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Benchmarks for rail vehicle dynamics simulation

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FRA VTI Modelling Best Practices Workshop

Dr Phil Shackleton

Cambridge, MA
30th June – 1st July 2015
Summary

- Overview of the Institute of Railway Research (IRR)
- Why benchmark?
- Recent benchmarking exercises
- Key learning points
- Gaps and opportunities
- Benchmark requirements
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Institute of Railway Research:
• Management Team

Centre for Innovation in Rail
• 17 Researchers + 1 MSc administrator

RSSB Strategic Partnership
• 1 Professor
• 9 Researchers

IRR Research
• 6 Research staff
• 2 Professors
**Wheel-Rail Interaction**: Modelling wheel-rail contact and resulting damage (wear, rolling contact fatigue corrugation etc). Methods of optimising the interface for heavy rail, light rail and metro systems.

**Railway Vehicle Dynamics**: Vehicle track interaction, derailment analysis, vehicle acceptance procedures and performance optimisation for heavy rail, light rail and metro vehicles.

**Track-system Dynamics**: Modelling of complete trackforms and vehicle interaction. Predictions of force distributions, track and fixing response and structural resistance. Trackform design and failure mode investigations.

**Instrumentation and Condition Monitoring**: Vehicle and track mounted measurement systems, condition monitoring and asset life optimisation.

**Railway Safety and Risk**: safety/risk modelling, data trend analysis, safety system development, societal risk (e.g. modal shift), SPAD analysis, integrating engineering and risk tools.
Vehicle dynamics
- Vampire
- Vi-Rail
- Simpack

Vehicle track interaction
- Coupled vertical dynamic models (Matlab)
- Coupled vertical/lateral dynamics (Matlab)
- Flexible Track System Model (VI-Rail)

Track system modelling
- FTSM (VI-Rail and Matlab)
New test facility for 2016
New test facility for 2016
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Why Benchmark?

- Verification
- Identify and quantify the effects of approximations, simplifications and compromises made
  - Range and sensitivity of input parameters
  - Implementation
  - Ease of use
  - Speed
  - Computational resources
  - Versus accuracy
Why Benchmark?

• Provide reassurance & confidence in the use of the software tools
  – When multiple codes with differing approaches, background or philosophies agree
  – Support increased use (e.g. in design and acceptance)
  – Reduce physical testing

• Provide a platform for developers to corroborate/validate new codes and methods
  – Could/can also propagate errors or bad practice or:
  – Lead to good matches in only one area

• Identify gaps in performance or knowledge and opportunities
  – Drive future developments
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Benchmarks for Rail Dynamics

- ERRI B176/3 (1993)
- Multi-body computer codes in vehicle system dynamics (1993)
- Models of railway track and vehicle/track interaction (1994-6)
- Manchester benchmarks for rail vehicle dynamics (1998/9)
- Benchmark test for models of railway track dynamic behaviour (2004/5)
- LD Benchmark (2008)
- Manchester Contact Benchmark (2008)
- Miscellaneous research articles
Multi-body computer codes in vehicle system dynamics (1993)

Kortüm, W. & Sharp, R.S.

- **Area covered:**
  - Wheel-rail contact forces
  - Vehicle dynamics - vehicle response

- **Aimed to ascertain:**
  - The process used to solve the problem
  - The level of skill required
  - The time taken
  - The resources required and efficiency

- **Conclusions (rail dynamics specifically):**
  - Contact modelling approach has a strong influence on the dynamic result
  - The approach used for modelling the springs should be done very carefully for the different arrangements used in practice
  - High frequency components play a major part in output. Similar filtering should be used when comparing signals

- **Conclusions (benchmarking general):**
  - The values of benchmarking lie in:
    - The precise specification of the problem
    - The provision of a “correct” solution to which the new solutions can be compared
    - The exposure of key open modelling areas, which are shown as crucial to obtaining good results but which are not circumscribed by conventional wisdom
    - Recording results which relate the method, skill, effort and resource necessary as well the ability to solve the problem
• Models of railway track and vehicle/track interaction (1994-6)
  – Split into high and low frequency

• Low frequency
  – Calculation of quantities for ride quality and track loading
  – Passenger coach
  – No references for results?

• High Frequency

• Aim:
  – Enable users to see the agreement between models for rigorously stipulated conditions
  – High frequency realm of noise, corrugation and track component damage

• Conclusions
  – The detail of the vehicle model appeared to be relatively significant
  – The Low Frequency model [MBD model] gave relatively poor correlation of most quantities
  – Time domain models benefited from accounting for low frequency phenomena [bow wave]
  – Difficulty in assessing the degree of correlation was noted
  – Both time and frequency domain models gave reasonable correlation (above exception)
  – Could not conclude calculations were accurate due to absence of experimental data
Manchester Benchmarks for Rail Vehicle Simulation (1998/9)

Iwnicki, S.

