Modeling of the Sound Transit Vehicle and Track Structure

VAMPIRE® Analysis

Wheel Rail Interface Conference

May 7, 2012

Prepared by:

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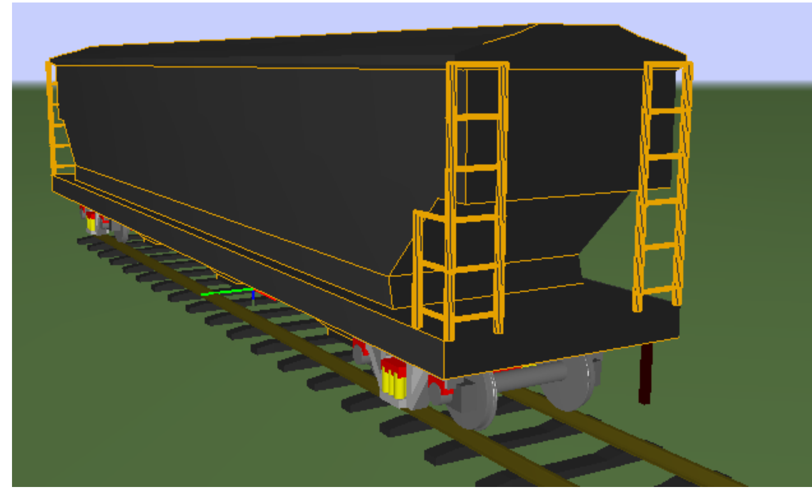
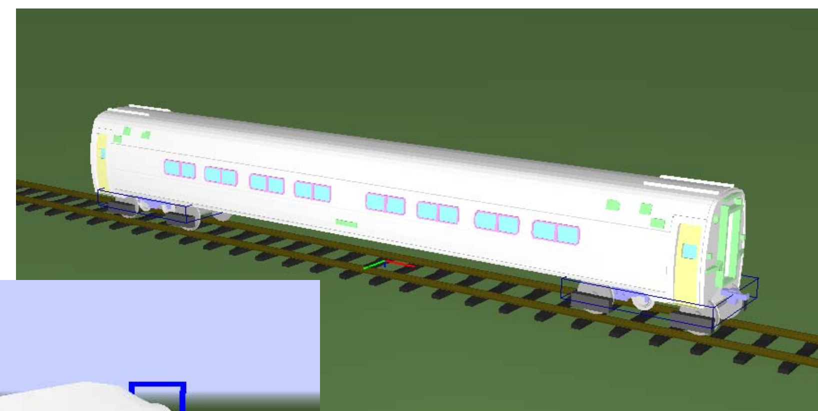
Executive Summary

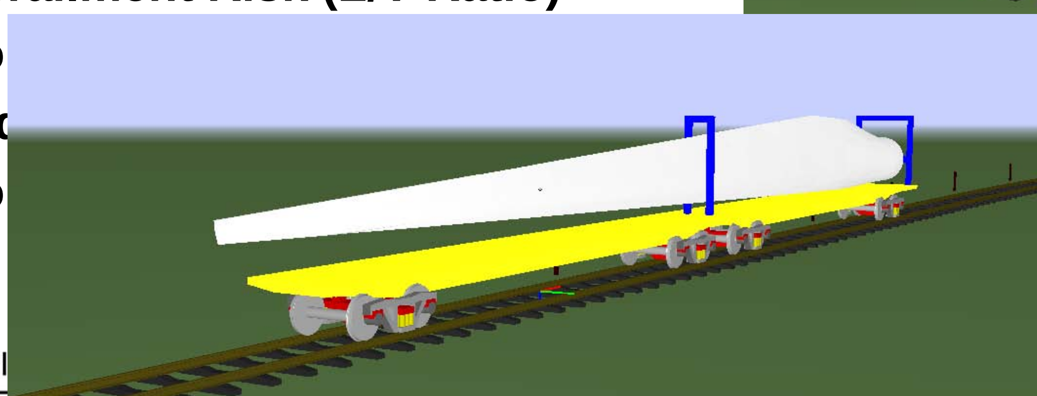
- TUV Rheinland Rail Sciences, Inc. used VAMPIRE® vehicle and track interaction simulation software to model a Sound Transit vehicle traveling over typical Sound Transit track in order to explore the effects of changes to wheel and rail profiles on wheel/rail wear, lateral creep forces on the tread and ride quality.
- Track geometry and rail profile measurements of Sound Transit's track structure were obtained, processed and implemented into VAMPIRE® simulation software for simulation.
- Wheel profile measurements of Sound Transit vehicles were obtained and implemented into the VAMPIRE® model for simulation.
- Engineering data of the vehicle structure (mass, inertia, stiffness, damping, connections, and dimensions) were supplied to TUV RSI and used for the modeling of the vehicle in VAMPIRE®.
- The base model was validated against known behavior of the vehicle to ensure confidence in the model predictions.
- The model was then used to evaluate effects of suggested changes to vehicle and track
- Proposed wheel and rail profiles that effected lower wear numbers and/or lateral creep forces when compared to the base model were considered an improvement.
- Reducing the wheel back to back spacing was suggested and evaluated using the model.
- Using a high conicity wheel on the center truck was proposed.
- The effectiveness of these proposed mitigation techniques were classified based upon wear number reduction and effects on vehicle lateral accelerations (ride quality).

VAMPIRE® is a vehicle – track interaction **computer simulation software.**

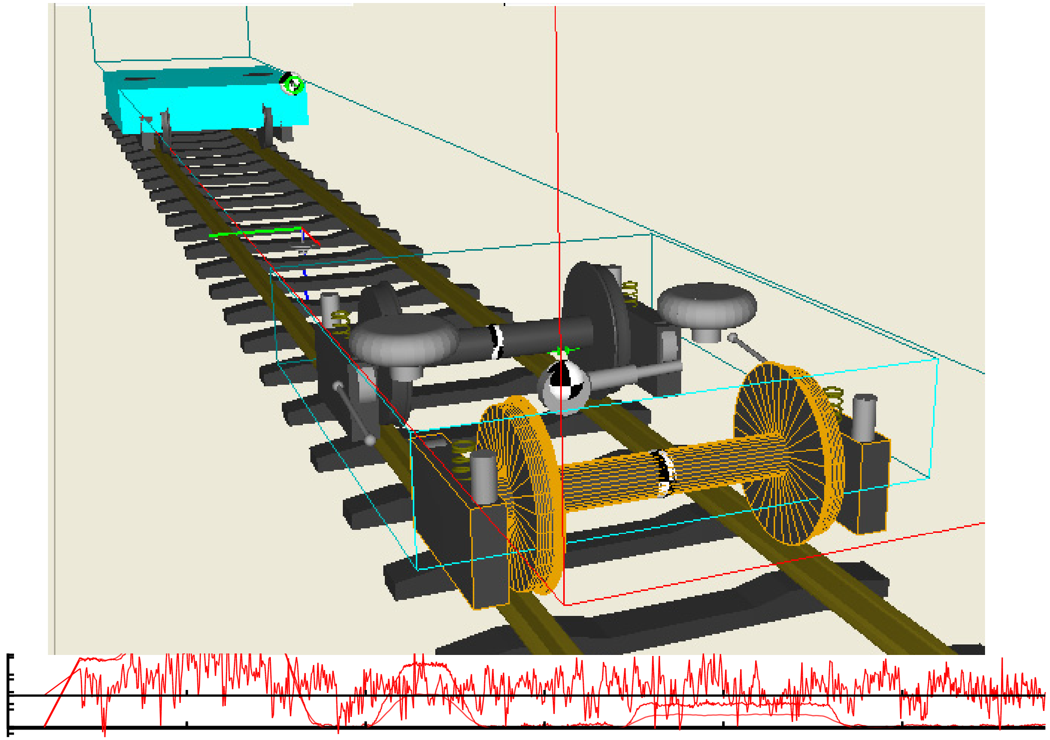
- It simulates rail vehicles with their suspension characteristics, and their performance travelling over track features.
- It is a useful tool to predict the following:
  - » **Derailment Risk (L/V Ratio)**
  - » **Fo**
  - » **Ric**
  - » **Fo**







