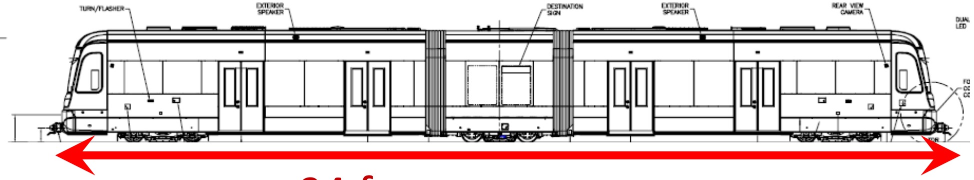
Developing WRIS requirements for a new Light Rail Vehicle Contract in North America

Shankar Rajaram, PhD
Executive Project Director – Revenue Vehicles
Sound Transit
shankar.rajaram@soundtransit.org

Principal Contributors

- **Bart Kuka, Nick Laverick, Mark Terry, Karen Steele, Andrew B, Chris Tindell, Jonathan Brake** – Mott MacDonald
- **William Robert, Jonathan Mabuni** – Spy Pond Partners
- **Eric Magel, Jan Mys, Gordon Bachinsky** – Global Rail/ARM
- **Briony Croft, Mark Reimer** – Sahaya
- **Stuart Grassie** – Stuart Grassie
- **Wesley Thomas, Ankur Ashtekar** – Loram
- **Jim Nelson, Luke Watry, Katie Krainc** – Wilson Ihrig Associates
- **Mike Landowski, Khang Vu, A J Yarnall, Charles Ng, Dan Brouwer, Kyle Froelich, George McGinn, Paul Denison** – Sound Transit
- **Jose Ballesteros, Victor Sanchez** – KCM

Series 1 & 2 Vs Series 3 LRVs

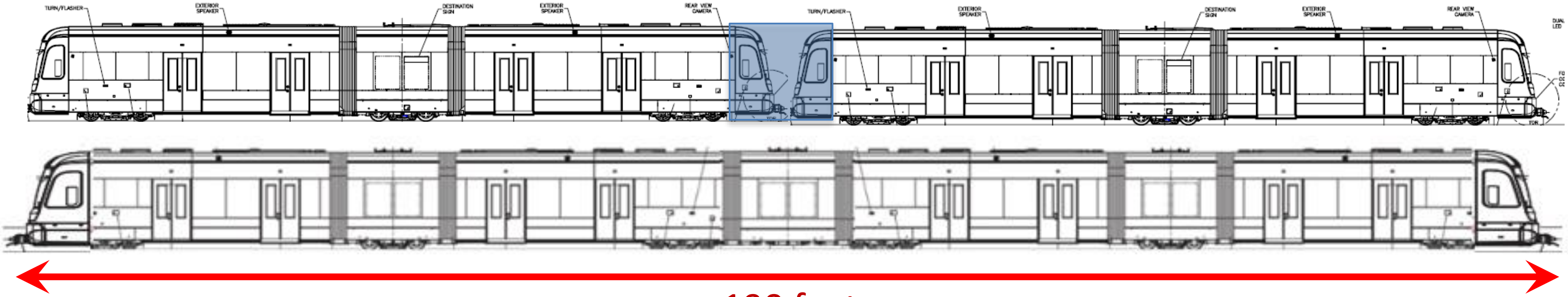


94 feet

Power Truck
(A-car)
Solid axle wheels

Trailer Truck
(C-car)
Independent rotating wheels

Power Truck
(B-car)
Solid axle wheels



190 feet

Courtesy: 190 feet Concept LRV Configuration shown in this slide was developed by Chris Tindell of Mott MacDonald in Dec 2023

Typical New LRV Specifications - Include

- High speed stability
- Truck performance, including prescriptive limits for primary suspension stiffness, secondary suspension stiffness, wheel load equalization, and truck swiveling.
- Wayside noise, ride quality, and in some cases, ground-borne vibration.

Typical New LRV Procurement Package Don’t Include

- **Rail wear pattern on the system**
- **Wheel wear pattern**
- **Conditions that trigger maintenance interventions**
- **Maintenance limits**

But….the car builder needs to perform a WRIS study using reasonable assumptions for worn condition of WRI.

Key Wheel Rail Factors for LRVs

1. **Wheel profile – New & Worn**
2. **Rail Profile – New & Worn**
3. **Wheel Roughness – Newly Cut & Worn**
4. **Rail Roughness – Newly Ground & Worn**
5. **Wheel Flats – Number of Instances & Sizes of Flats**
6. **Rail Surface – Studs, Corrugation, etc.**

LRV Performance Factors Impacted by WRI

1. Noise reference levels
2. Vibration levels
3. Ride Quality
4. Rail Roughness
5. Wheel Flats & Rail Surface Damages
6. Life Cycle Costs

Interior Noise: Series 2 LRV Spec

1. At 55 mph and 50 ft, exterior noise shall not exceed 75 dBA on open tracks
2. At 55 mph and 50 ft, exterior noise shall not exceed 80 dBA in tunnels

Exterior Noise: Series 2 LRV Spec

Test Condition	Meter Response	Noise Level
Vehicle stationary, empty	Slow	68 dBA
Vehicle empty, on tangent track accelerating from 40 mph (64 km/h) or in maximum dynamic braking or maximum friction braking from 40 mph (64 km/h) (whichever is worse). The vehicle shall be operated with wheels in new condition.	Fast	75 dBA
Two vehicles empty, on tangent track accelerating from 40 mph (64 km/h) or in maximum dynamic braking or maximum friction braking from 40 mph (64 km/h) (whichever is worse). The vehicle shall be operated with wheels in new condition.	Fast	78 dBA

Ride Quality: Series 2 Spec

The ride quality shall be evaluated according to ISO 2631-4.

RMS vertical and lateral acceleration values shall not exceed 1.05 ft/s^2 (0.32 m/s^2) and the vibration total value (root sum of squares summation) shall not exceed 1.64 ft/s^2 (0.5 m/s^2) over the range of 1 Hz to 80 Hz for AW0 and AW3 load conditions

Frequency weighting Wb, shall be used.

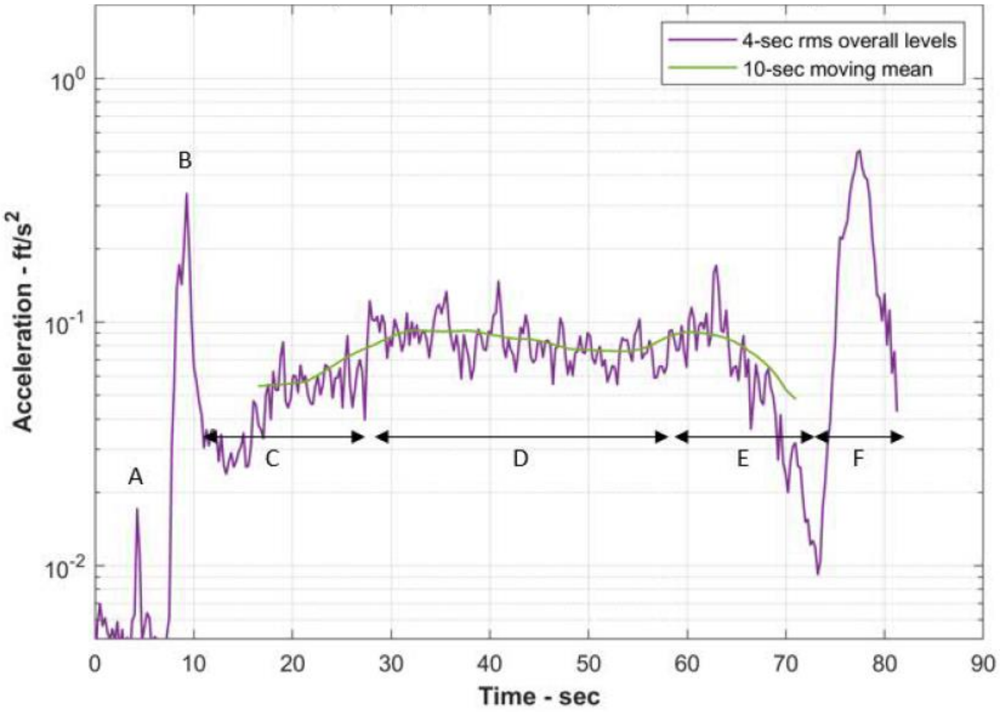
Testing on both ballast track and direct fixation with non-corrugated welded rail.

Measurements shall be made with 1/3 octave band analysis.