- **Area covered:**
  - Vehicle dynamics – vehicle response

- **Aims:**
  - To allow assessment of the suitability of the various software packages that now exist for simulation of vehicle dynamics
  - To explore the possibility of an approved list of packages to be used interchangeably by railway organisations

- **It did not aim to:**
  - Provide accurate validation of the software packages

- **Conclusions:**
  - It was difficult to draw clear conclusions
  - Generally good agreement between packages was noted
  - Users should have confidence of a similar result using an alternative package
  - The treatment of contact patch elasticity requires further work
  - There is no agreement on the method used to determine the exact location of the contact patch and the point at which the contact forces act
    - Those variations did not lead to large differences in the overall results and are insignificant
    - The case may exist where these small differences become important
Benchmark test for models of railway track dynamic behaviour (2004/5)

• **Area covered:**
  – Vehicle and track dynamics
  – Rail and track response

• **Aim:**
  – Examine the capabilities of available track dynamics models against measurements of real track behaviour
  – Assist railway engineers in selecting the railway dynamic model that would be most suitable for their specific requirements

• **Conclusion:**
  – None of the benchmark participants were able to produce results that were consistently comparable to either:
    • Field data
    • Other models
  – Each model had particular strengths and the practising engineer must consider those strengths for a given need

Leong, J., Murray, M., Steffens, D.
**Area covered:**
- The benchmark involved the computation of contact forces resulting from elastic impact of wheel flanges on stiff track
- Typical of conditions associated with higher speed derailments

**Aim:**
- Analyse normal contact force calculations and modelling of flanging with impacts
- Understand how different modelling assumptions influence the results
- Promote technology transfer to produce more consistent predictions

**Conclusions:**
- For flanging impacts results are very sensitive to input parameters
  - Parametric studies are required for assessing derailment risk for the studied mechanism
- When input parameters and modelling assumptions were the same good agreement between codes was observed
Manchester Contact Benchmark (2008)

- **Area covered:**
  - Investigate the difference in wheel rail contact parameters predicted by different models
  - Investigate the effects of the different contact models on dynamic vehicle simulations

- **Aim:**
  - Allow an informed choice of wheel-rail contact model for railway simulations
  - To help inspire direction for future wheel-rail contact research

- **Conclusions:**
  - The method of constraint for the wheelset was not specified and differing implementations affected the results presented
  - For certain applications (such as wear calculations) results could be significantly affected by the contact model used
  - The second part of the benchmark “Case B” – to investigate the effects on dynamic vehicle simulation – was never undertaken

Shackleton, P. & Iwnicki, S.
Research articles

- A multitude of comparative research
- Not necessarily set out as a benchmark exercise they can often partially serve the purposes of one
- Normally the work sets out to prove a specific point
  - Scenarios can be quite specific
  - Emphasis often on the benefits of new methods over existing
  - A balanced comparison not always presented
  - The consequences for the general case may not be obvious
- Identify and fill gaps in the state of the art
- Help drive best practices
- Can help justify more comprehensive benchmarking exercises
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Conclusions from recent benchmarks

• Vehicle dynamic response
  
  – Good agreement in multi-body dynamic response can be achieved
    • Where the benchmark conditions are clearly specified and interpreted in the same way
  
  – Differences in output are normally attributed to differing modelling philosophies (e.g. contact model) or differing interpretation of specifications
  
  – Subjective factors such as user skill required, ease of implementation and time required to construct models are not well compared
  
  – There appears to be little need for further verification of multi-body codes themselves
    • Simulation packages and codes provide correct answers for the given input parameters
Conclusions from recent benchmarks

• **Wheel-rail contact**
  – There is agreement that the contact model or philosophy used affects the outcome of dynamic simulations
  – In certain areas can be significant
    • E.g. post-processing for wear and RCF prediction, high speed derailment
  – Quantification of the errors/variation expected in dynamic vehicle response is not well established
    • E.g. what level of sophistication is necessary for derailment analysis, gauging, curving, etc.
    • How do errors attributable to wheel-rail contact compare to other errors and uncertainties (e.g. component degradation, tolerances, etc.)

• **Track dynamics**
  – Consistently comparable output from codes has not been demonstrated
  – Different codes providing different answers – low confidence in outputs might be inferred
    • Complex models require a wide range of precise inputs (which might not be precisely known)
    • There is not wide agreement in the modelling approach/assumptions/philosophy used
  – Opportunity for quantifying the influence of track model on vehicle response
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Gaps and opportunities for benchmarking

- **Wheel-rail contact – more could be done**
  - Relating wheel-rail contact model to variation in dynamic or quasi-static vehicle response
  - Quantify differences expected in wear and RCF calculations
    - Provide guidance for use in asset life management
    - Increase confidence in asset life predictions

- **Latest benchmark for vehicle dynamics packages is somewhat dated**
  - Is there a clear need to repeat benchmark?
  - Benchmarking simulation codes against measurement data is lacking