- Mass and Inertia
  - Car body
  - Trucks
- Stiffness
  - Suspension Springs
  - Air Springs
- Damping
  - Snubbers
  - Yaw Dampers
  - Viscous Dampers
- Excitation Source
  - Track feature inputs
  - Speed of travel



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    -785.8431         20.3363          785.8431        20.3363
    -785.3179         23.4099          785.3179        23.4099
    -784.1274         26.1929          784.1274        26.1929
    -783.3040         27.4434          783.3040        27.4434
    -782.3418         28.5848          782.3418        28.5848
    -781.2504         29.6065          781.2504        29.6065
    -780.0405         30.4972          780.0405        30.4972
    -778.7214         31.2453          778.7214        31.2453
    -777.3012         31.8381          777.3012        31.8381
    -775.7881         32.2611          775.7881        32.2611
    -774.2251         32.5424          774.2251        32.5424
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    -768.2
    -765.4
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    -757.6
    -755.2
    -752.8
    -750.5
    -748.2
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    -736.2
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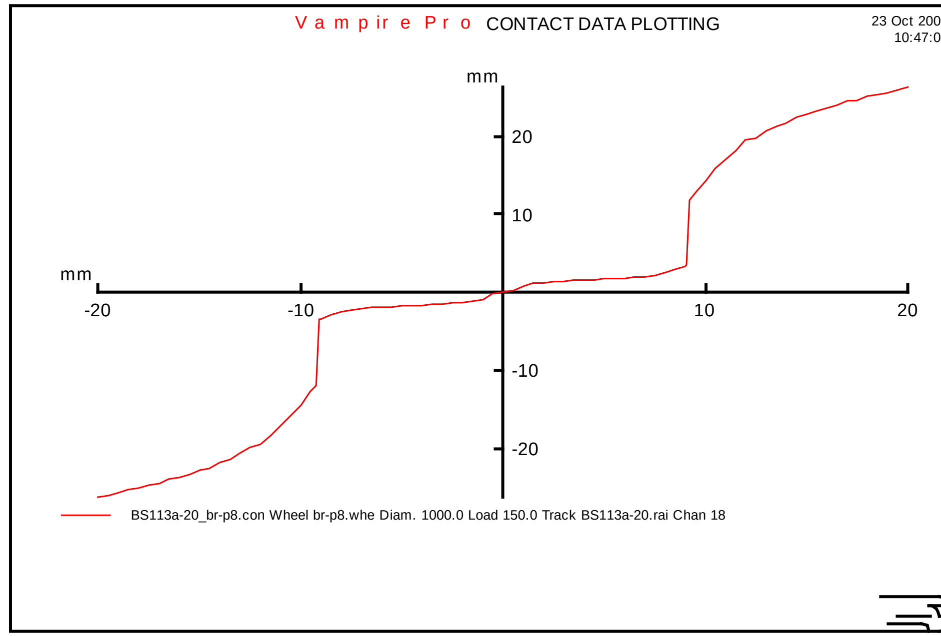
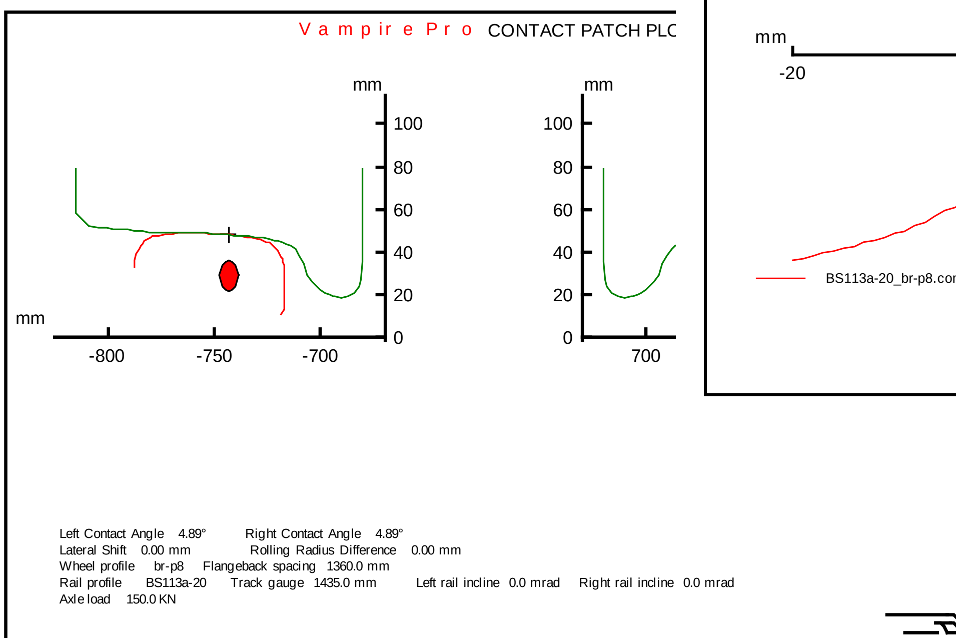
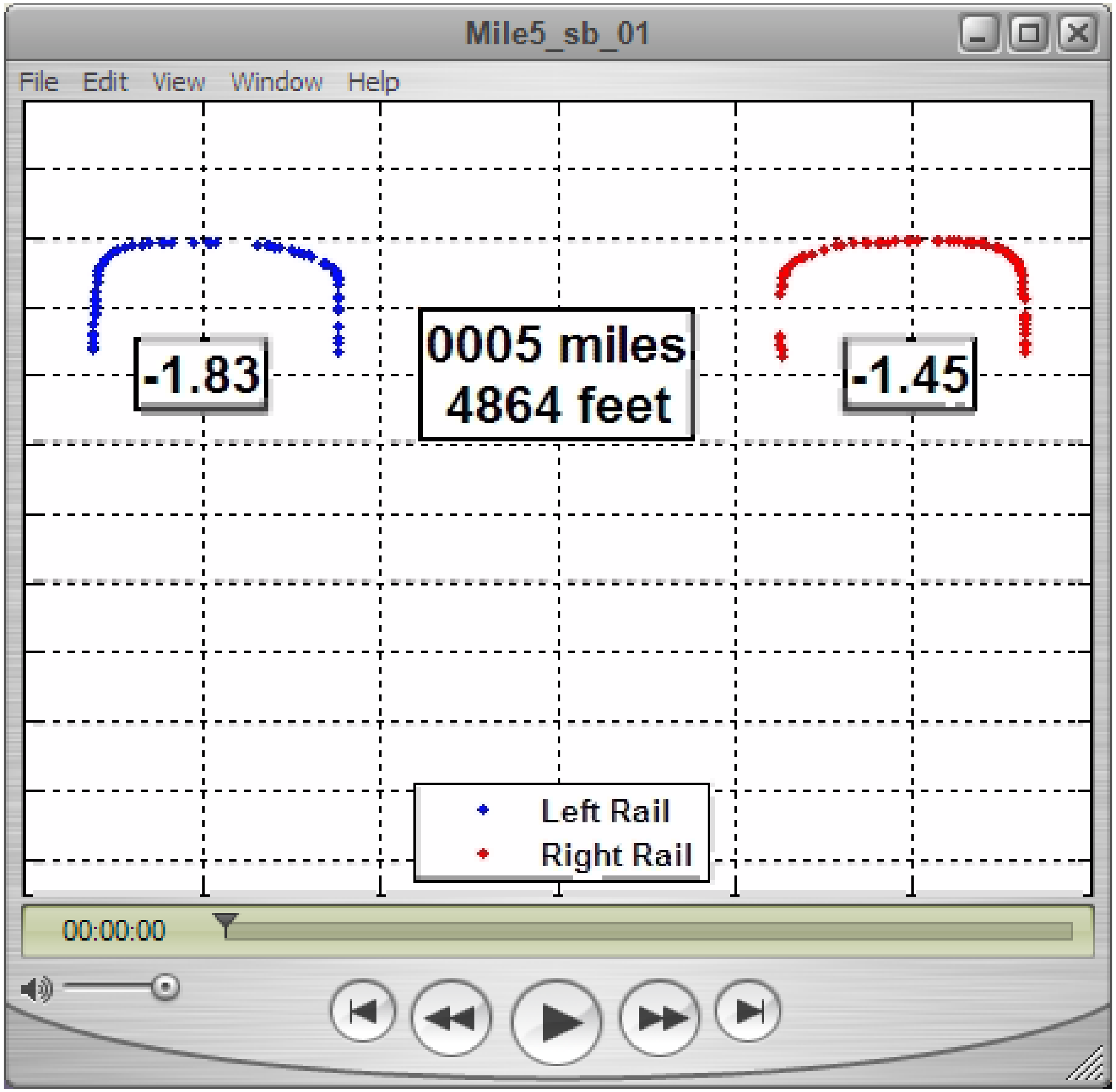


