Effective Management of the Wheel-Rail Interface on Light-rail Networks

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Overview

- Characteristics and maintenance challenges
- Key degradation mechanisms and mitigation measures
- Optimising the WRI:
  - Wheel-rail profiles
  - Rail wear limits
  - Rail steel grades
- Conclusions

Characteristics of Light-rail

- On-street (embedded) and ballasted track operation
- Very sharp curves (≈18 m in radius)
- Steeper gradients
- Lighter axle loads
- Smaller wheel diameters
- Low-moderate speeds (50-70kph)
- Frequent stop / start

Maintenance Challenges

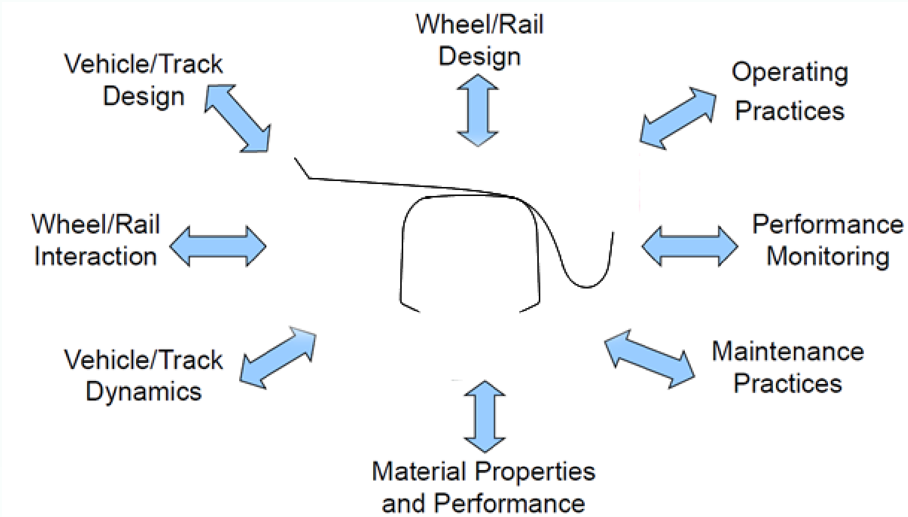
- Very arduous operating environment
- Large variation on operating conditions between different networks
- Lack of relevant standards and guidance
- Short maintenance window (track and rolling stock)
- Location of utility works
- Additional cost of replacing embedded or underground track

Key Degradation Mechanisms

Track Radius Range	Key degradation Mechanisms	Available Mitigation Measures
<50m	1. High Side (& Keeper) wear 2. Vertical wear 3. Corrugation	1. Harder steel grades offering greater resistance to wear and corrugation 2. Weld restoration for side & keeper wear 3. Rail grinding to remove corrugation 4. Track or vehicle mounted lubrication/friction management to reduce wear 5. Optimisation of WR contact conditions to reduce wear
>50 to <250m	1. Side (& Keeper) wear 2. Vertical wear 3. Corrugation	
>250 to <1000m	1. Limited side wear 2. Vertical wear 3. Corrugation	1. Harder steel grades offering greater resistance to wear and corrugation 2. Rail grinding to remove corrugation
>1000m	1. Vertical wear 2. Corrugation	

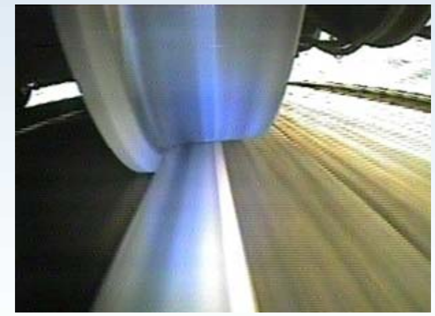
Wheel-Rail Interface Management

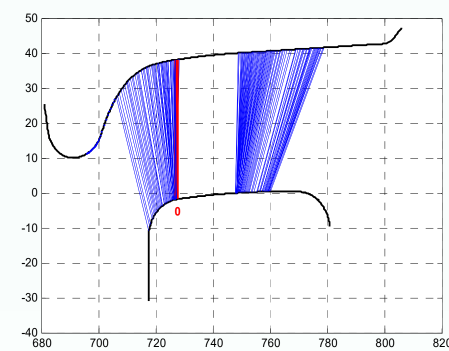
- Requirements for effective WRI :
  - Maintain safety and reduce derailment risk
  - Minimise damage to vehicle/track
  - Ensure good vehicle dynamic performance (curving, ride...)
  - Increase asset life and reduce whole life costs