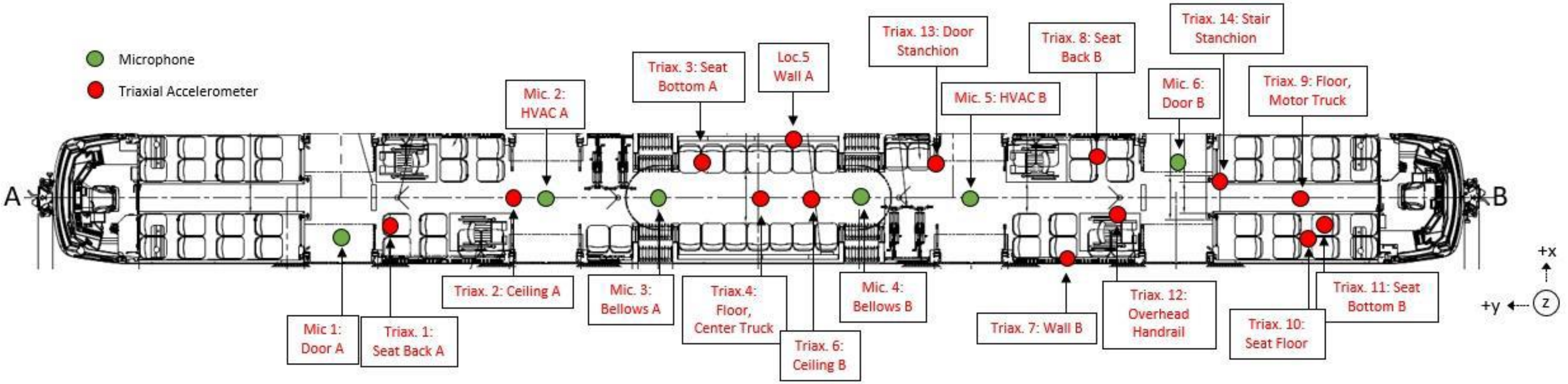
Steady-state ride quality is the RMS value with effective averaging time from 1 to 4 s

Averaged vibration level during any 10 s period shall not exceed the defined limitation.

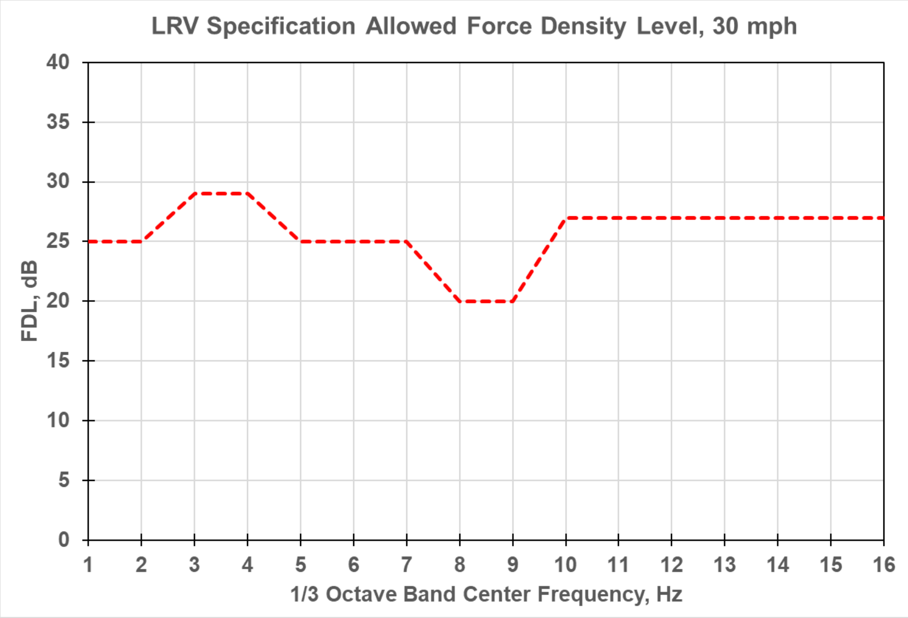
Ride Quality: Series 2 Tests

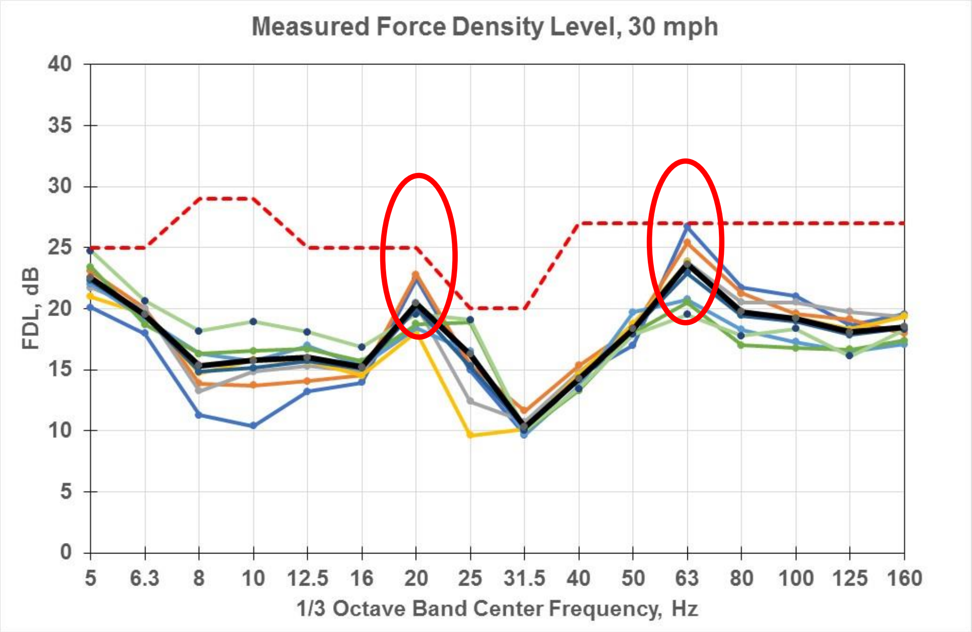


Ride Quality: Series 2 Tests



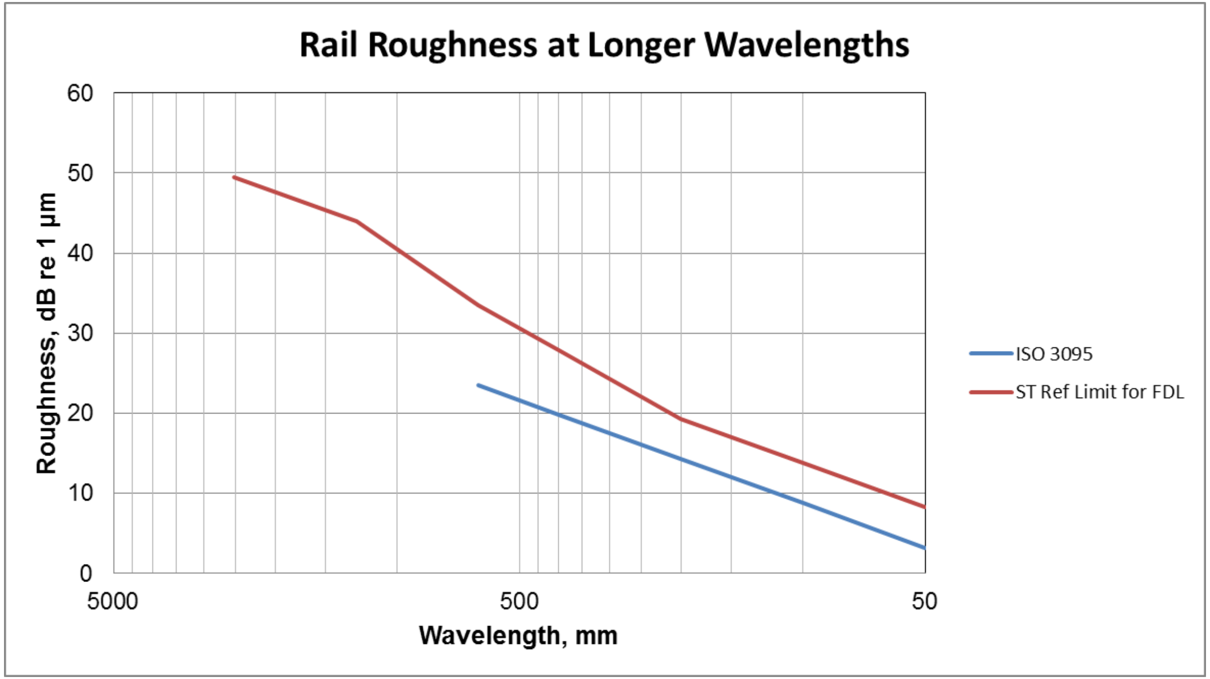
Series 2 LRV Vibration Acceptance Criteria





