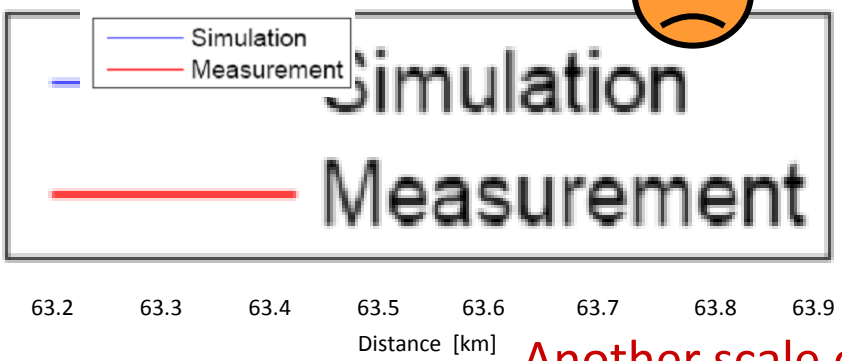




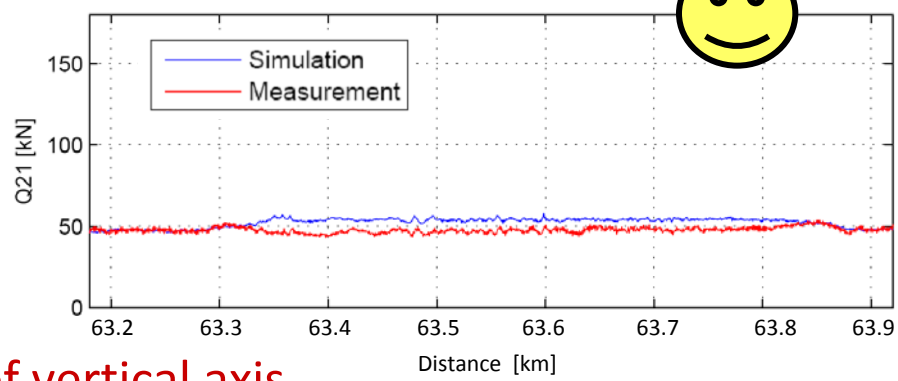


Effect of the form of diagram on the assessment result

Validated: 15%

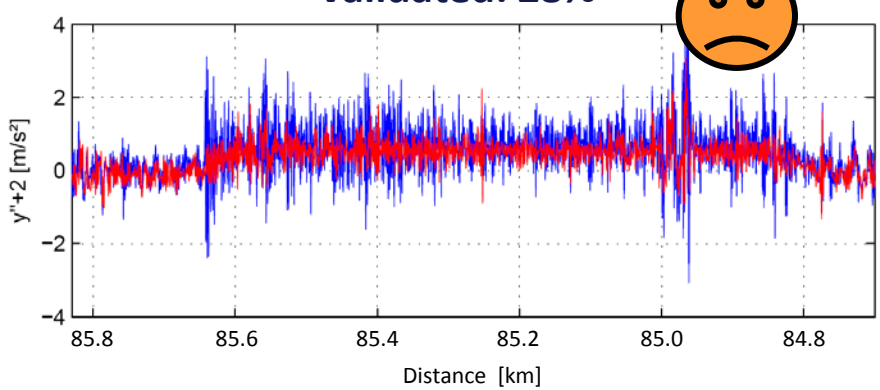


Validated: 62%

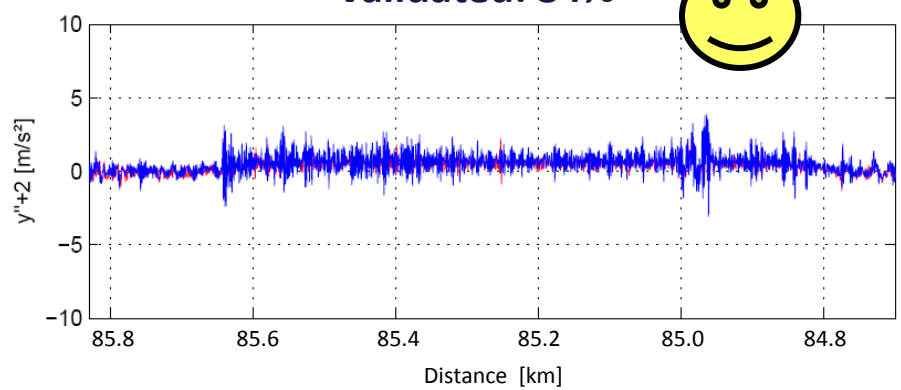


Another scale of vertical axis

Validated: 28%



Validated: 84%



Another scale of vertical axis & Exchange of signals: front ↔ background

Evaluation of comparisons simulation - measurement

Validation exercises (sections) selected from DynoTRAIN WP 1 on-track tests:

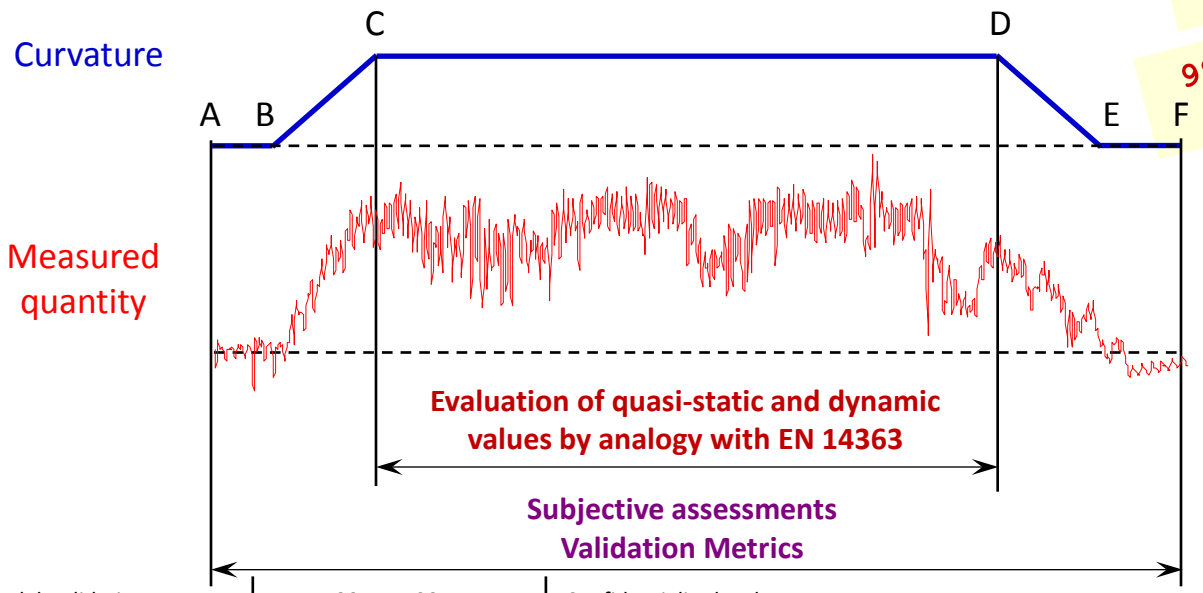
- Locomotive and passenger coach: 17 track sections
- Freight wagons: 14 track sections

Evaluation of comparisons simulation – measurement

- Single values processed and evaluated by analogy with EN 14363:
  - Quasi-static values (50%-values)
  - Dynamic values (0.15%/99.85%-values, RMS-values)

58 quantities

986 values per model configuration



Assessment of a large set of comparisons

Application of validation limits on a few single pairs comparing simulation and measurement does not provide sufficient information about an overall model performance

The proposed model validation method is based on a set of differences simulation-measurement, assessed statistically for each quantity