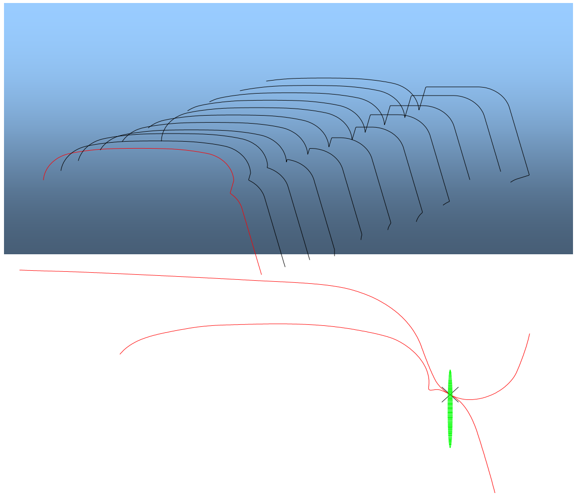
VAMPIRE Plot



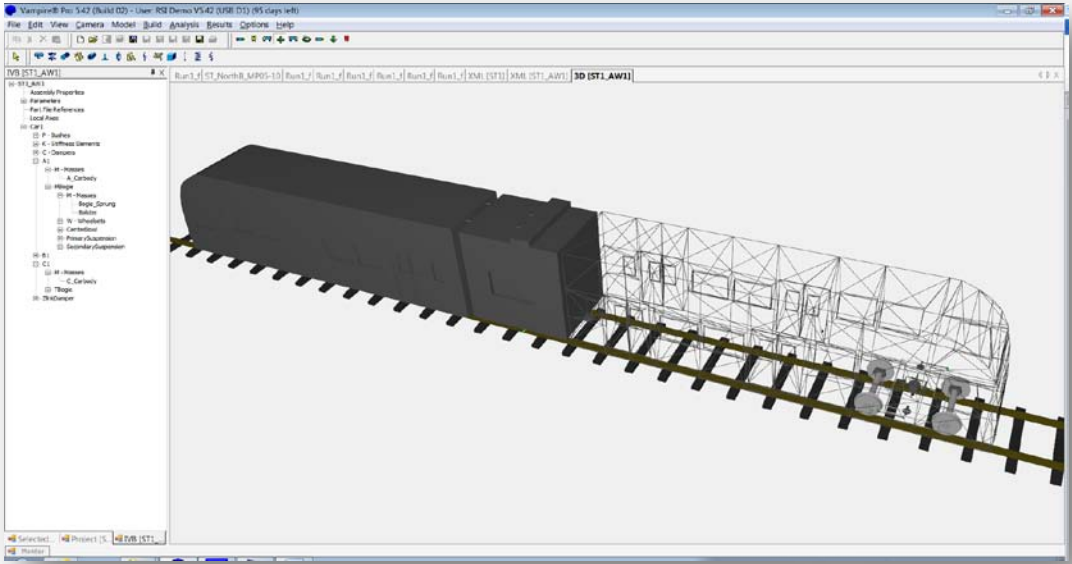
VAMPIRE Plot

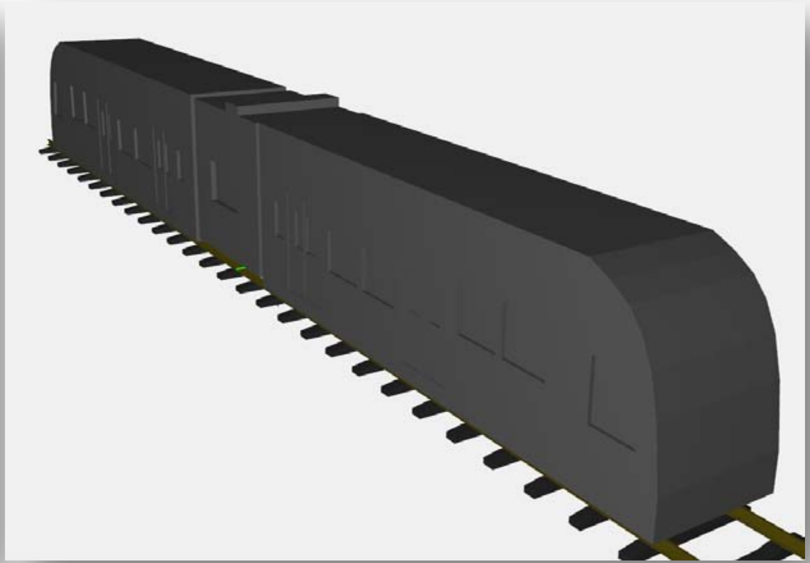


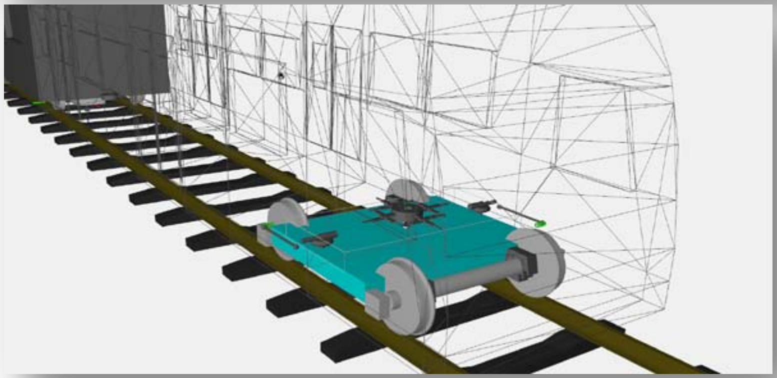
- Example of measured rail profiles
- Measured rail profiles were processed and incorporated into the base model at their corresponding locations along the track to accurately assess the current wheel rail contact mechanics on Sound Transit track.

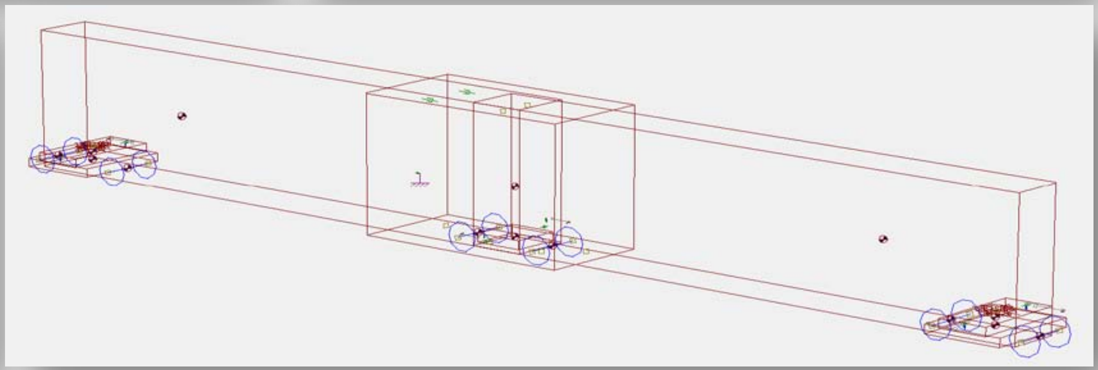


- VAMPIRE vehicle model images showing the physical arrangement of mass, spring, damper, friction and wheel set elements that mathematically represent the Sound Transit Vehicle.