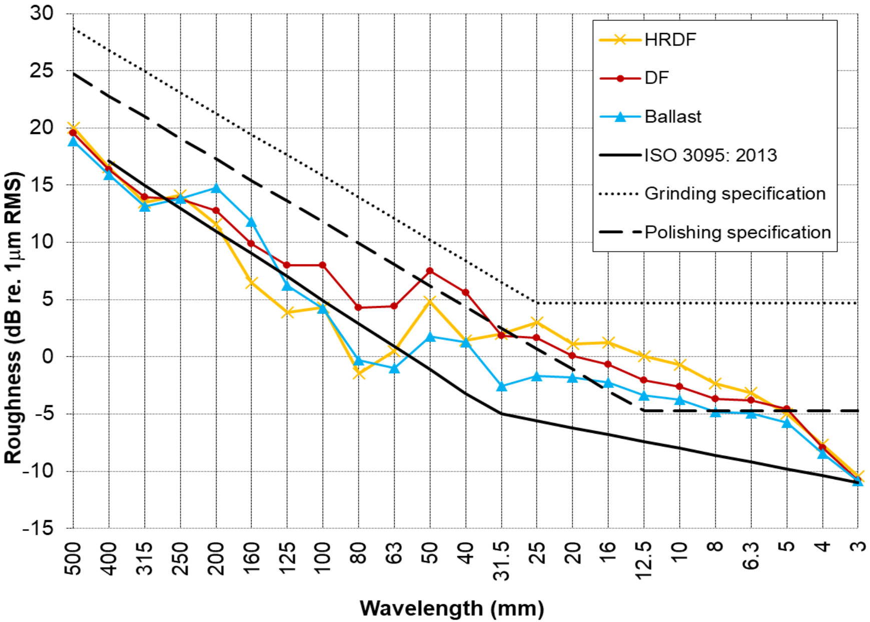
Courtesy: Shankar Rajaram of Sound Transit and Jim Nelson of Wilson Ihrig Associates developed the FDL Limit in 2016

Rail Roughness: Series 2 LRV Spec



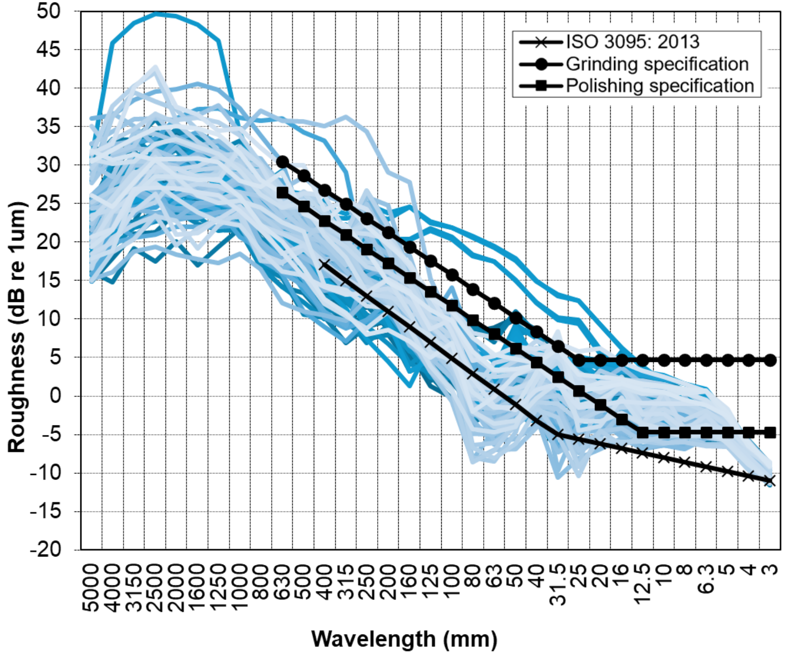
Courtesy: Shankar Rajaram of Sound Transit and Jim Nelson of Wilson Ihrig Associates developed this limit in 2016

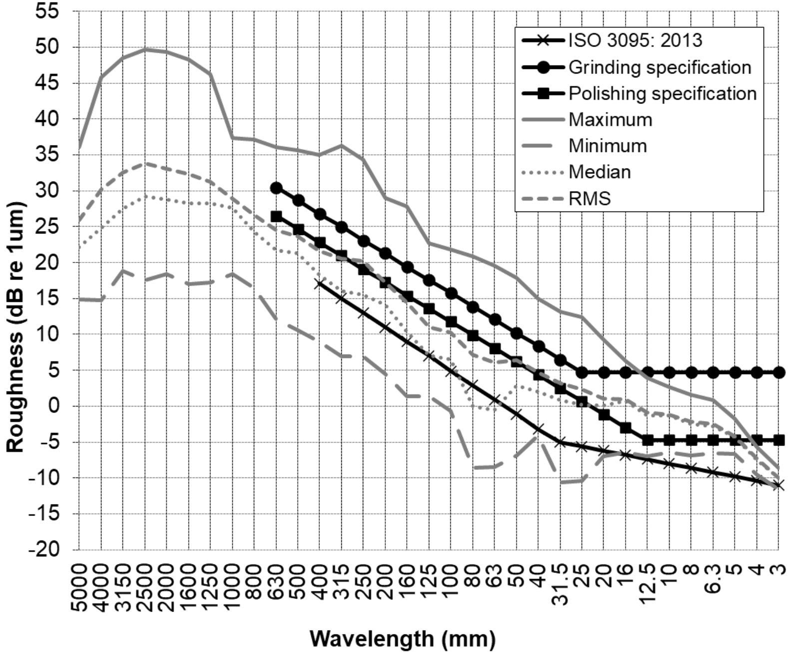
Link Rail Roughness



Courtesy: Rail roughness was evaluated by Briony Croft of Acoustics Studio & Wilson Ihrig Associates in 2022

Link Rail Roughness



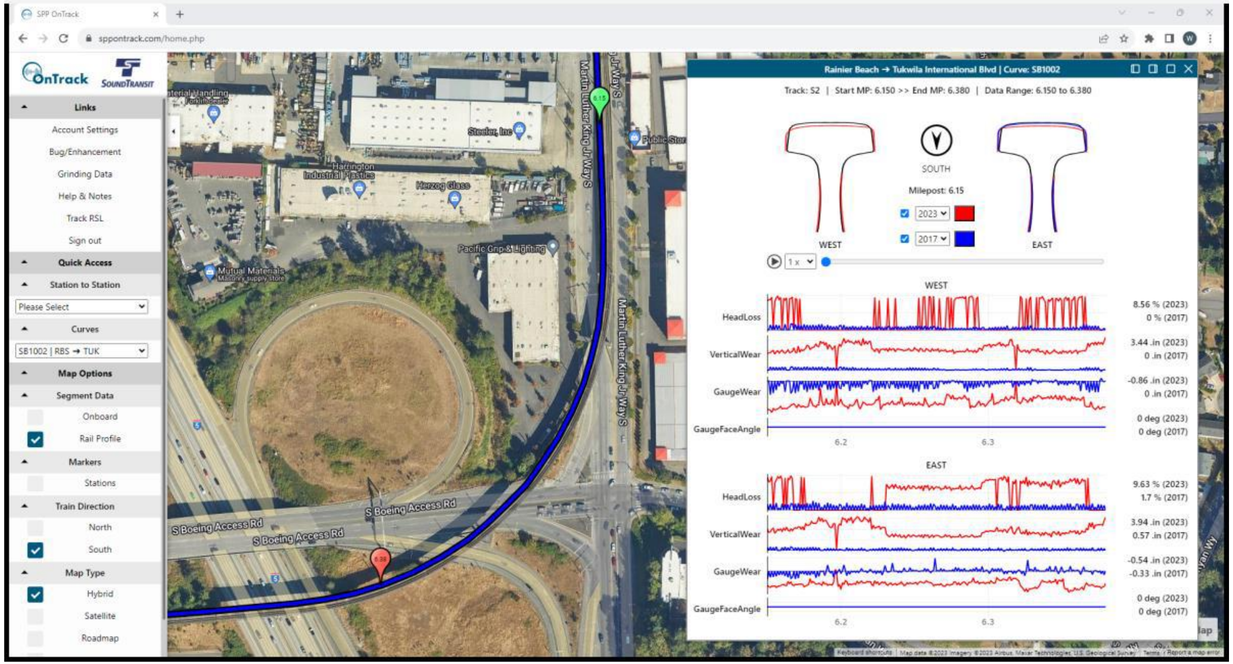


Acknowledgement: Rail roughness summary was developed by Briony Croft of Sahaya in April 2024

Rail Wear – Measurements & Model

Acknowledgement: Database managed by Bill Robert & team of SpyPond. Digital Twins model developed by Wesley Thomas & team of Loram.