Quantity Y_{qst}

Exercise 1 Exercise 2 Exercise 3

S_v - M_v

S_v – simulated value
M_v – measured value

Quantity ΣY_{qst}

Nomenclature	Unit	Ex. No. 1	Ex. No. 2	Ex. No. 3	Ex. No. 4	Ex. No. 5	Ex. No. 6	Ex. No. 7	Ex. No. 8	Ex. No. 9	Ex. No. 10	Ex. No. 11	Ex. No. 12
Y11qst	kN	10.460	10.404	-2.445	11.146	2.217	7.341	-2.855	-0.772	-0.575	-0.904	-1.831	-1.224
Y12qst	kN	9.546	10.145	-4.036	7.467	-5.577	-0.159	-12.739	-1.591	4.400	0.725	0.373	-4.449
Y21qst	kN	-3.031	-1.827	-4.051	-2.889	1.292	-4.020	0.720	-0.898	3.402	1.236	0.190	-0.525
Y22qst	kN	6.432	1.911	-2.528	-5.332	-0.618	-4.890	0.355	-1.828	-1.155	-0.229	-0.466	2.443
Q11qst	kN	9.183	9.224	-3.498	3.561	-1.130	1.082	1.125	-2.315	-4.908	-3.811	-3.324	-0.679
Q12qst	kN	14.280	13.458	7.007	9.060	-2.725	6.879	-3.629	6.865	3.346	4.935	4.340	2.229
Q21qst	kN	-10.956	-10.985	-4.517	-8.868	6.466	-5.916	7.469	-0.360	-0.637	-0.943	-0.397	7.999
Q22qst	kN	3.010	3.240	12.726	9.711	5.476	11.764	4.469	8.927	-1.938	-1.447	-1.338	8.018
Y/Q11qst	[-]	0.043	0.045	-0.009	0.080	0.034	0.057	-0.032	-0.008	-0.005	-0.009	-0.019	-0.014
Y/Q12qst	[-]	0.044	0.056	-0.085	0.063	-0.037	-0.031	-0.093	-0.017	0.040	0.006	0.003	-0.046
Y/Q21qst	[-]	-0.021	-0.012	-0.031	-0.022	0.012	-0.031	0.005	-0.009	0.034	0.011	0.001	-0.010
Y/Q22qst	[-]	0.061	0.018	-0.040	-0.065	-0.008	-0.065	-0.001	-0.020	-0.011	-0.003	-0.005	0.021
SY1qst	kN	0.911	0.037	1.420	3.753	-7.760	7.497	-10.049	-3.269	3.856	-2.313	-1.925	-3.396
SY2qst	kN	6.079	5.469	-6.560	-7.960	0.690	-9.015	1.260	-3.088	3.710	-1.177	-1.088	1.924
Y11	kN	9.643	26.481	3.361	24.852	7.617	24.694	-0.389	-9.429	-10.569	6.203	20.782	-3.896
Y12	kN	8.196	7.627	-3.963	9.389	-4.638	3.013	-3.130	-22.698	-10.136	3.098	9.479	-1.784
Y21	kN	-4.301	-4.738	-4.561	-10.280	0.932	1.363	0.942	-1.813	-17.951	-3.297	1.066	3.482