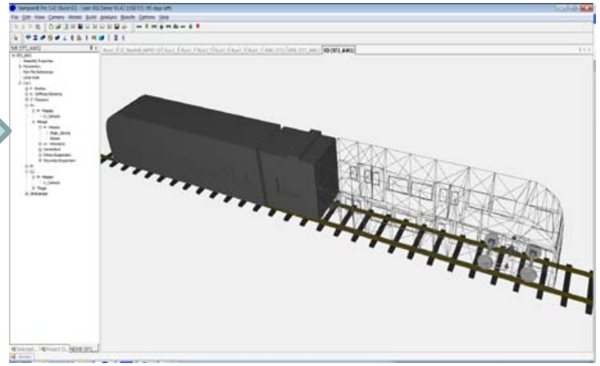




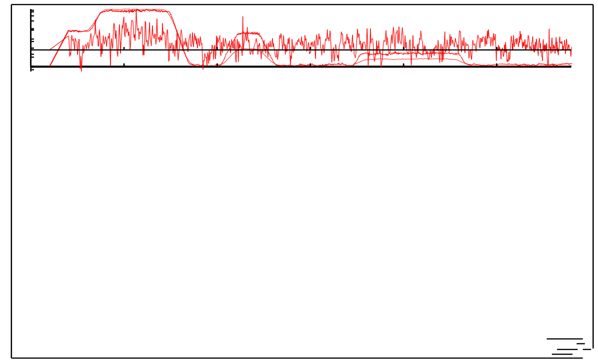


Model Validation Methodology

Vehicle Model



Track Model



Simulate Vehicle Model Traveling over Track Model

Do Simulation Results Acceptably Match Known/Expected Behavior?