Rail Wear – Measurements & Model



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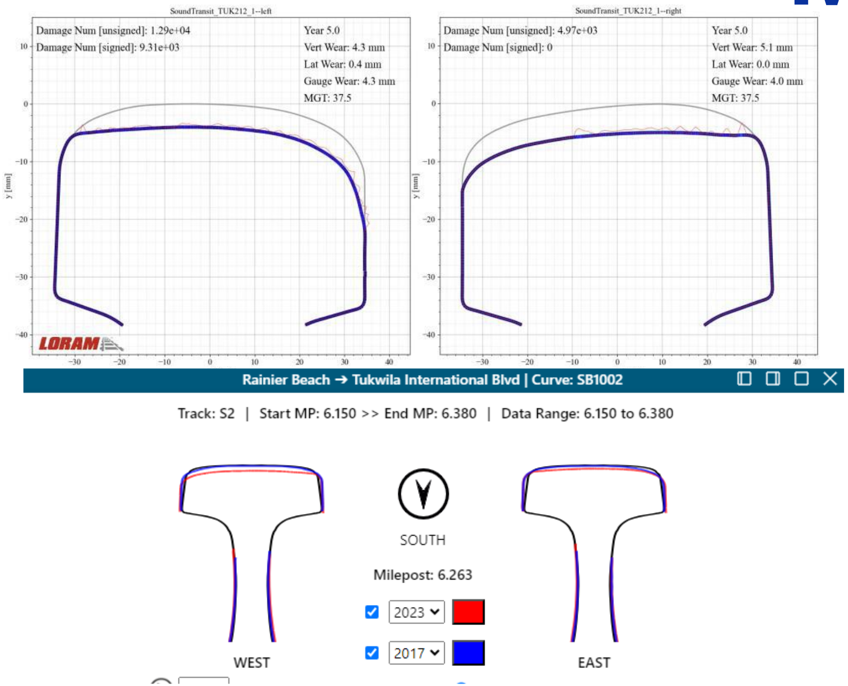
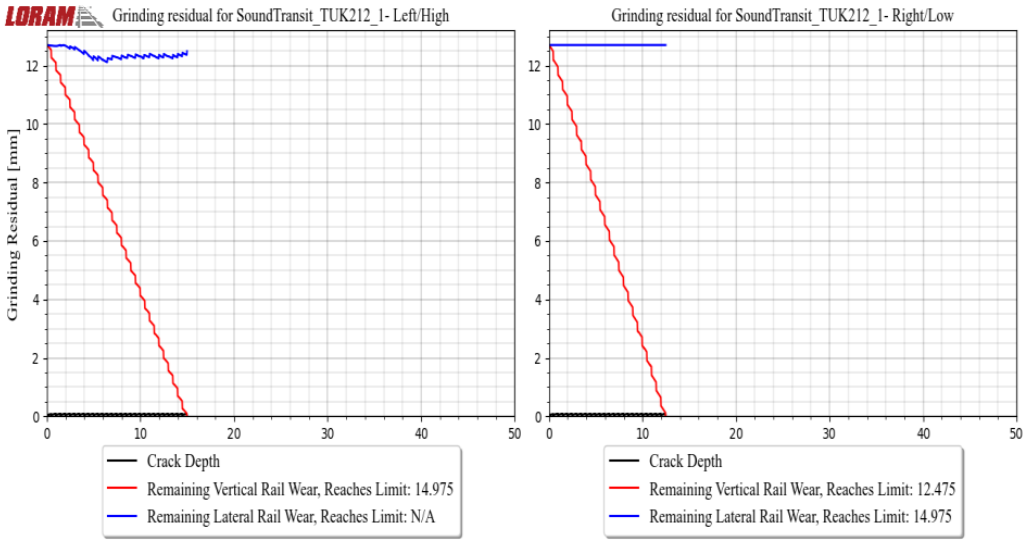
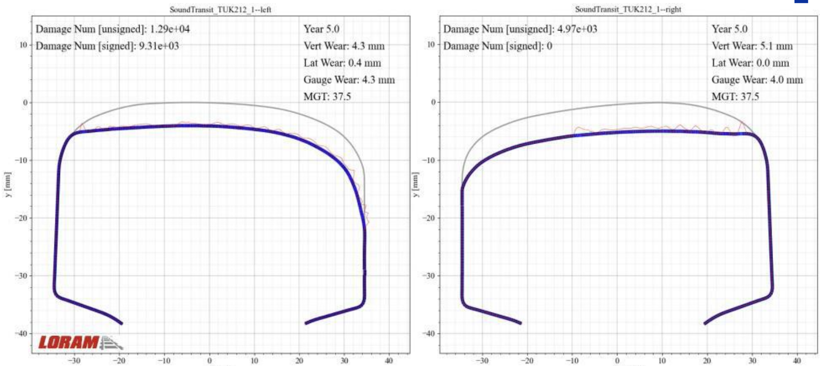
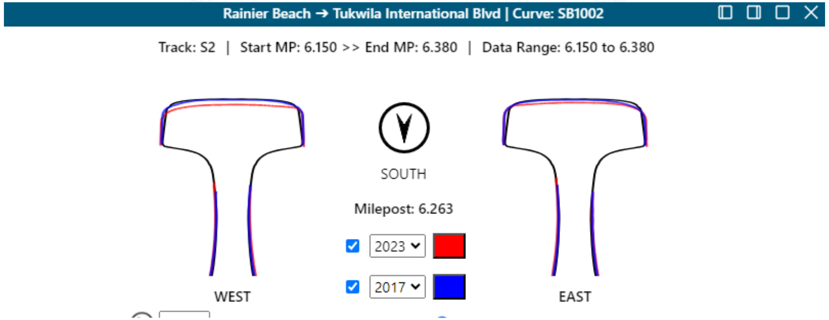




Acknowledgement: Digital Twins and analysis performed by Wesley Thomas & Ankur Ashtekar of Loram.

Rail Wear – Measurements & Model



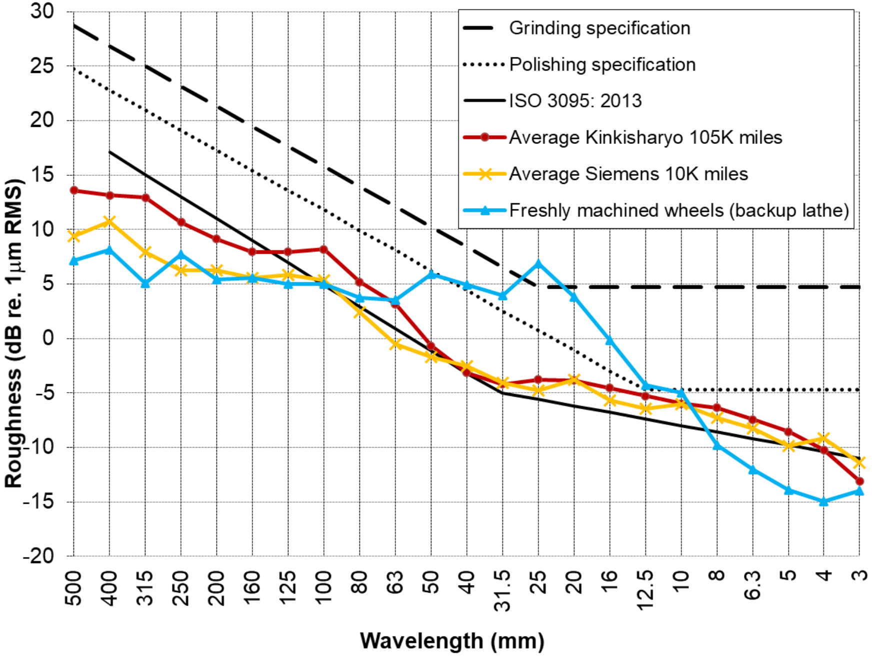


Parameter	Value
Curve Radius (degrees)	8.2
Super Elevation (inches)	5.2
Annual Traffic (MGT)	7.5
Speed (MPH)	37.1
Route (Wheel Profile Detector)	NA
Rail Weight (lb)	136
Rail Material Hardness (Brinnel)	401.0
Target Grind Profile (HR/LR)	HRC LOW
Grind Frequency (MGT)	[3.5, 3.5]
Grind Depth (mm)	[0.25, 0.28]
Friction Level (Effective/Dry)	Top of Rail: Dry Gauge: Dry
Wear Limit (mm)	[12.7, 12.7]

Parameter	Value
Wear Life [Years]	[15.0, 12.5]
Wear Life [MGT]	[112, 94]
RCF Life [Years]	[15.0, 12.5]
Vertical Wear %	[100, 100]
Lateral Wear %	[1.7, 0.0]
Grinding Depth [mm]	[7.5, 6.9]
Damage Number [E6]	[0.01, 0.005]

Acknowledgement: Digital Twins and analysis performed by Wesley Thomas & Ankur Ashtekar of Loram.