48 values

24 values

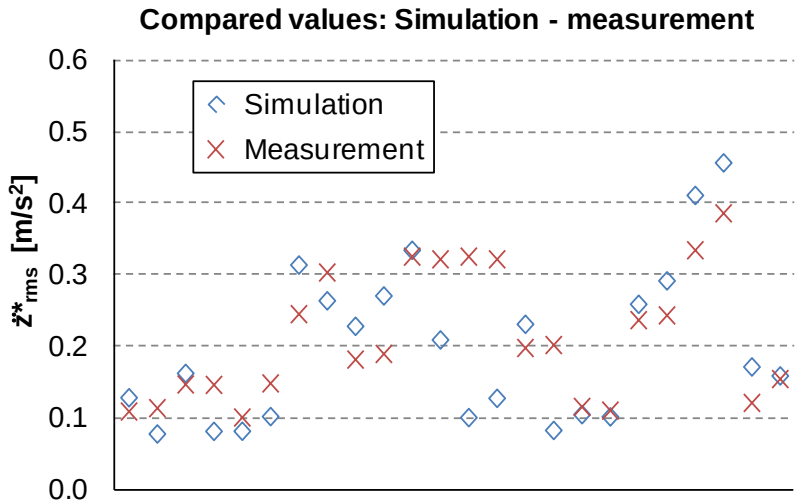
- **Compared pairs simulation – measurement:**
  - Minimum 24 per quantity -> Minimum 288 per vehicle model

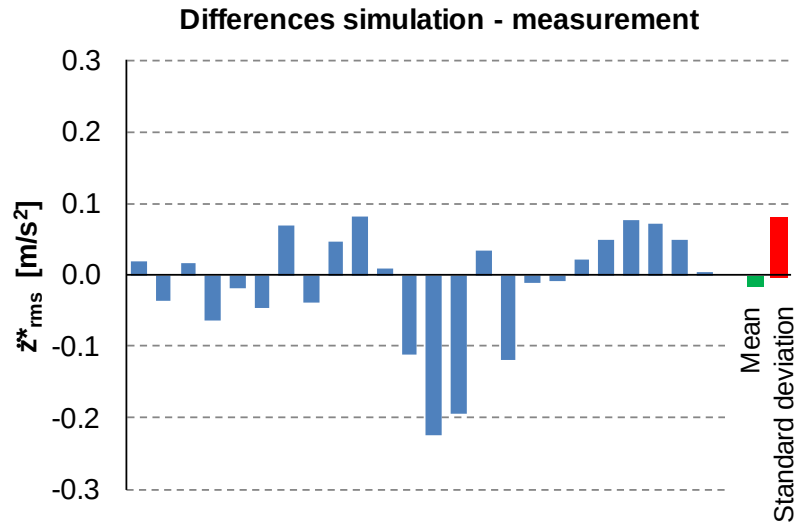
Procedure to be applied - Example of evaluation

- Transformation of differences
- Calculation of mean and standard deviations per quantity
- Comparison with validation limits

$$D_v = (S_v - M_v)\frac{M_v}{|M_v|} \quad \text{for} \quad M_v \neq 0$$

$$D_v = S_v \quad \text{for} \quad M_v = 0$$





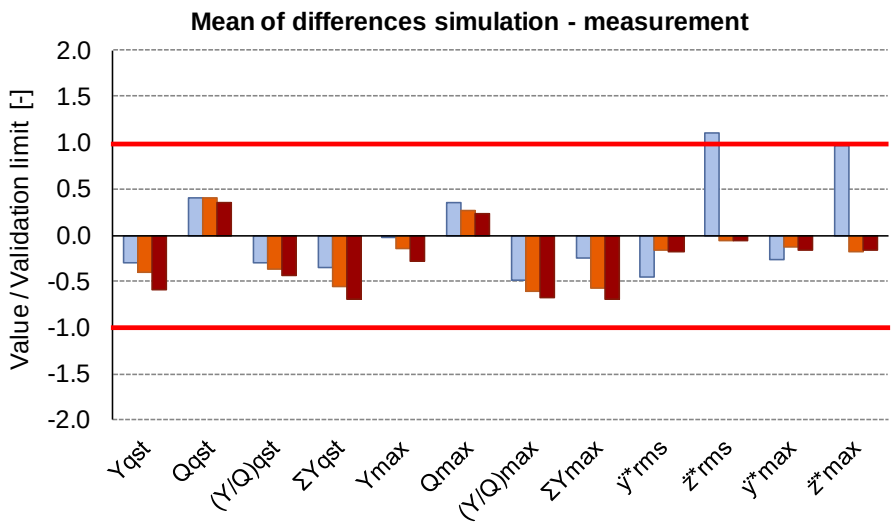
Section	1		2		3		4		5		6		7		8		9		10		11		12	
Simulation S_v	0.129	0.078	0.163	0.082	0.082	0.102	0.314	0.264	0.229	0.271	0.335	0.210	0.101	0.128	0.231	0.083	0.105	0.102	0.259	0.292	0.411	0.457	0.172	0.159
Measurement M_v	0.110	0.114	0.147	0.147	0.101	0.149	0.245	0.304	0.182	0.190	0.326	0.322	0.326	0.322	0.198	0.202	0.116	0.111	0.237	0.244	0.335	0.386	0.122	0.155
Difference D_v	0.019	-0.036	0.015	-0.065	-0.019	-0.046	0.069	-0.040	0.047	0.081	0.009	-0.113	-0.225	-0.194	0.033	-0.119	-0.011	-0.009	0.022	0.048	0.077	0.070	0.050	0.004