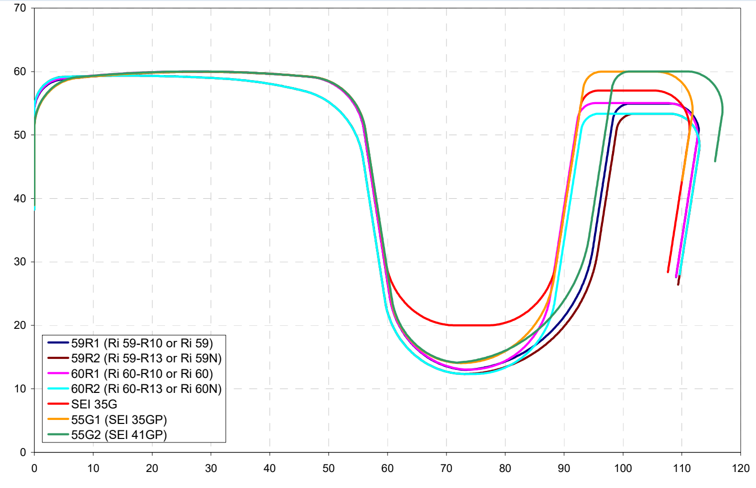
Wheel-Rail Profiles

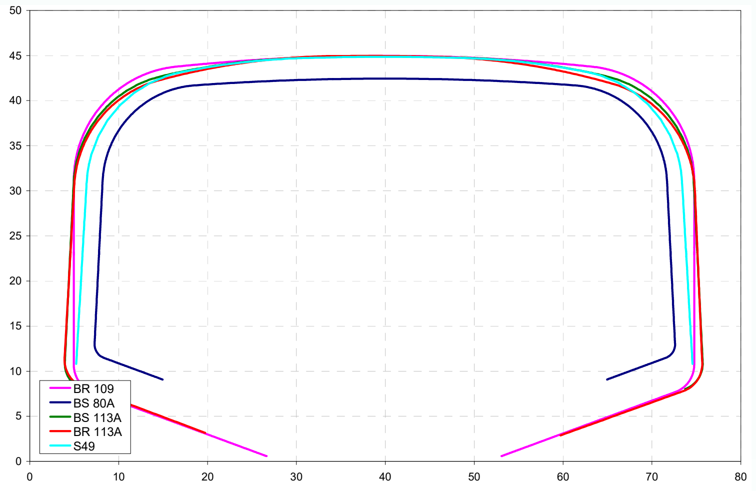
- Large variation in wheel and rail profiles used on light-rail systems
- Profiles must be geometrically compatible, with respect to:
  - Wheelset fit (e.g. track gauge, groove width, depth)
  - Compromise between steering and vehicle lateral stability
  - Minimise wear rates, contact stress, squeal noise and derailment risk
- Contact conditions generated by chosen wheel-rail profiles can be checked to ensure they do not produce excessive contact stress and wear
- Vehicle dynamics simulations can be used to select optimal profile combinations
  - Optimise conicity for a given system





Rail Profiles

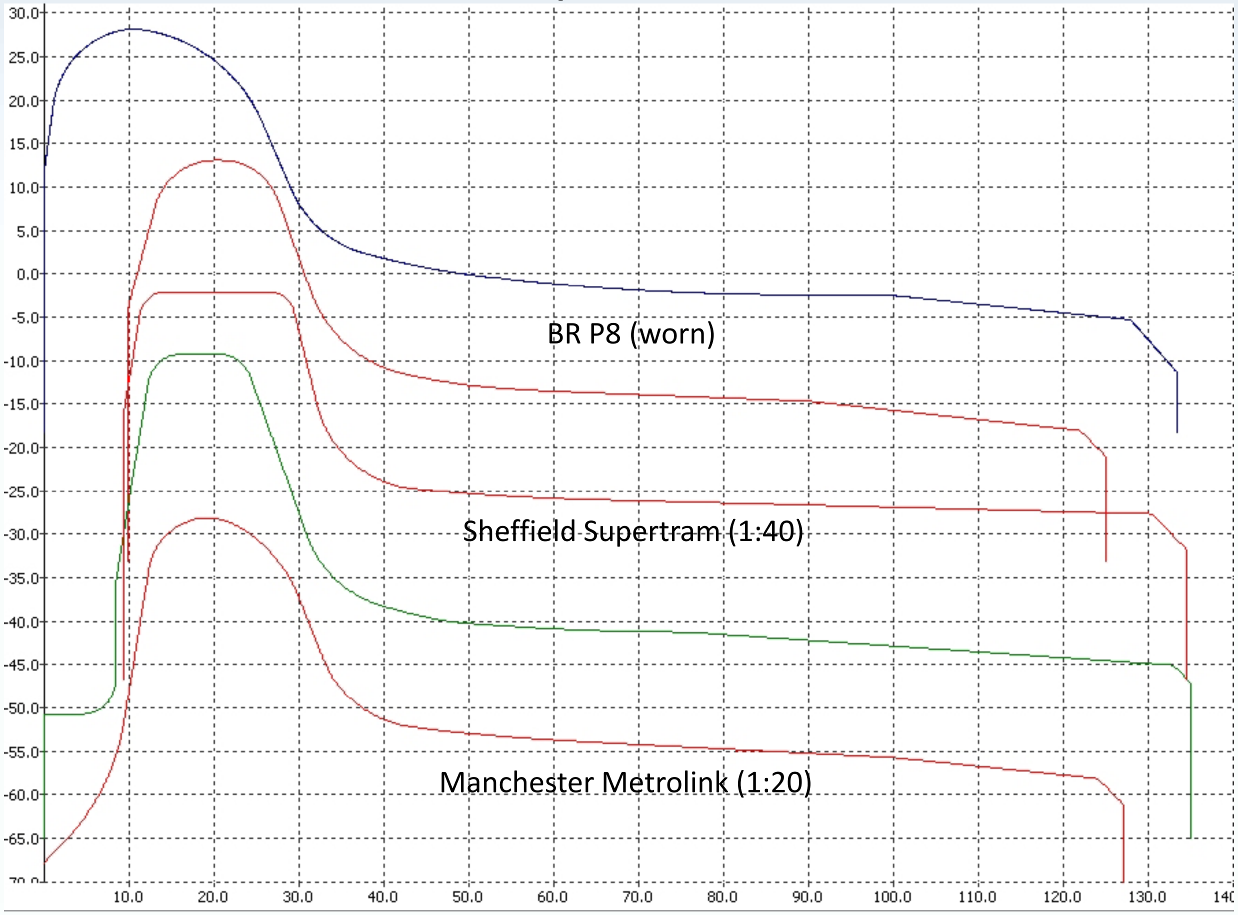


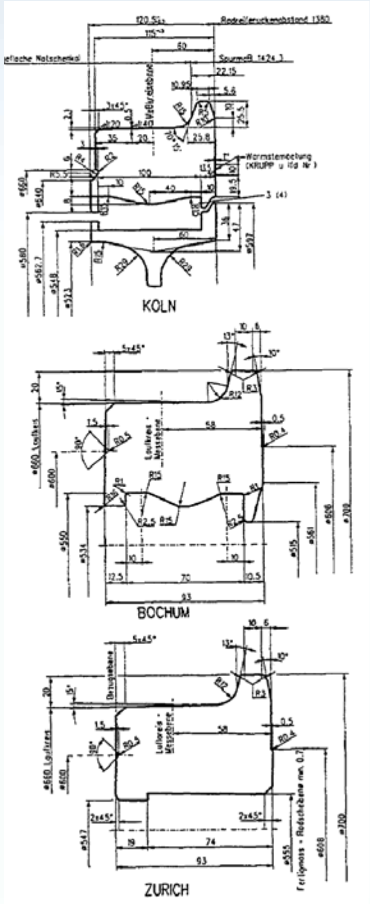


Rail Section	Cross-section Area (mm^2)	Weight (kg)	I_{xx} (cm^4)	Rail Height (mm)	Groove Depth (mm)	Groove Width (mm)	Keeper Thickness (mm)	Gauge Corner Radii (mm)	Crown Radii (mm)
Grooved Rails									
55G1 (35GP)	69.78	54.77	2075.6	152.50	45.9	35.94	19.65	10.0	225
55G2 (41GP)	70.53	55.37	2081.6	152.50	45.9	40.94	19.73	10.0	225
59R1 (RI59-R10)	75.12	58.97	3266.8	180.00	47.0	42.00	15.00	10.0	225
59R2 (RI59-R13)	74.13	58.20	3213.8	180.00	47.0	42.36	14.82	13.0	300
60R1 (RI60-R10)	77.19	60.59	3352.9	180.00	47.0	36.00	21.00	10.0	225
60R2 (RI60-R13)	76.11	59.75	3298.1	180.00	47.0	55.83	20.82	13.0	300
Flat-bottom Rails									
39E1 (BS80A)	50.66	39.77	1204.9	133.25	-	-	-	11.1	305
49E1 (S49)	62.92	49.39	1816.0	149.00	-	-	-	13.0	300
56E1 (BR113A)	71.69	56.30	2321.0	158.75	-	-	-	12.7	305