Link LRV Wheel Roughness



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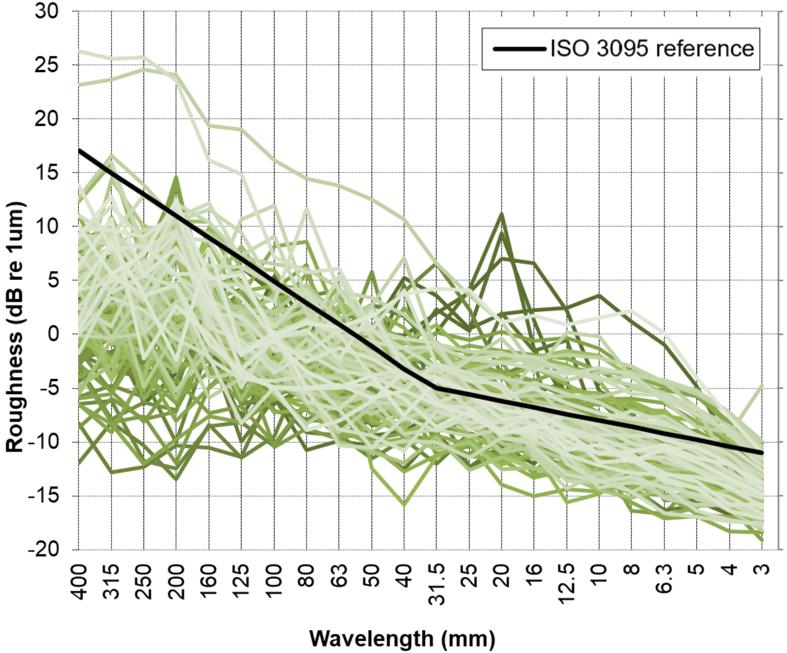
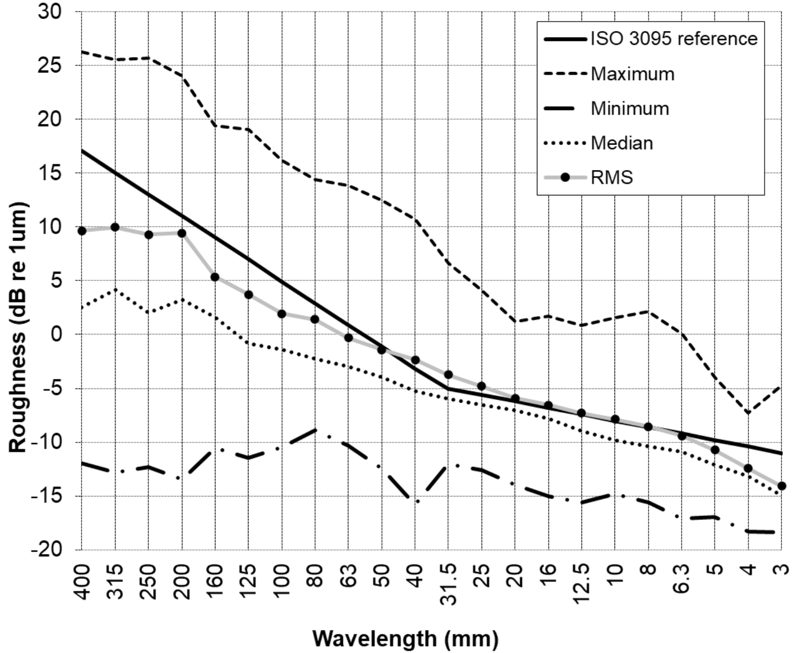
Link LRV Wheel Roughness





Acknowledgement: Rail roughness summary was developed by Briony Croft of Sahaya in April 2024. Luke Watry and Katie Krainc of Wilson Ihrig Associates collected the data.

Series 2 LRV Wheel Specification

Wheel Dimensions*	
Profile:	The tentative wheel profile for motor truck wheels is shown on Figure 2-5, Wheel Profile.
Motor truck, diameter	
New, nominal:	26 to 28 in (660 to 711 mm)
Minimum allowable wheel-diameter wear:	2 in (51 mm)
Center truck, diameter	
New, nominal:	24 to 26 in (610 to 660 mm)
Minimum allowable wheel-diameter wear:	2 in (51 mm)
Track gauge:	56.5 in (1435 mm)
Back-to-back dimension:	53.80 in, ±0.06 in (1,367 mm, ±1.5 mm)
Wheel width	
Motor truck:	5.25 in (133 mm)
Center truck:	5.0 to 5.25 in (127 to 133 mm)

*Note: The dimensions given are nominal and may ultimately be modified as a result of the Wheel-to-Rail Interface Study (WRIS).

Acknowledgement: Hatch/LTK Engineering.

Series 3 LRV Goal for Wheels

Wheel Dimensions*	
Profile:	The tentative wheel profile ~~for motor truck~~ wheels is shown on Figure 2-5, Wheel Profile.
Motor truck, diameter	
New, nominal:	26 ~~to 28 in~~ (660 ~~to 711 mm~~)
Minimum allowable wheel-diameter wear:	~~2 in (51 mm)~~ 2.75 in (70 mm)
~~Center~~ Trailer truck, diameter	
New, nominal:	24 to 26 in (610 to 660 mm)
Minimum allowable wheel-diameter wear:	~~2 in (51 mm)~~ 2.75 in (70 mm)
Track gauge:	56.5 in (1435 mm)
Back-to-back dimension:	53.80 in, ±0.06 in (1,367 mm, ±1.5 mm)
Wheel width	
Motor truck:	5.25 in (133 mm)
~~Center~~ Trailer truck:	5.0 to 5.25 in (127 to 133 mm)