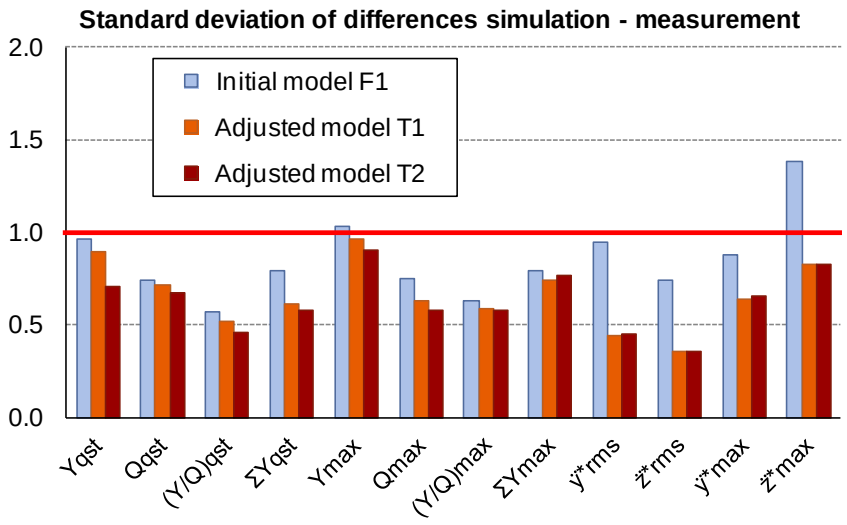
	Calculated value	Limit value	Normalised value
Mean of D_v	-0.014	0.10	-0.138
Standard deviation of D_v	0.081	0.15	0.542

Model adjustments - Locomotive BR 120

Model improvements:

- Model T1: Adjustment of uncertain parameters
  - by comparisons with stationary tests
  - by comparison with on track tests
- Model T2: Extension of the modelling of tractive effort in the sections where this locomotive was hauling the test train





Summary

- Comparisons of the simulation and measurement values by analogy with EN 14363 were carried out in the part of the test track with constant curvature
- Inside this part of the test track, the simulation and measurement values were filtered and processed according to EN 14363
- The simulation and measurement values were compared section by section
- The validation limits proposed by the partners considered:
  - Error in the measurement of running dynamic quantity and other measurement errors (track irregularities, wheel and rail profiles…) as well as scatter of test conditions
  - Relation of the simulation and measurement values to the limit for vehicle acceptance according to EN 14363
- The proposals were compared and preliminary validation limit for all investigated quantities based on EN 14363 agreed
- The comparisons of the simulation and measurement values based on EN 14363 were conducted on the same manner for all model configurations using the agreed preliminary validation limits