Wheel Profiles (1)

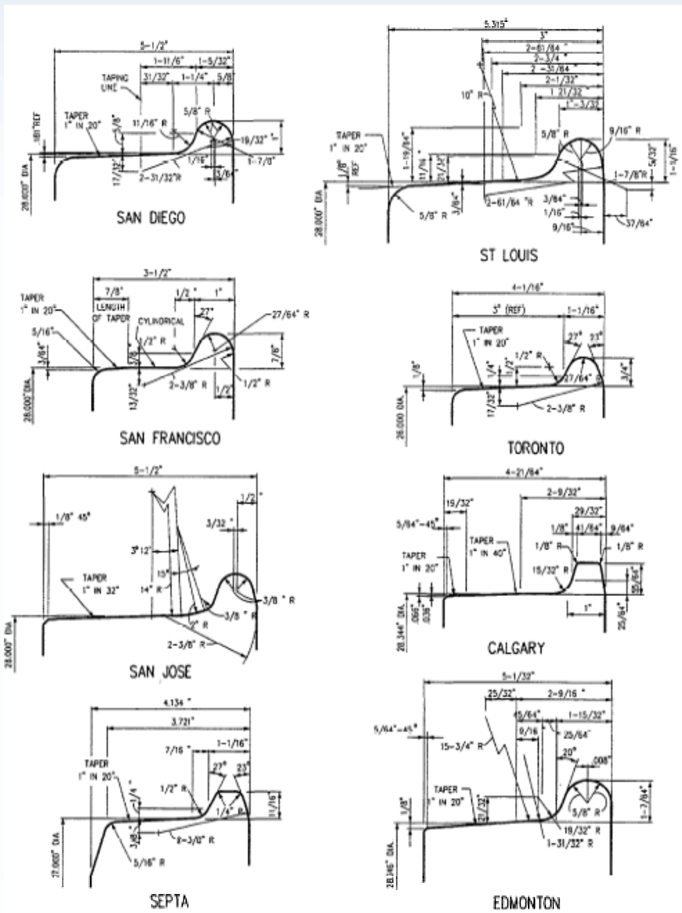
- Selection UK / European Wheel Profiles

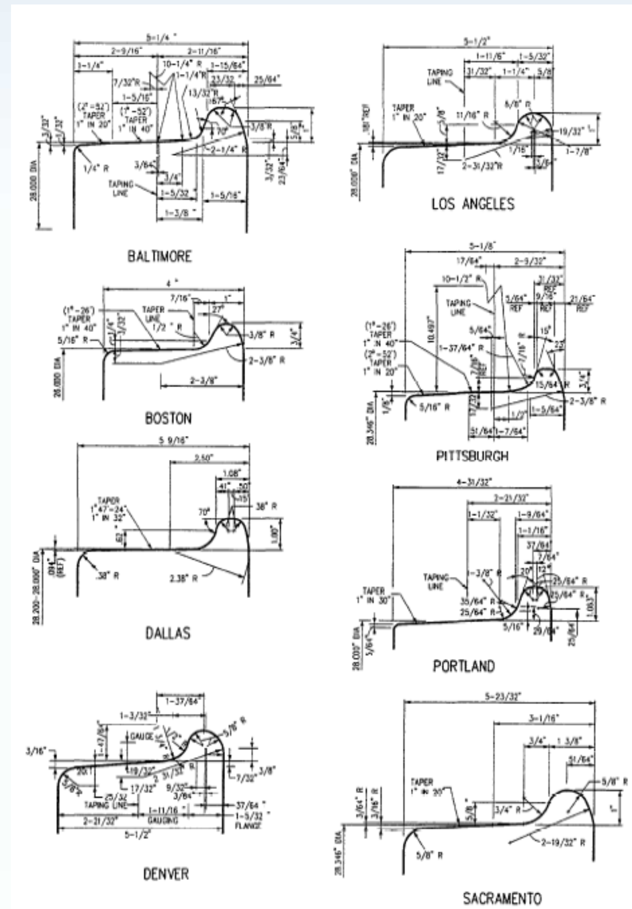




Wheel Profiles (2)