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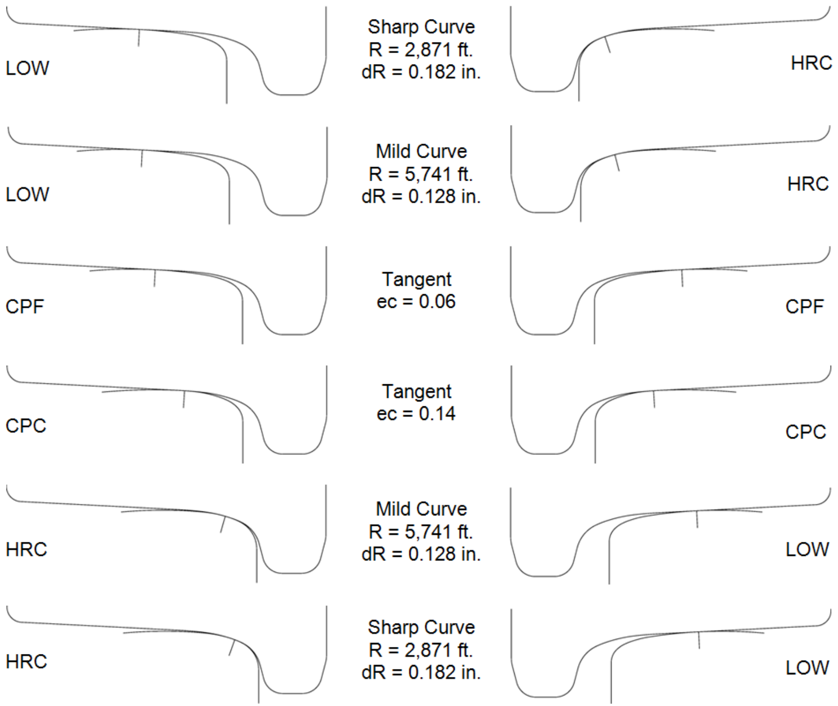
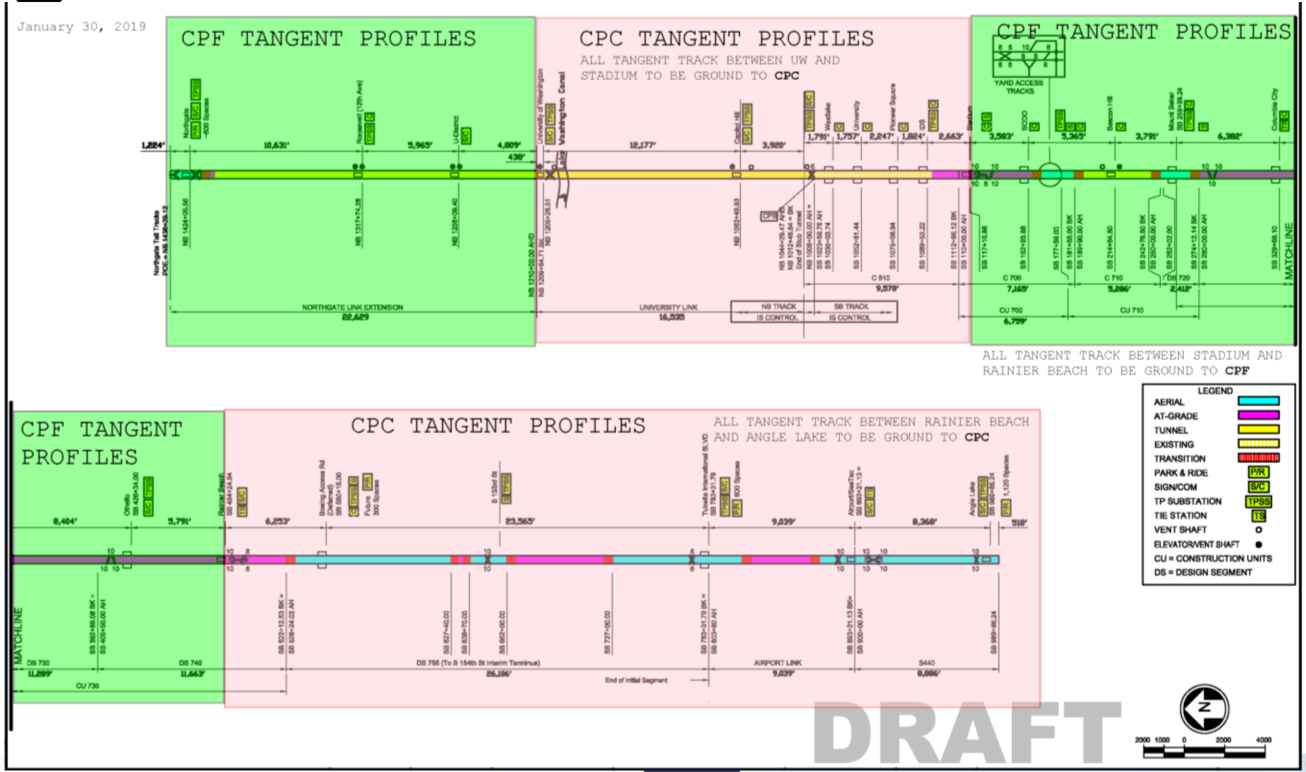
Rail Shape

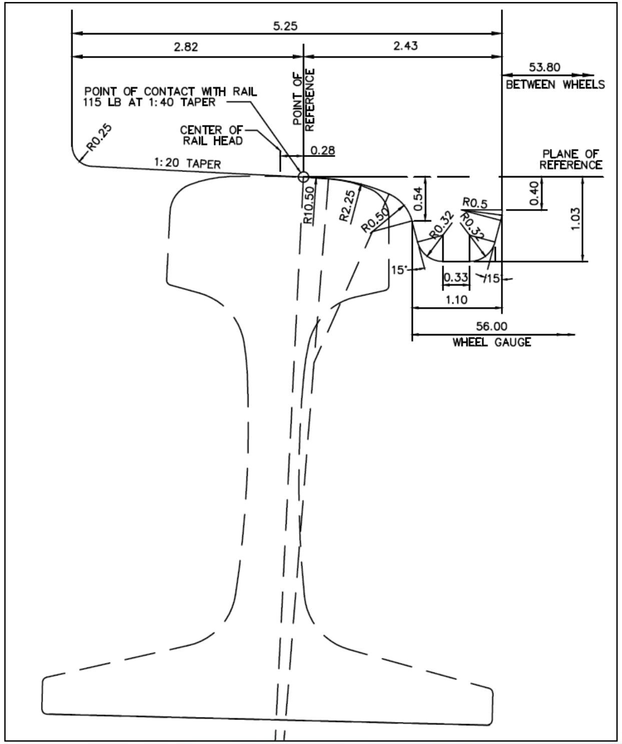


- **4 Rail Profiles**
- **CPC and CPF for Tangent tracks**
- **High Rail Profile**
- **Low Rail Profile**

Tangent Rail Profile Distribution



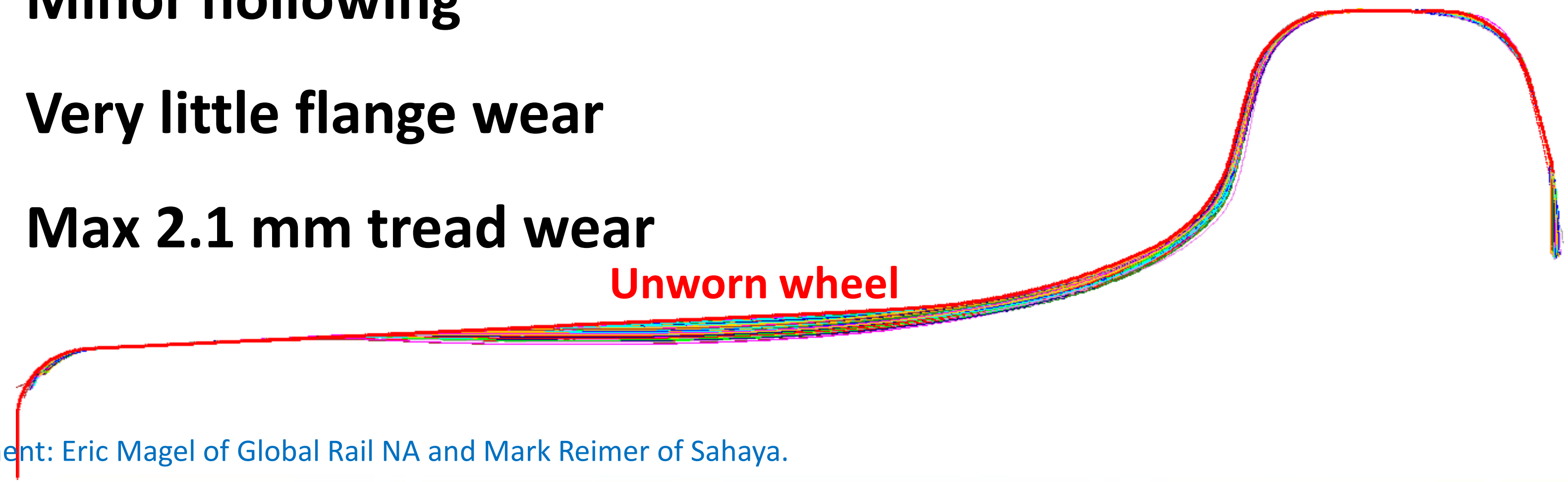
Wheel Shape



- Conical wheel shape with 1:20 Taper
- Wheel Gauge = 56”

ST Wheel Wear Pattern is Minor

- 376 measured worn wheels aligned against the unworn wheel. Highest mileage measured was 114,000 miles
- Minor hollowing
- Very little flange wear
- Max 2.1 mm tread wear