DynoTRAIN WP5 - Conclusions

Recommendations for vehicle modelling for virtual certification

- ✓State of the art report produced

Proposal for standardised model validation process

- ✓Quantitative criteria developed
- ✓Alternative to current use of independent reviewer
- ✓Incorporated in EN14363

Update of EN14363

Model validation in EN14363

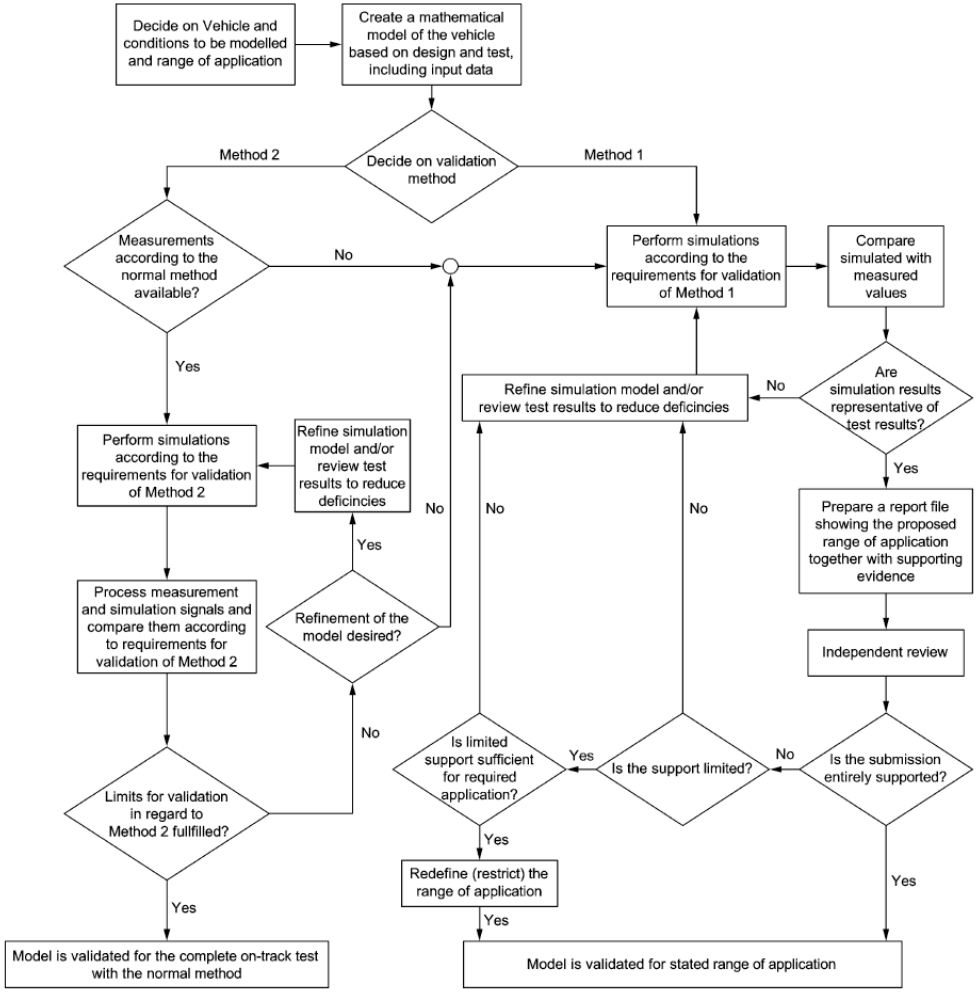
- Validation is by comparison with test results
- Independent review method from UIC518 still available
- Added the proposal from DynoTRAIN

- Application of simulations to
  - Extension of approval or modification of vehicle
  - Comparison with previously accepted reference vehicle
  - To complete approvals where some test results are missing

Validation options in EN14363

Method 2
New process using mathematical comparison

Validation required for full range of conditions



Method 1
Previous process using independent reviewer

Can include validation for restricted range of conditions

Thank you

Any questions?