- Selection of North American Wheel Profiles





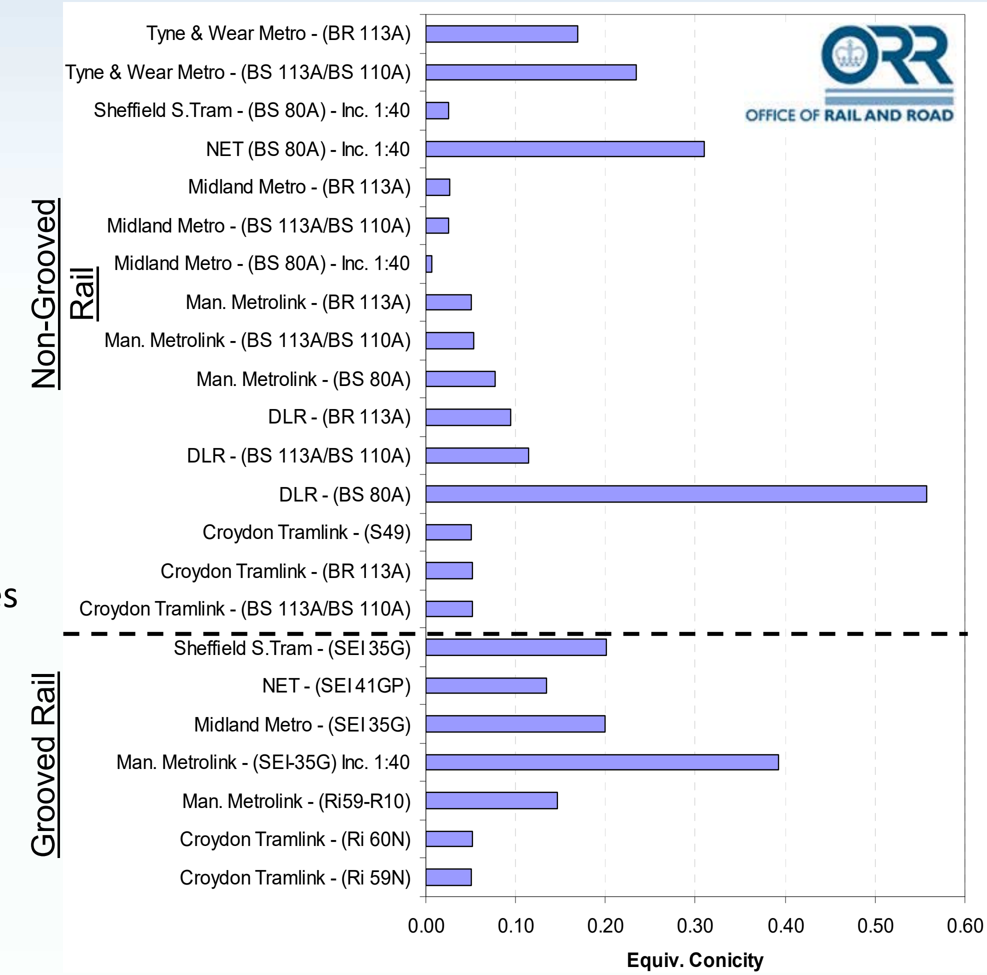
Wheel-Rail Profile Selection

- Light-rail engineers face particular problems:
  - Insufficient consideration given to profile selection at design stage
  - Varying rail profiles (street and ballasted track, S&C etc.)
  - Low speed / very tight curves on street running (flange contact), higher speeds / heavy rail alignments elsewhere
  - Varying bogie types (conventional and IRW)
  - Steep gradients, grooved rail etc.
  - Shared running

- But…also have some advantages:
  - Closed, geographically small systems running a single vehicle type
  - Lighter axle loads
  - Predictable and stable wear conditions
  - Control both vehicles and track conditions

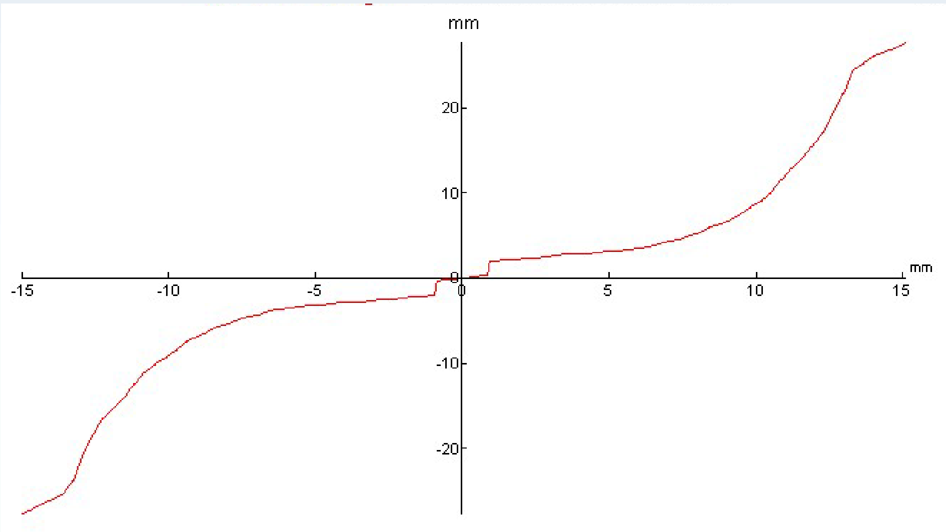
Variation in Conicity

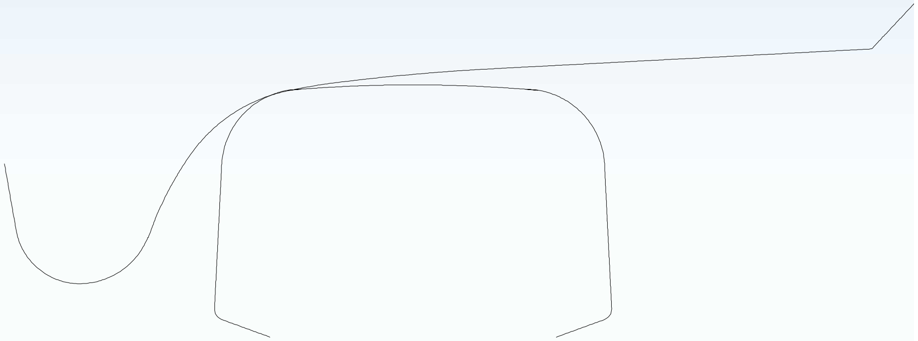
- Large variation in equivalent conicity:
  - Increasing conicity:
    - Increases steering (flange free curving)
    - Reduces critical speed
    - May increase tread wear / gauge shoulder wear
    - Will increase forces, contact stresses
  - Reducing conicity:
    - Reduces steering (flange contact at larger curve radii)
    - Increases critical speed
    - Will increase flange / side wear

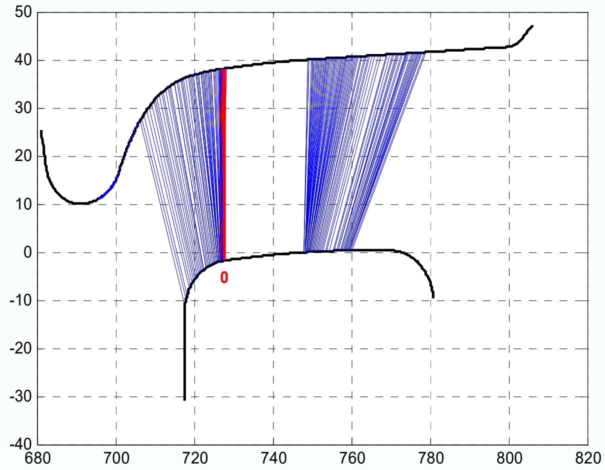


Wheel Profile Design

- Example 1: Wheel and rail shapes very different (1)