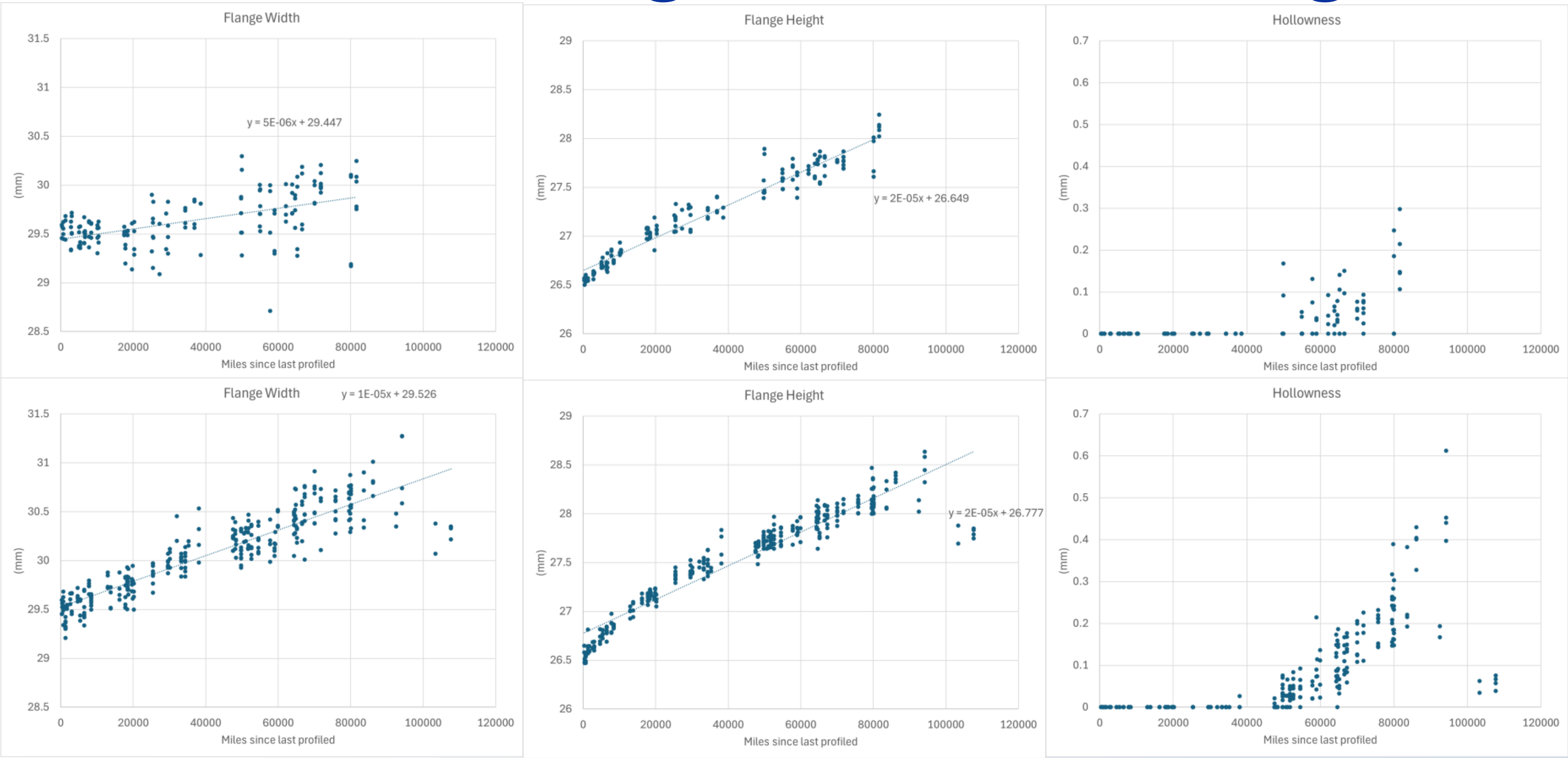


Acknowledgement: Eric Magel of Global Rail NA and Mark Reimer of Sahaya.

Wheel Changes Over Mileage

Axles 3,4 (IRWs)

Axles 1,2,5,6

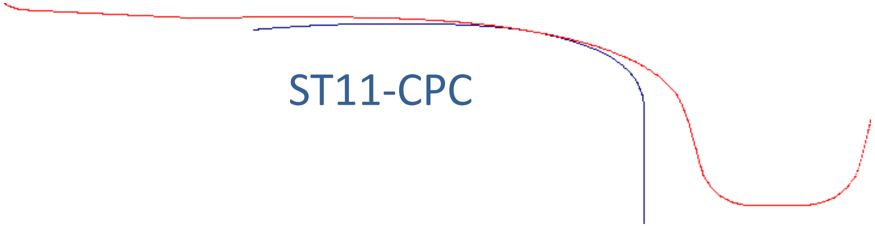


Example of High Wheel Conicity

Worn wheel very conformal to CPF

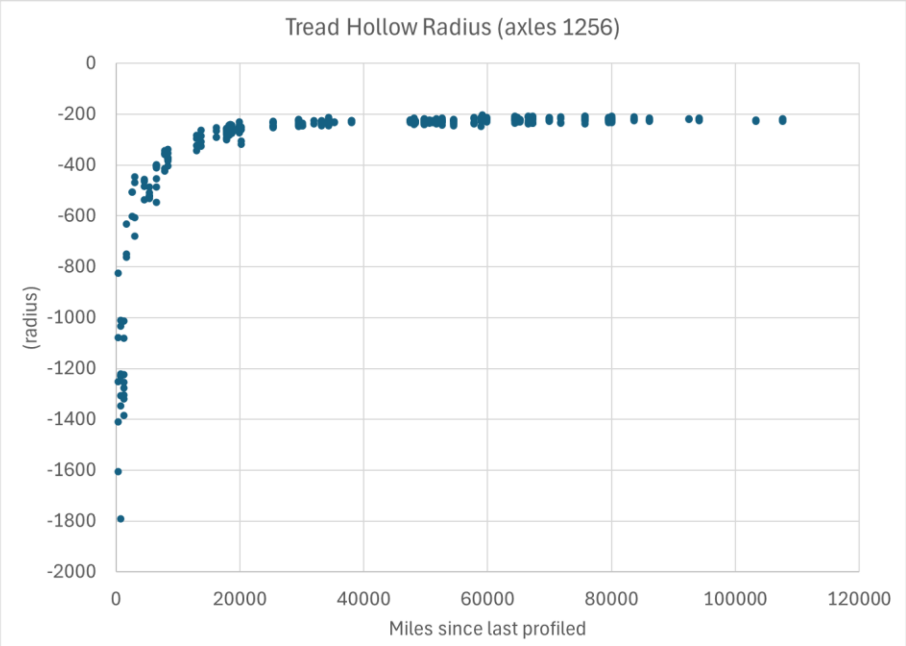
Car 286, axle 6, 60,000 miles
20240404-0088.whl

Same wheel is not conformal to CPC

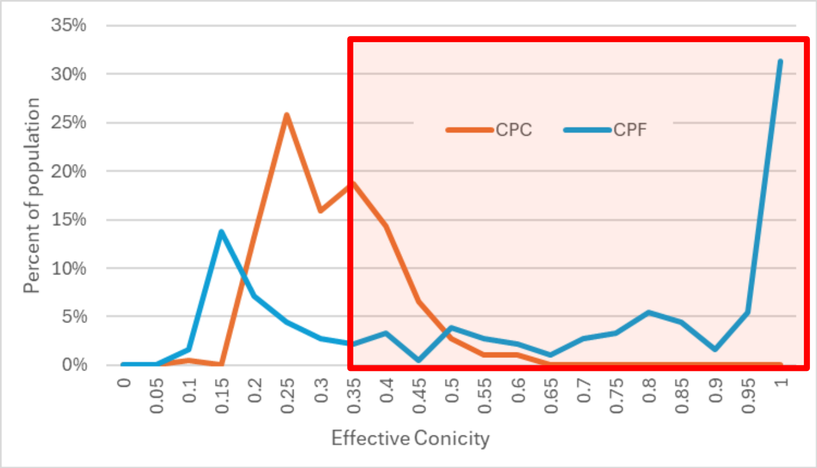


Acknowledgement: Eric Magel of Global Rail NA and Mark Reimer of Sahaya.