No

Make Corrections to Vehicle Model

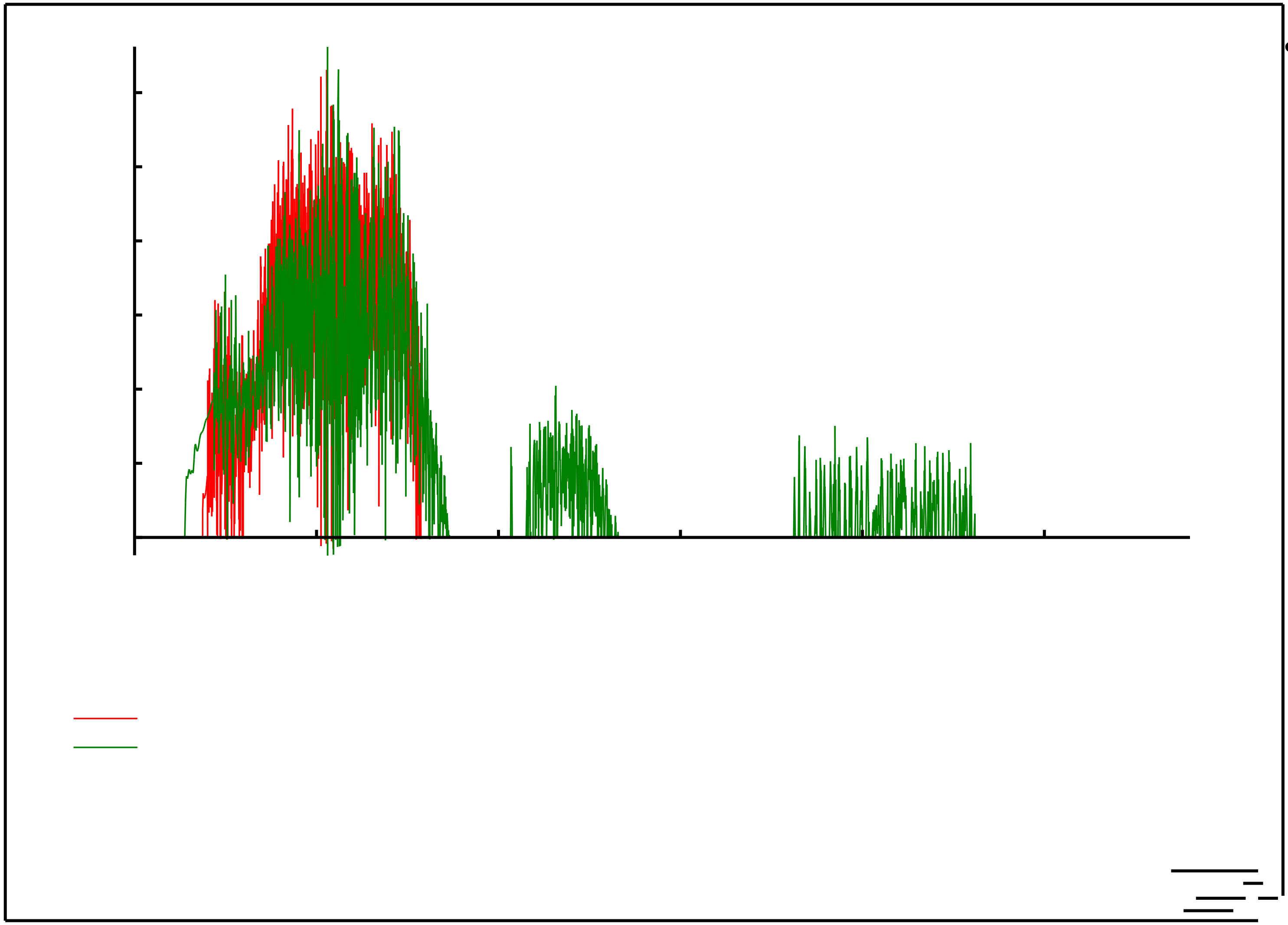
Yes

Base Vehicle and Track Model Is Validated

Model Validation

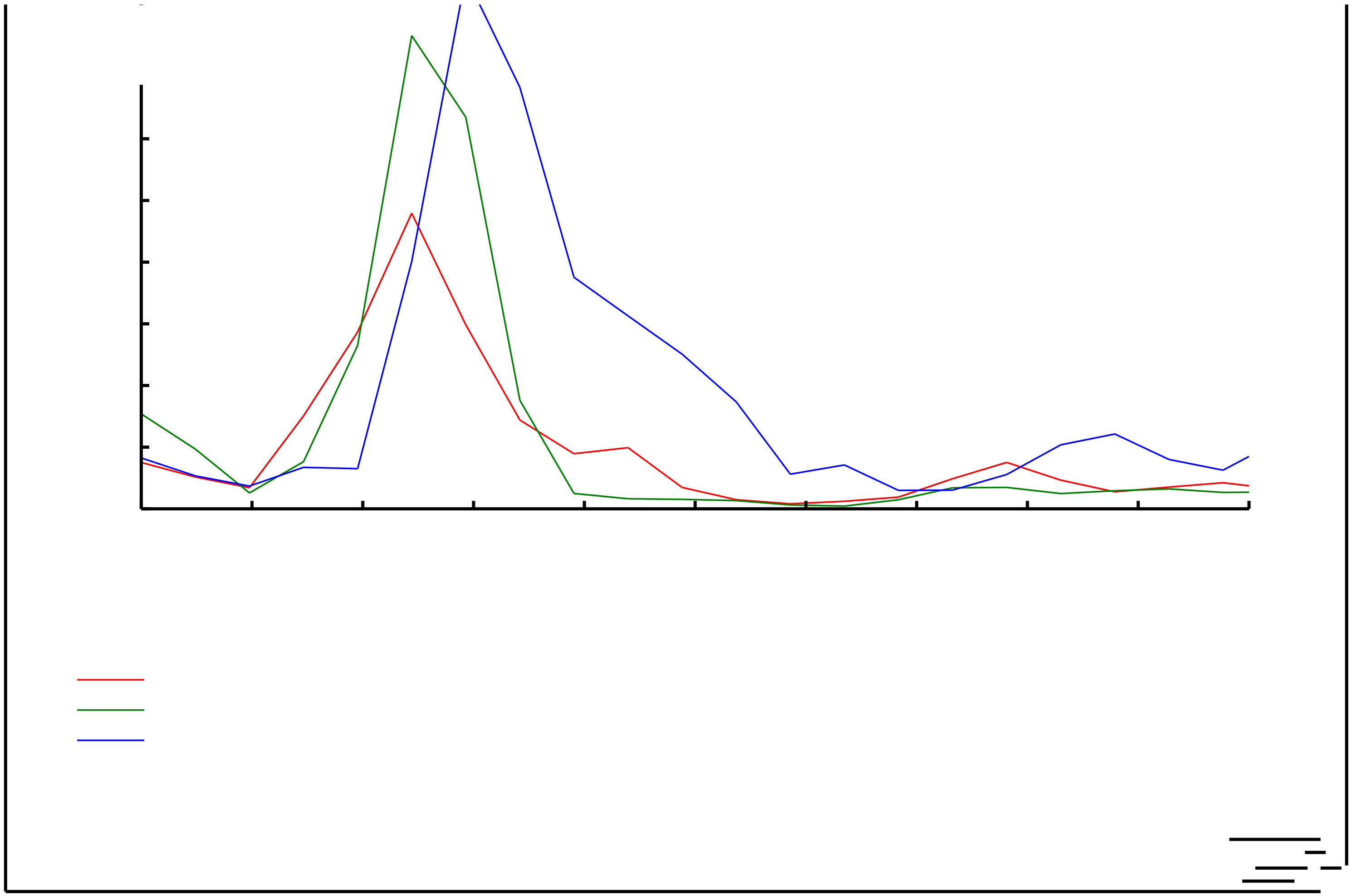
- The behavior and trends exhibited by the VAMPIRE® vehicle model were compared to known behavior of the Sound Transit vehicles to determine if the model behaved in a similar fashion and could be confidently used for predictive and evaluation purposes
- It was generally accepted that in actual practice the center truck of the Sound Transit vehicles exhibit higher wheel wear than on the other two trucks of the vehicle.
- This would suggest that the model should calculate that the center truck wheels generally output a higher wear number.
- It was generally accepted that the car bodies of the Sound Transit vehicles in actual service will oscillate with a 2 to 3 Hz lateral acceleration in curves, and this type of car body oscillation is not observed on tangent track.
- The VAMPIRE® base model calculations were consistent with these observations and accurately recreated this behavior.
- Thus, the VAMPIRE® base model was deemed validated for use in analyzing effects and **TRENDS** of suggested remediation on wheel wear number, creep forces and lateral acceleration (ride comfort).

Model Validation - Difference between Center and End Trucks



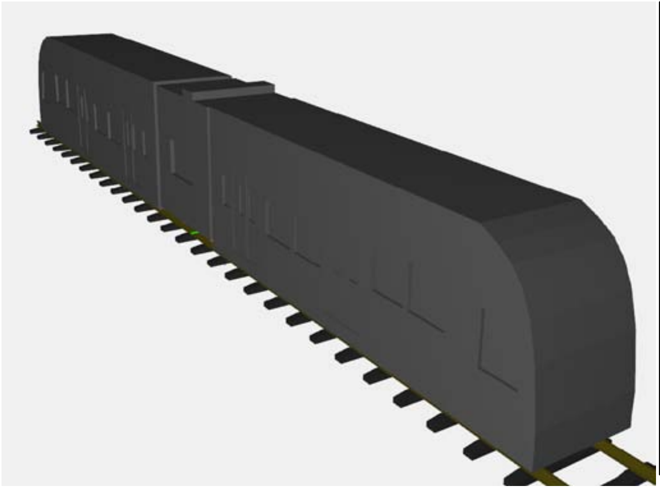
- Generally higher flange wear numbers calculated for the center truck is consistent with observed behavior

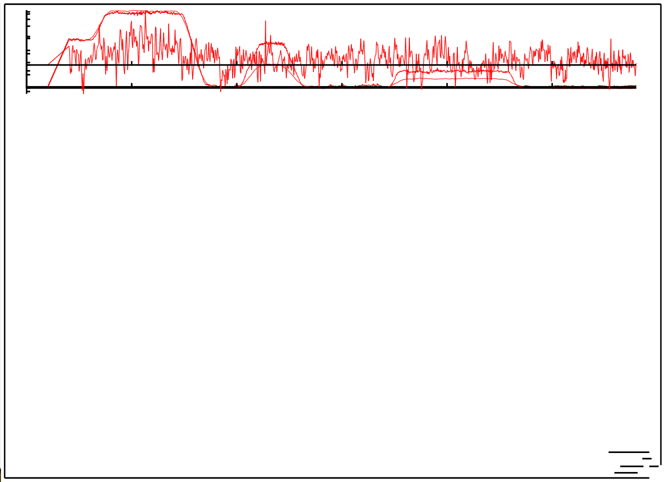
Model Validation - PSD of the Lateral Acceleration of the Car Bodies



- Presence of spikes at the 2-3 Hz location in a frequency analysis of the lateral accelerations of the car bodies in curving is consistent with observations

Add Proposed Modifications to Model for Simulation





Calculate Flange Wear Number, Tread Wear Number, and Car Body Lateral Acceleration

Compare Results Incorporating Modifications to Base Model Results

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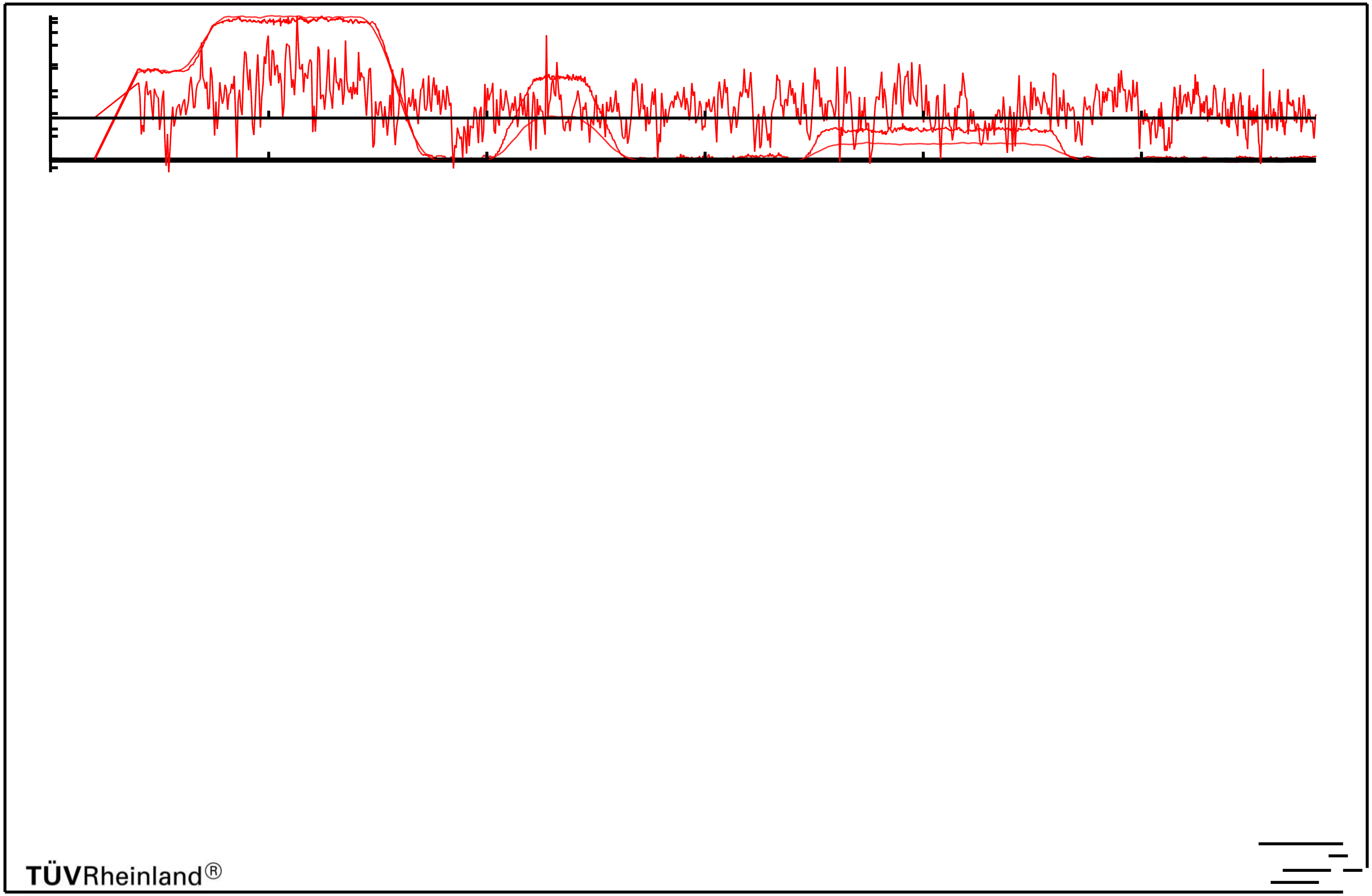
Track Model