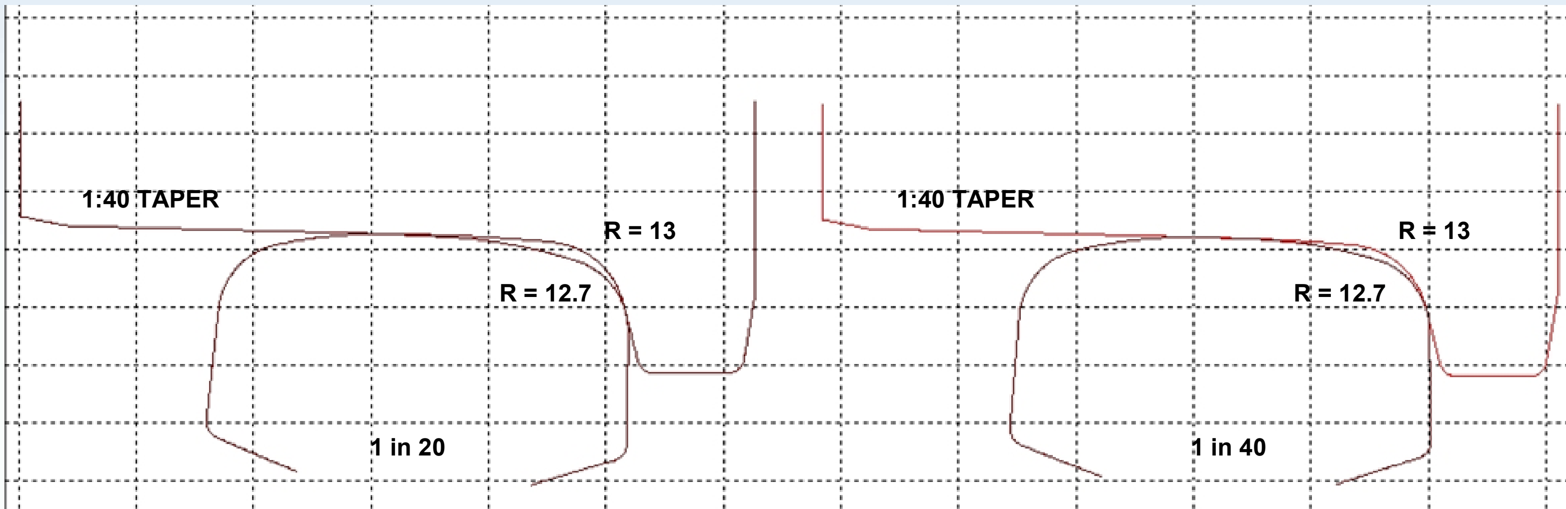




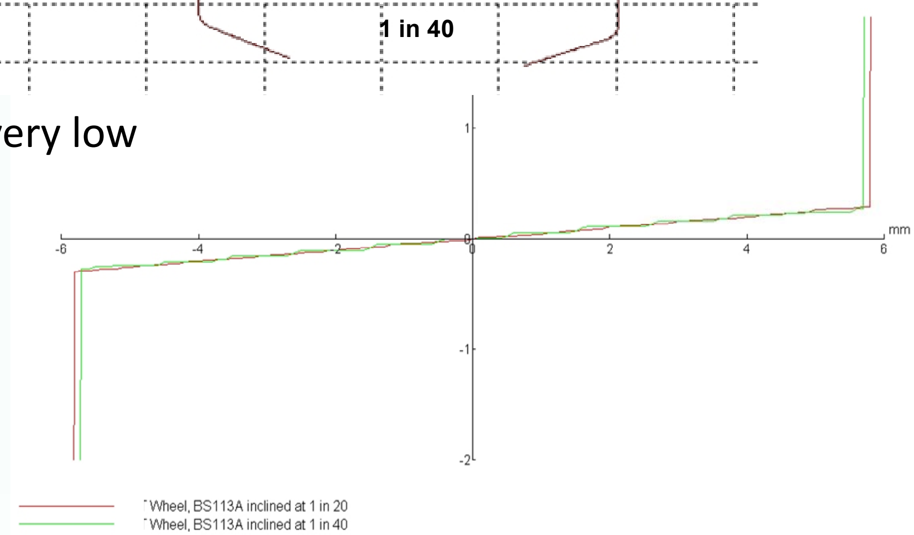
  - Tread slope, flat rail and large flange root radius gives large RR difference
  - Single point contact
  - Excellent steering in sharp curves with low flange wear
  - High contact stresses even in metro applications
  - Potential stability problems

Wheel Profile Design

- Example 2: Wheel and rail shapes different (2)

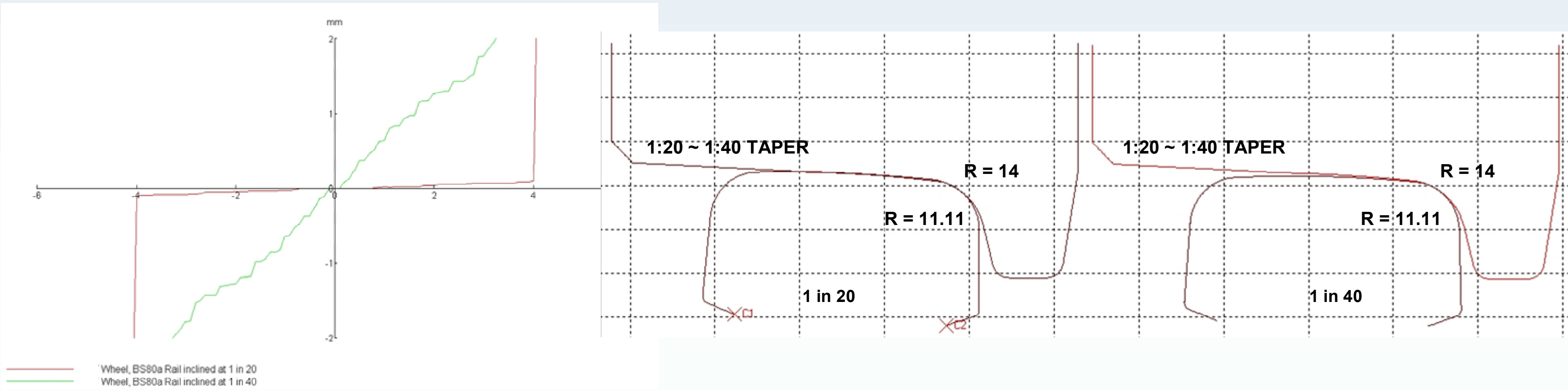


  - No contact gauge shoulder / flange root = very low conicity
  - Two point contact
  - Little steering except in shallow curves
  - Potential for high flange wear
  - Relatively insensitive to rail inclination
  - Potential stability problems