Conformal Contact in Tangent Track



Results in very high conicities



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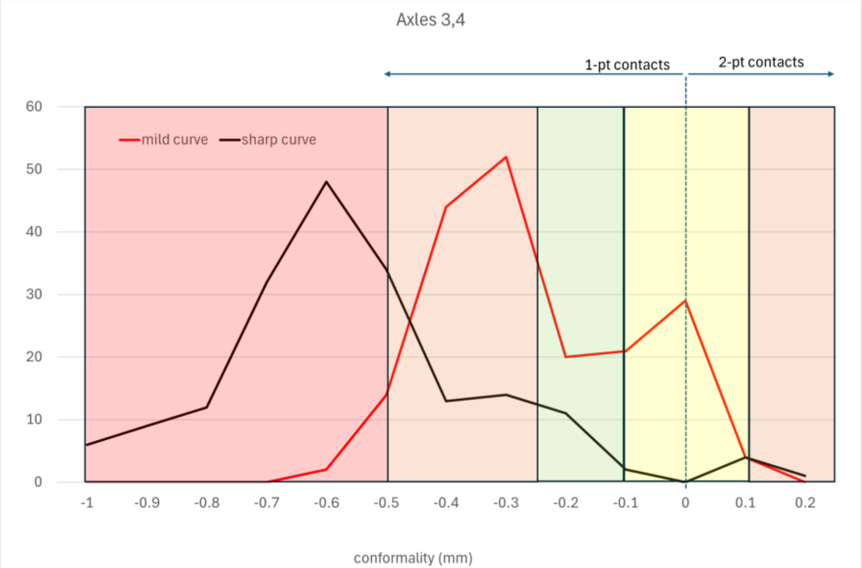
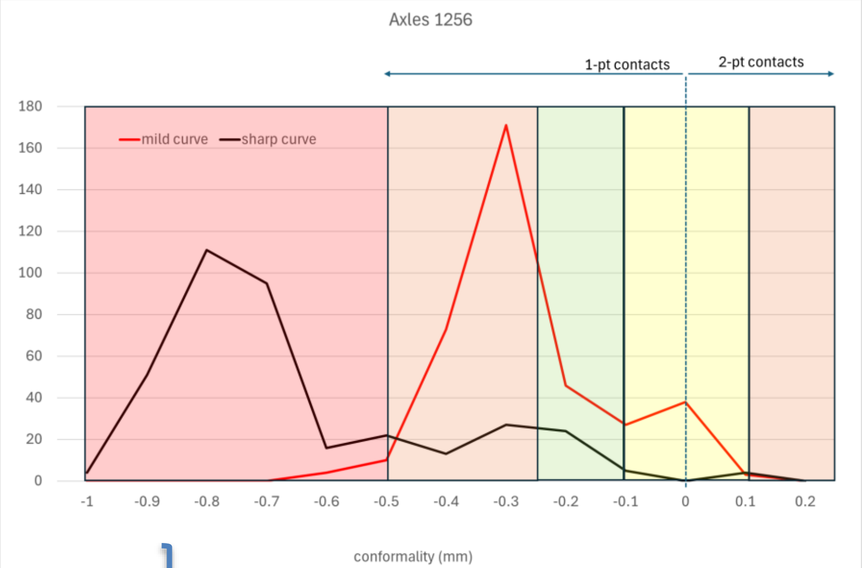
Conformality with High Rail Profile





Nearly all contacts are single point.
In mild curves, the profiles are mostly non-conformal
In sharp curves the profiles are very non-conformal

No large difference between Axle 34 and 1256 wheels

Acknowledgement: Eric Magel of Global Rail NA and Mark Reimer of Sahaya.

Wheel Flats

- Caused by Max braking from Automatic Train Protection and Emergency Push Button events

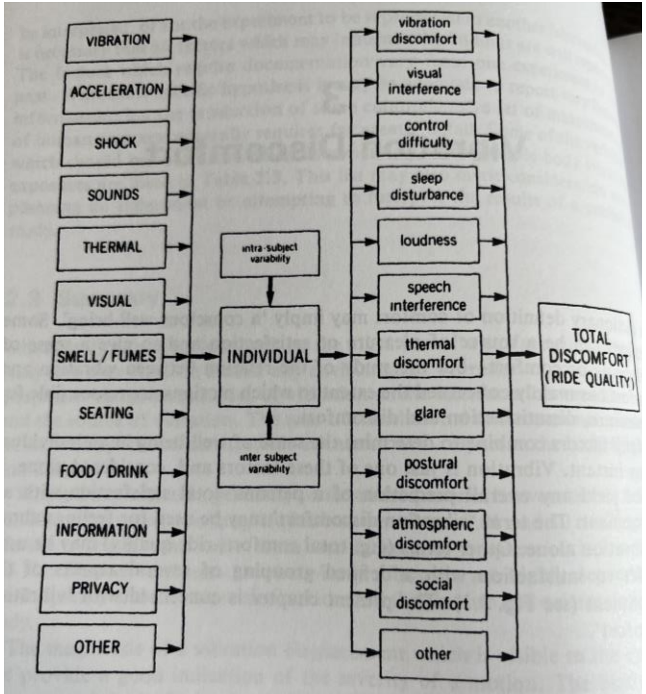
Exterior Noise: Series 3 LRV Spec

Test Condition	Meter Response	Noise Level
Vehicle stationary, empty	Slow	68 dBA
Vehicle empty, on tangent track accelerating from 40 mph (64 km/h) or in maximum dynamic braking or maximum friction braking from 40 mph (64 km/h) (whichever is worse). The vehicle shall be operated with wheels in new condition.	Fast	75 dBA (72)
Two vehicles empty, on tangent track accelerating from 40 mph (64 km/h) or in maximum dynamic braking or maximum friction braking from 40 mph (64 km/h) (whichever is worse). The vehicle shall be operated with wheels in new condition.	Fast	78 dBA (75)

Interior Noise: Series 3 LRV Spec

1. At 55 mph and 50 ft, exterior noise shall not exceed 75 dBA on open tracks (70 dBA is the design target)
2. At 55 mph and 50 ft, exterior noise shall not exceed 80 dBA in tunnels (75 dBA is the design target)

Ride Quality



ig. 3.1 Factors contributing to discomfort.

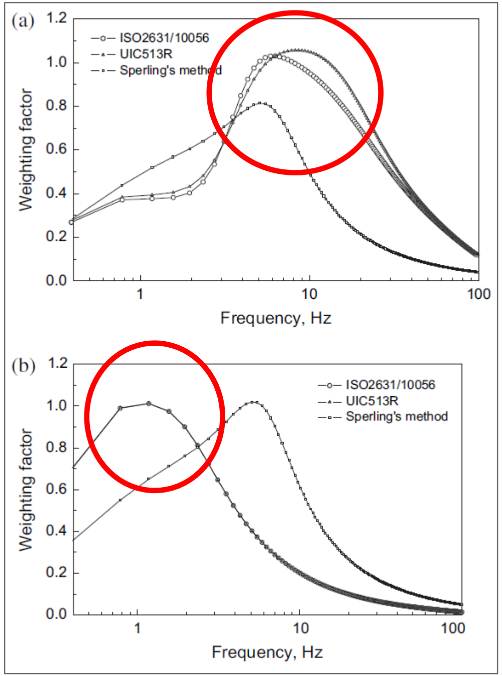
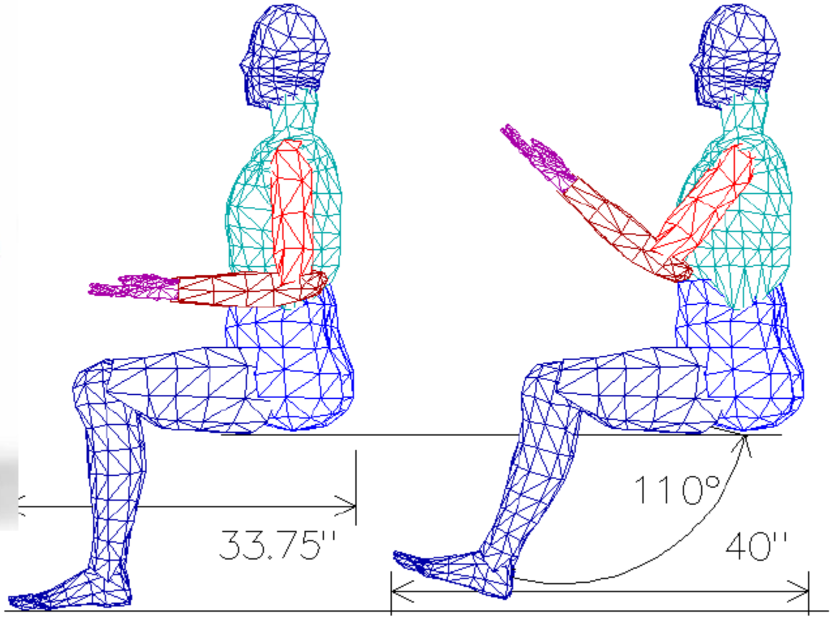


Fig. 2: Frequency weight functions for different standards: (a) vertical direction and (b) lateral and longitudinal directions

1. **ISO 2631 is a ride quality methodology standard. Not a criteria standard.**
2. **ISO 2631 NOT rail vehicle-specific.**
3. **Vertical vibration has higher sensitivity between 4 Hz and 12 Hz.**
4. **Lateral vibration has high sensitivity between 0.5 Hz and 2 Hz.**
5. **Sitting vs Standing**
6. **Duration of vibration/shocks –**

   Vibration Dose Value (VDV)

Ride Quality – Seat Harmonics & Damping



Conclusions

1. Series 3 LRV spec expects to have guidance documents with rail and wheel wear data on existing system.
2. Guidance documents on maintenance limits and maintenance practices will be available
3. Incentive-based design target in addition to acceptance criteria envisioned for performance properties such as noise
4. Ride Quality requirement is expected to be refined.
5. Life Cycle Cost will be a consideration for WRIS.