- The track model was coded from track geometry data obtained on the Sound Transit North bound track between mile post 5 and 10.
- The geometry data is composed of cross level, curvature, and gauge measurements.
- Vehicle dynamics is excited as the vehicle model is simulated to travel over these perturbations at a prescribed speed.
- Wheel/rail contact forces are calculated through the wheel/rail surfaces described by the wheel and rail profile geometry.
- For the base model calculations, actual measured rail profiles were processed and incorporated into simulations at their corresponding locations along the track model.
- The following slides show samples of track geometry and rail profiles used for simulation purposes.

- Track geometry car data were used as track input for the simulation. A sample of the cross level, curvature, and gauge variation data are plotted below.



Effects of Wheel Back to Back Spacing and High Conicity Wheel

- It was suggested that bringing the wheel backs of a wheel set closer together may lower the wheel’s tendency to flange by moving the flange farther away from the gauge face of the rail and subsequently lowering noise from flanging and perhaps the vehicle’s tendency to oscillate laterally as well.
- It was also suggested that the use of a high conicity wheel on the center truck may help to reduce flanging, wheel wear and oscillation on the center vehicle.
- Starting from the results from the validated base model, simulations were then conducted with various combinations of wheel back to back spacing and wheel/rail profiles to test the effects of these hypotheses.
- With these combinations, the model was used to calculate lateral oscillation, flange wear number and tread wear number to see if any of these values were lowered in comparison to the base model case.
- The vehicle model was simulated to pass along a curved portion of the Sound Transit track and a tangent section to observe the behavior in both curving and tangent track travel with these remediation ideas in place.

Effects of Wheel Back to Back Spacing and High Conicity Wheel on Wear

- To study the effects of wheel back to back spacing and high conicity wheel, the following rail and wheel profiles were tried:
  - Rail profile: perfectly conformal
  - Rail profile: 1 point closely conformal
  - Rail profile: 1 point conformal
  - Rail profile: 2 point closely conformal
  - Rail profile: 2 point conformal
  - Wheel profile: New Sound Transit Wheel
  - Wheel profile: High Conicity Wheel
- TUV RSI personnel obtained field measurements of multiple wheel profiles from Sound Transit vehicles. A pair of these wheel profiles were chosen and considered as average worn wheel profiles. Standard AREA 115lb rail profile was also included in the simulations.
- Multiple simulations were performed with different wheel/rail profile combinations which were listed in the table below.

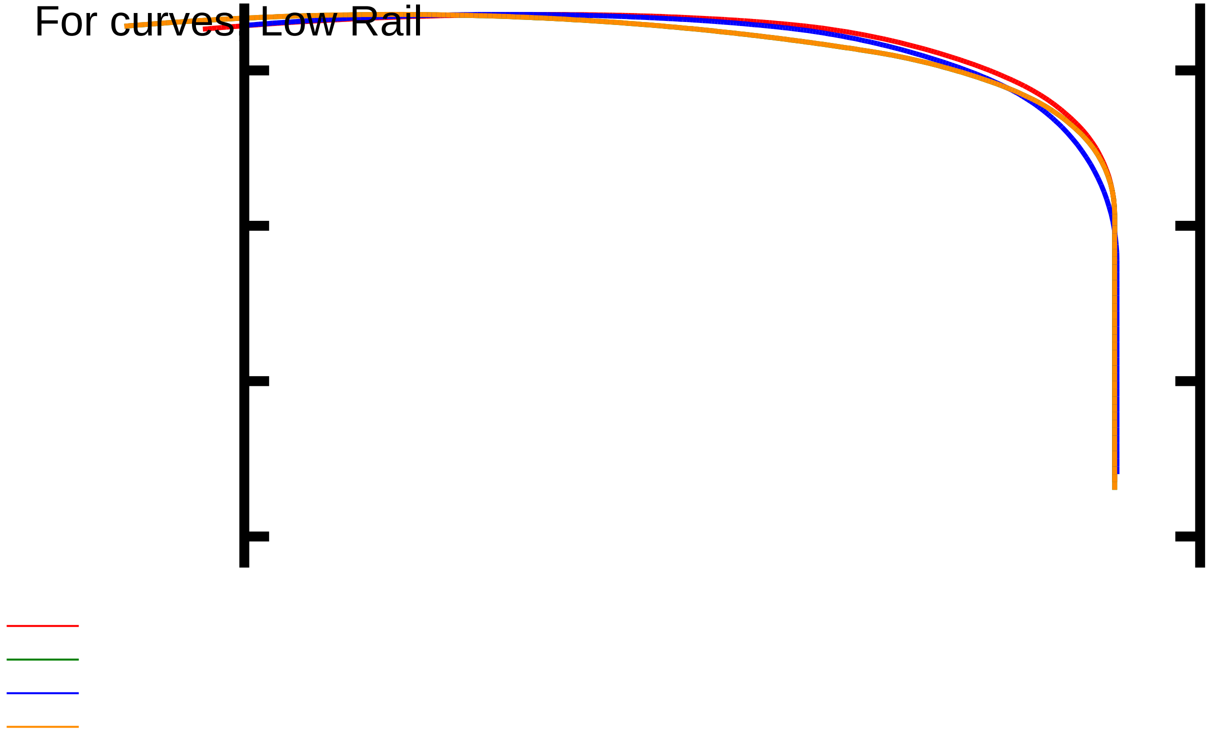
New Wheel					Worn Wheel					High Conicity Wheel			
Left Rail	Right Rail	Left Wheel	Right Wheel		Left Rail	Right Rail	Left Wheel	Right Wheel		Left Rail	Right Rail	Left Wheel	Right Wheel
AREA_115_40	AREA_115_40	ST_new	ST_new		AREA_115_40	AREA_115_40	L5	R6		AREA_115_40	AREA_115_40	ST_hctest2	ST_hctest2
perfect_confor	AREA_115_40	ST_new	ST_new		perfect_confor	AREA_115_40	L5	R6		perfect_confor	AREA_115_40	ST_hctest2	ST_hctest2
1pt_closely_co	AREA_115_40	ST_new	ST_new		1pt_closely_co	AREA_115_40	L5	R6		1pt_closely_co	AREA_115_40	ST_hctest2	ST_hctest2
1pt_conformal	AREA_115_40	ST_new	ST_new		1pt_conformal	AREA_115_40	L5	R6		1pt_conformal	AREA_115_40	ST_hctest2	ST_hctest2
2pt_closely_co	AREA_115_40	ST_new	ST_new		2pt_closely_co	AREA_115_40	L5	R6		2pt_closely_co	AREA_115_40	ST_hctest2	ST_hctest2
2pt_conformal	AREA_115_40	ST_new	ST_new		2pt_conformal	AREA_115_40	L5	R6		2pt_conformal	AREA_115_40	ST_hctest2	ST_hctest2

Wheel Back to Back Spacing and High Conicity Wheel Analysis Summary

- little difference in lateral acceleration performance or wheel wear numbers was seen through the use of decreased back to back wheel spacing.
- little difference in lateral acceleration performance or wheel wear numbers is seen through the application of a high conicity wheel.
- Neither magnitude nor frequency content of lateral accelerations were appreciably changed through the application of reduced wheel back to back spacing or high conicity wheel profiles.
- Reducing wheel set back to back spacing slightly decreased flange contact wear numbers especially on the end truck.
- Little change in average wheel wear numbers were seen on the center truck through the application of high conicity wheels in comparison to the results with new wheels.
- No hunting was observed for any conditions which would negate the idea that hunting may be a contributing factor to wheel wear, noise or lateral oscillations.