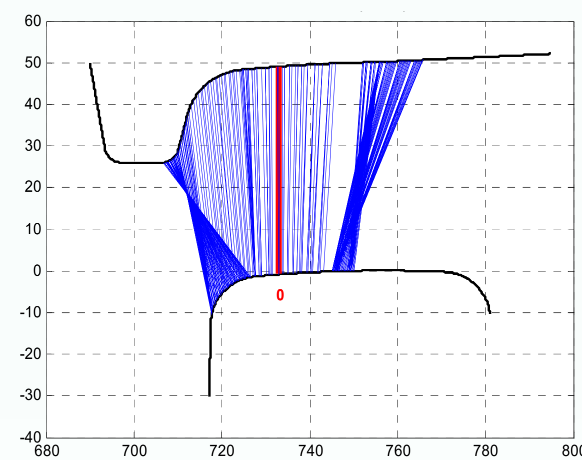


Wheel Profile Design

- Example 3: Wheel and rail shapes closely conformal

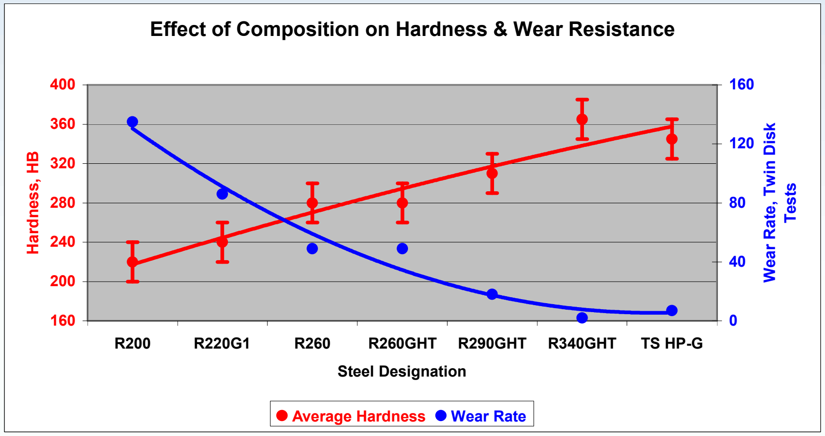


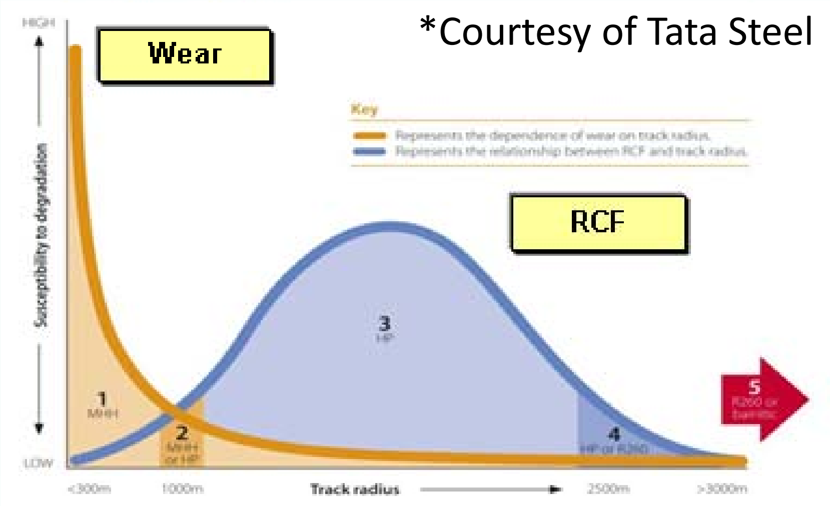
  - Moderate RR difference with good distribution of contact (even wear)
  - Mostly single point contact
  - Good steering in moderate curves with controlled flange wear
  - Suitability will depend on characteristics of system
  - Sensitive to changes in rail inclination



Rail Steel Grade Selection

- Primary cause of rail replacement on light-rail systems is wear (particularly in tight curves)
- To maximise rail life appropriate steel grades should be selected
  - Based on track conditions and degradation mechanisms experienced in service
- Selection of steel grade which offer high resistance to wear and corrugation, but also ability to weld restore rail side wear in-situ (in very tight curves)

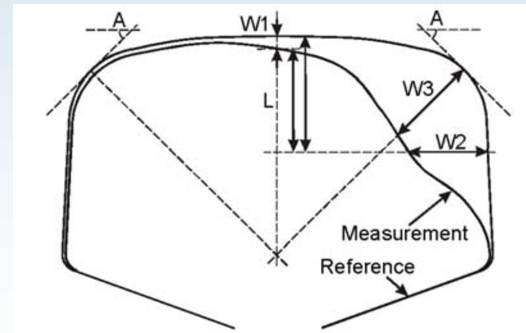


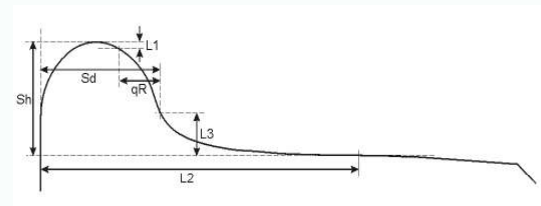


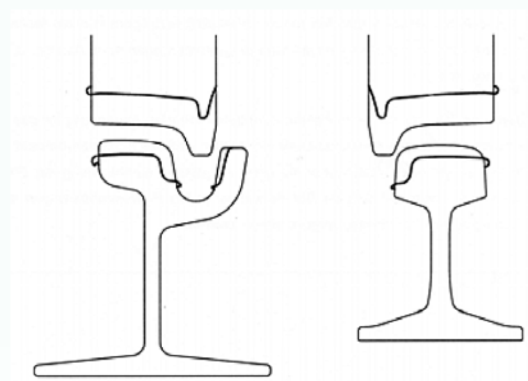
*Courtesy of Tata Steel

Maintenance Limits

- Large variation in wear limits adopted by light-rail systems
  - Selected based on experience or heavy rail standards
- Lack of relevant standards or guidance for selection of optimum wear limits and asset management
- Conflicting requirements:
  - To maintain safe operation
  - To prolong rail and wheel life