- **Benchmark modelling techniques and element representation**
  - E.g. varying detail of friction suspension and effects in accuracy observed
  - Identify the optimum detail versus modelling efficiency balance
Gaps and opportunities for benchmarking

- **Track model**
  - Far less validation for track
  - Influence of track model on vehicle response
  - Consequences of variation in higher frequency output for post processing activities (e.g. S&C damage)
  - Innotrack recommended further benchmark studies to build on work of Leong and Steffens

- **The representation and necessity of vehicle flexible bodies**
  - Required modes for differing uses
  - Requisite accuracy of modal data
Gaps and opportunities for benchmarking

• Quantification of the effects of the subjective and uncertainty factors associated with developing a validated vehicle model
  – DynoTrain sought to reduce the influence of subjectivity on validation
    • Simulation versus measurement data
    • No published simulation-simulation comparisons?
    • Effects of residual subjectivity
    • Correlation between independent models could further increase confidence
    • Particularly near limit cases
  – Reality of imperfect validation and/or test data
  – Fitting model response to test data
    • Non-unique solutions (e.g. sway tests matching)
      – Vertical CoG or suspension geometry?
  – Consideration of uncertainties and unknowns
Gaps and opportunities for benchmarking

- **Quantification of effects associated with input data qualities**
  - Guide best practices
  - Requirements to avoid ambiguous implementation
  - Frequency content and resolution of time and distance data
  - Data pre-processing e.g. worn profile smoothing or resampling
  - Spatial resolution of measured rail profiles

- **Methods used to quantify benchmark results**
  - Frequency content and resolution of time and distance data
  - Data post-processing
    - E.g. filtering and statistical representation
  - Quantifiable correlation metrics
  - Comparators for expertise and user time required
    - Help drive cost reduction for end users
    - Increase use
    - Lower skill level
    - Shorter time or greater productivity
Gaps and opportunities for benchmarking

• Precision or variation - which is more informative:
  – Likely dependent on the specific realm of simulation

• Given finite resources we might aim to:
  – Solve one (or a small number) of scenarios very precisely
    • More useful for improving understanding the problem
  – Solve wide variations of a scenario less precisely
    • Can account for a range of uncertainty and real world variation

• Which combinations of sophistication are appropriate?

• Consider:
  – Nominal scenario high precision (top left)
  – Fringe scenario with variation (top right)
  – Fringe scenario high precision (bottom left)
  – Nominal scenario with high precision and compensation for variations and uncertainties
    OR:
  – Nominal scenario with variation (bottom right)
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Benchmark requirements

• **A need**
  – Verification
  – Instil greater confidence in the application
  – Drive future developments
  – Identify gaps and deficiencies in the state of the art
  – Guide best practice

• **Subject**
  – Benchmarking the entire vehicle-track dynamic system would be ambitious
    • Conclusions would be difficult to draw
  – A small or isolated benchmark subject allows clearer comparisons and conclusions
    • Increased difficulty in relating conclusions to the more complex case

• **Benchmark conditions**
  – Clearly defined
  – Unambiguous (unless desired…)
  – Unwanted effects from ‘externalities’ of the subject must be controlled or removed
Benchmark requirements

• Participants/contributors
  – Most larger benchmarks have been an open call for contributions
  – Distribute workload
  – Ensure expert implementation of codes
  – Removes the inference of any partiality

• Appropriate comparison methods and metrics
  – Measurement or experimental data increases scope of activity, however:
    • “…validation examples may alter from a model justification to a justification and correction of the measurement inexactness.” (Polach & Evans)
  – Validation metrics in DynoTrain did not provide sufficient contribution towards objective and reliable validation – the same ought to apply to corroborative comparisons
  – Statistically derived metrics (EN14363)
  – Draw out pertinent conclusions
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D1.3.6 The state of the art of the simulation of vehicle track interaction as a method for determining track degradation rates. Part 2 – High Resolution models and the level of validation generally. Innotrack project deliverable, July 2009.

D5.5 — Final report on model validation process, Dynotrain project deliverable. WP5 — Model building and validation, June 2013

ERRI B176/3, Benchmark problem – Results and assessment, B176/DT290, Utrecht 1993. Note: Original text not obtained but cited in several references below.


GM/TT 0088, Issue 1, Permissible Track Forces for Railway Vehicles, British Railways Board, October 1993.

Grassie, S., L., Models of Railway Track and Vehicle/Track Interaction at High Frequencies: Results of Benchmark Test, Vehicle System Dynamics, 1996.


Iwnicki, S., Results of the Manchester Benchmarks, Vehicle System Dynamics, Supplement 31, 2-12, 1999

Kortüm, W., Sharp, R.S. (editors), Multibody computer codes in vehicle system dynamics, Vehicle System Dynamics Supplement 22, Swets & Zeitlinger 1993.