Devised Rail Profiles recommended by NRC

- Four rail profiles were recommended. They are:
  - For tangent track, Contact Point Center (CPC)
  - For tangent track, Contact Point Field (CPF)
  - For curves, High Rail
  - For curves, Low Rail



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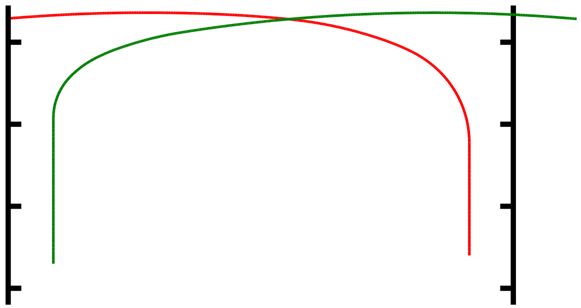
Devised Rail Profiles recommended by NRC

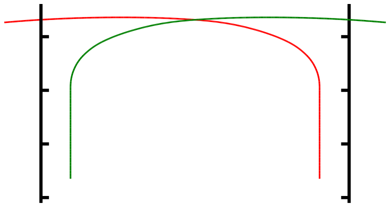
NRC recommended rail profiles for high and low rails in curves



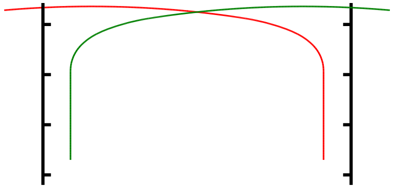
High Rail Profile

Low Rail Profile

NRC recommended rail profiles on tangent sections of track



Contact Point Center



Contact Point Field

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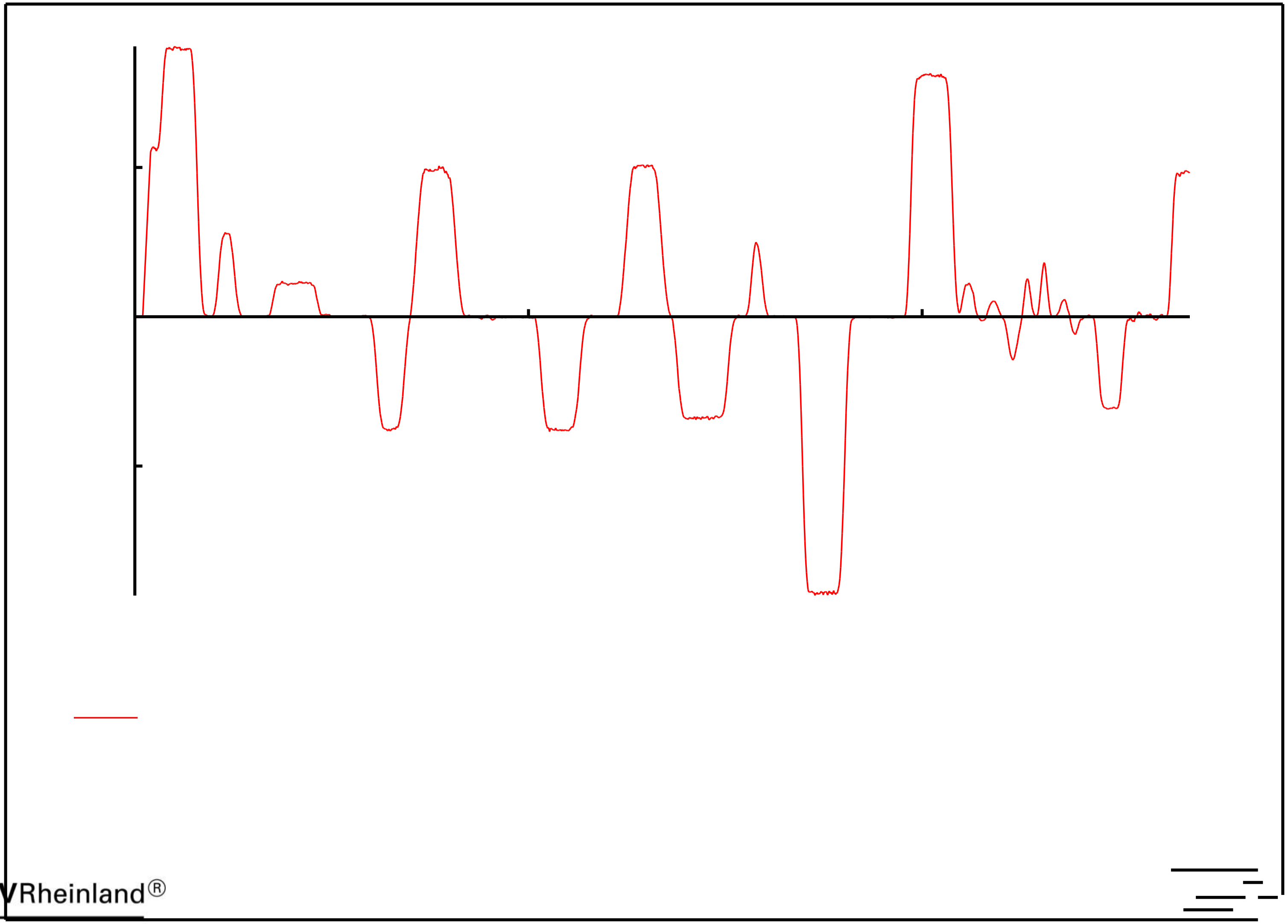
Track Used to Simulate the Effects of Devised Rail Profiles

- The entire 5 miles of North Bound track (MP10 to MP5) were modeled and used in this part of the analysis. The graph below displays the curvature of the 5 miles of track.