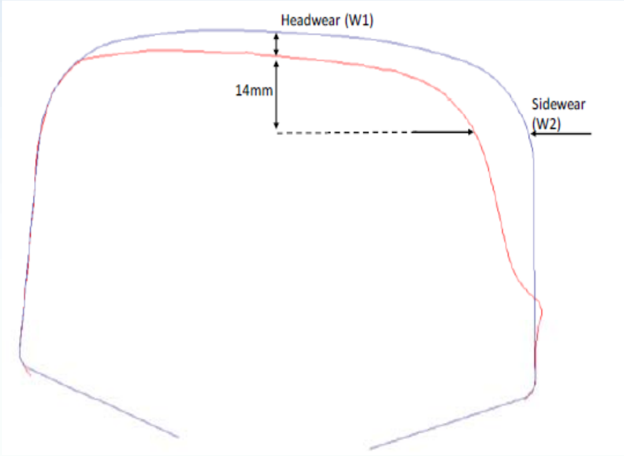


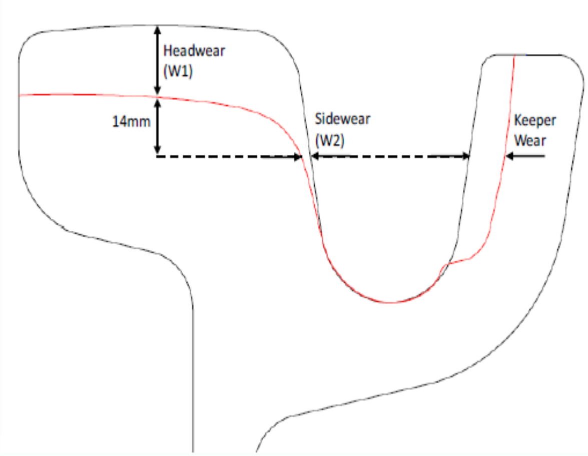




Rail Wear Limits

- To ensure safe operation and to prolong asset life it is important that appropriate rail wear limits are specified
  - Limits which are overly conservative can result in premature rail replacement and therefore increased renewal/maintenance costs
  - Limits which are too lax can compromise the operational safety of the system





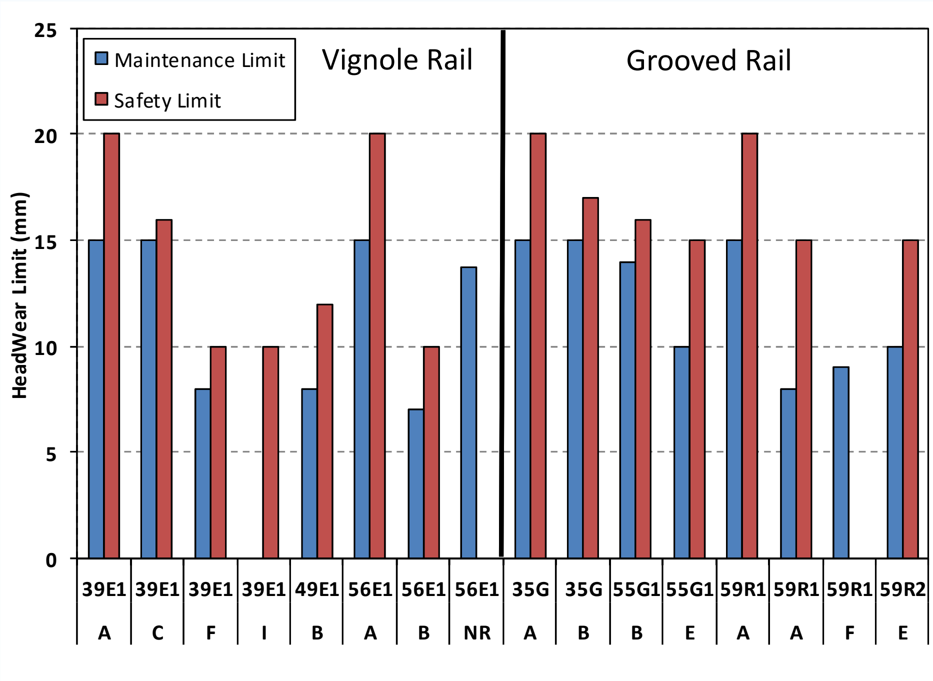
Comparison of Rail Wear Limits

- Significant variation in the maintenance limits for both grooved and vignole rail