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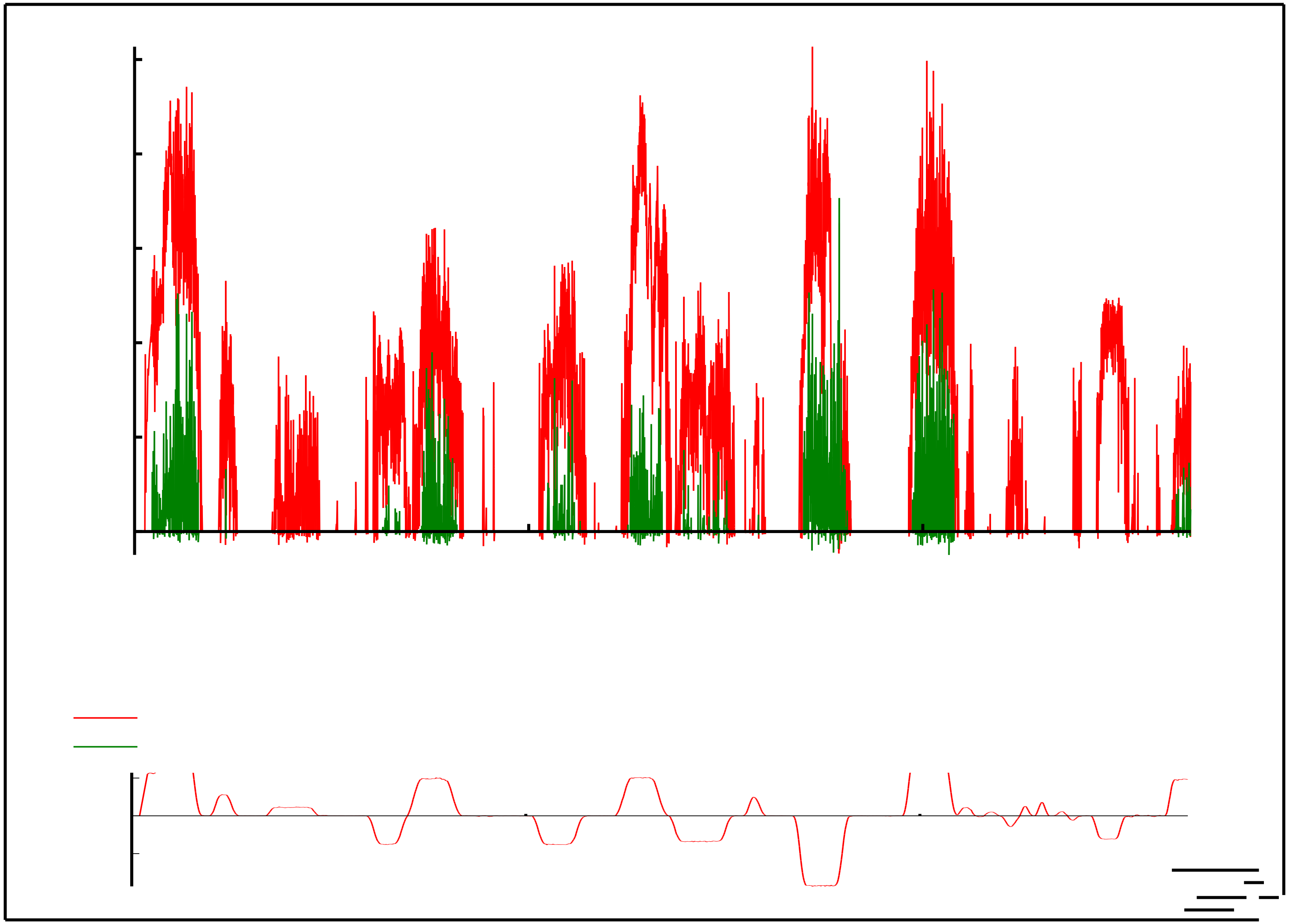
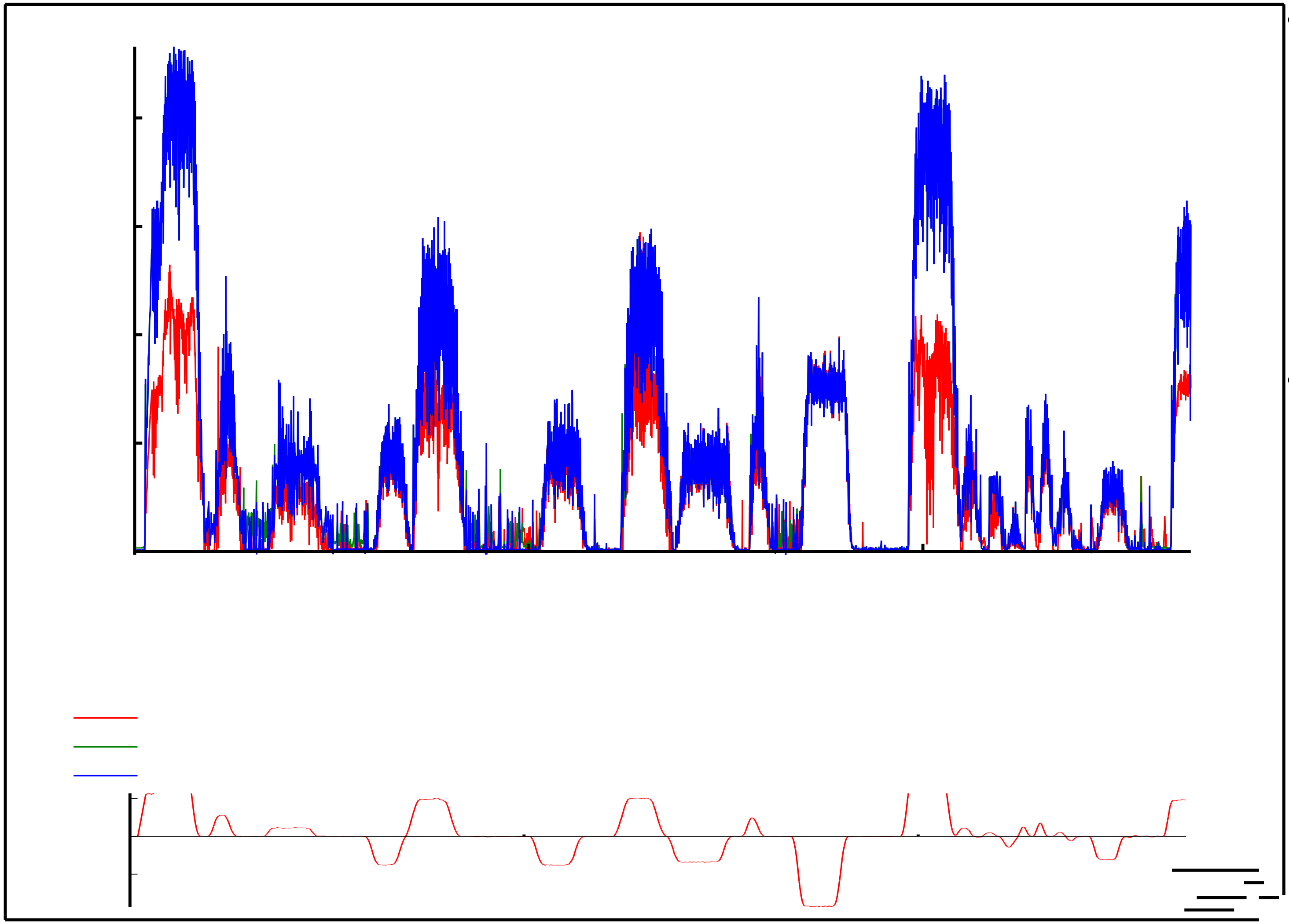
Flange Contact Wear Number



- Significant reduction of flange wear is seen with the application of the designed rail profiles
- This is particularly noted in curves

Tread Contact Wear Number



- Use of the NRC recommended profiles results in increased tread wear in curves when compared to the base model.
- This trend is not noted in tangent sections of track

Comparison between the Rail Profiles

- The average wear numbers over the entire 5 miles of North Bound track are listed in the table below.

Average Wear Number	Measured Rail Profiles	Designed Rail Profiles (CPC on tangent)	Designed Rail Profiles (CPF on tangent)
Flange (center truck)	8.181	0.629	0.629
Flange (end truck)	6.821	0.412	0.412
Tread (Center truck, Left wheel)	5.589	8.480	8.338
Tread (End truck, Left wheel)	5.763	8.455	8.410
Tread (Center truck, Right wheel)	5.435	7.146	7.064
Tread (End truck, Right wheel)	6.711	7.949	7.904

- While increase is seen in tread wear number, a significant decrease in flange wear is noted.
- Again, more severe flange wear were observed on the center truck than on the end truck in all cases.

Conclusions and Recommendations

- Based on simulation results, the benefits of reducing wheel back to back spacing are slight.
- Based on simulation results, the benefits of using a high conicity profile wheel on the center trucks are slight.
- The profiles devised by NRC for the low and high rails in curves were found to significantly reduce the flange wear number in curving.
- The profiles devised by NRC for the low and high rails in curves were found to increase the tread wear number in curving.
- The profiles devised by NRC for the low and high rails in curves were found to slightly decrease the lateral creep forces on the low rail in curves.
- Use of both the Contact Point Center (CPC) and Contact Point Field (CPF) rail profiles on tangent track resulted in nearly zero flange contact and hence, zero flange wear on tangent track.

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