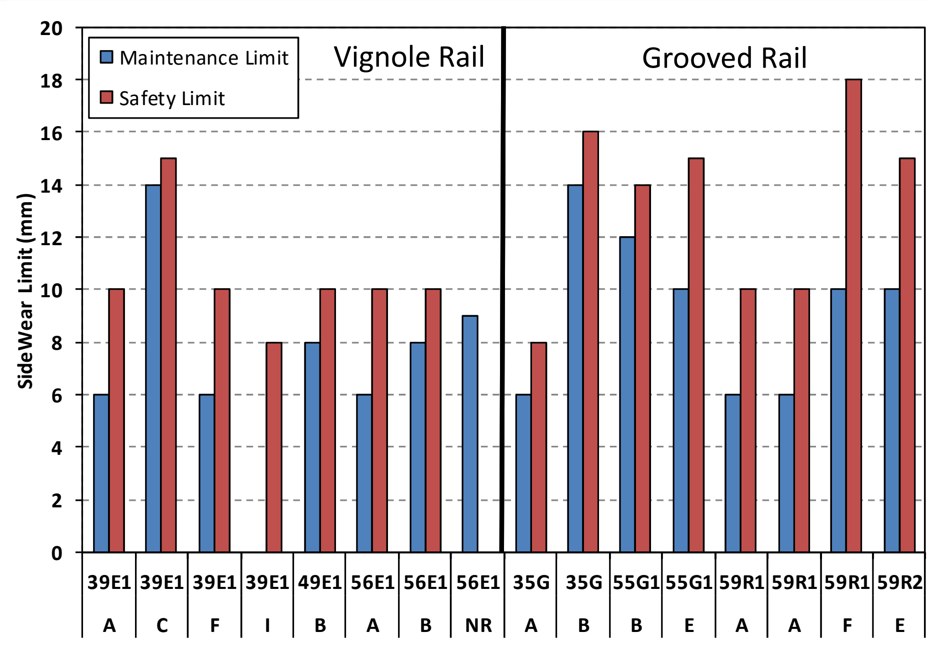
System	Wheelset			Rail Section	Rail Section Dimensions (mm)				Rail Wear Limits (mm)			% of Head Height		% of Keeper Thickness	
	Flange Height (mm)	Flange Thickness (mm	Back-to-Back (mm)		Head Height	Groove Depth	Groove Width	Keeper Thickness	Head	Side	Keeper	Inter.	Safety	Inter.	Safety
A	26.3 (~29.3)	22 (~19)	1362	59R1	41.15	47.00	40.40	15.20	15 (20)	6 (10)	2 (5)	36%	49%	13%	33%
				35G	40.50	40.00	36.00	19.20	15 (20)	6 (8)	5 (8)	37%	49%	26%	42%
				56E1	49.21	-	-	-	15 (20)	6 (10)	-	30%	41%	-	-
B	25.5 (~29.8)	23.2 (~20.2)	1380	59R1	41.15	47.00	40.40	15.20	12 (15)	6 (10)	2 (5)	29%	36%	13%	33%
				59R2	41.15	47.00	42.17	14.39	12 (15)	6 (10)	2 (5)	29%	36%	14%	35%
				60R1	41.15	47.00	34.40	21.20	12 (15)	6 (10)	2 (5)	29%	36%	33%	52%
				60R2	41.15	47.00	36.00	20.57	12 (15)	6 (10)	7 (11)	29%	36%	34%	53%
				56E1	49.21	-	-	-	8 (12)	8 (10)	-	16%	24%	-	-
				49E1	51.15	-	-	-	7 (10)	8 (10)	-	10%	29%	-	-
C	24.0	23 (~19)	1379	35G	40.50	40.00	36.00	19.20	15 (17)	14 (16)	12 (14)	37%	42%	62%	73%
				55G1	40.50	45.90	34.40	19.20	15 (17)	14 (16)	12 (14)	37%	42%	62%	73%
				39E1 (CWR)	42.47				15 (16)	14 (15)	-	35%	38%	-	-
				39E1 (FP)	42.47				12 (13)	14 (16)	-	28%	31%	-	-
D				62R1	41.20	41.00	32.83	26.23	22.00	25.00	-	-	53%	-	-
E				60R2	41.15	47.00	36.00	20.57	18.00	15.00	-	-	44%	-	-
F	24 (~29)	23 (~19)	1379	59R2	41.15	47.00	42.17	14.39	10 (15)	10 (15)	-	24%	36%	-	-
	25.5	22.2 (~18.2)	1379	55G1	40.50	45.90	34.40	19.20	10 (15)	10 (15)	2 (4)	22%	37%	10%	21%
				39E1	42.47	-	-	-	8 (10)	6 (10)	-	19%	24%	-	-
G	25.5	22.2	1379	51R1	41.15	47.00	42.17	14.39	9	10 (18)	4	22%	-	28%	-
				49E1	-	-	-	-	-	-	-	-			
H	25.5	21.2 (~18.9)	1384	59R2	-	-	-	-	-	(20)	-	-			
				49E1	-	-	-	-	-	(20)	-	-			
I	30.1 (31.5)	27.6 (25)	1362	390.00	42.47	-	-	-	(10)	(8)		24%			
Network Rail (NR/L2/TRK/001)				56E1 (tangent track)		-	-	-	13.75	-	-	-			
				56E1 (curved)		-	-	-	9.25	9	-	-			

Comparison of Rail Wear Limits

- Significant variation in the maintenance limits defined both grooved and vignole rail



Headwear



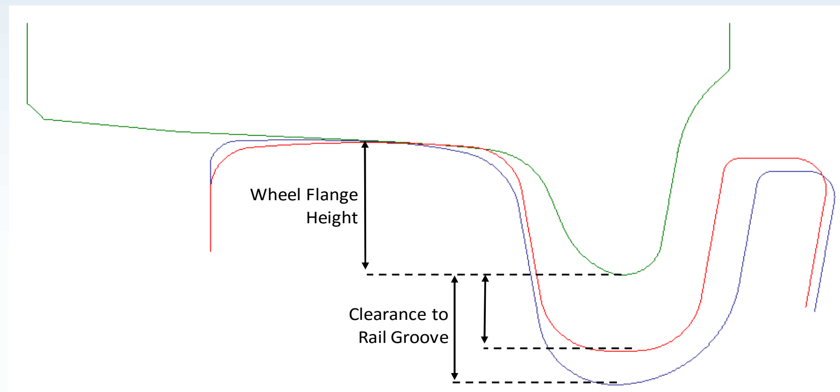
Sidewear

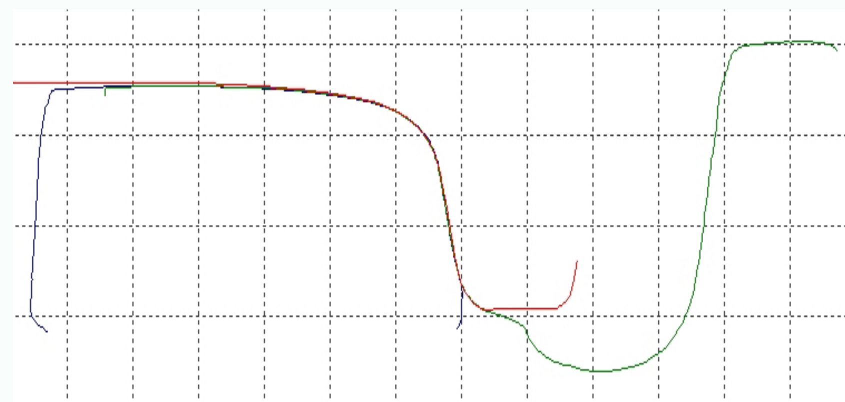
Optimised Rail Wear Limits

- Following variables play a key role:
  - Structural integrity of the rail and keeper due to a loss in cross-section
  - Reduction in clearance to vehicle and lineside equipment, structures and road surface
  - Maintaining track gauge, ride quality and derailment protection
  - Interaction of side wear scar and new/worn wheel profile shape

Vertical Rail Wear

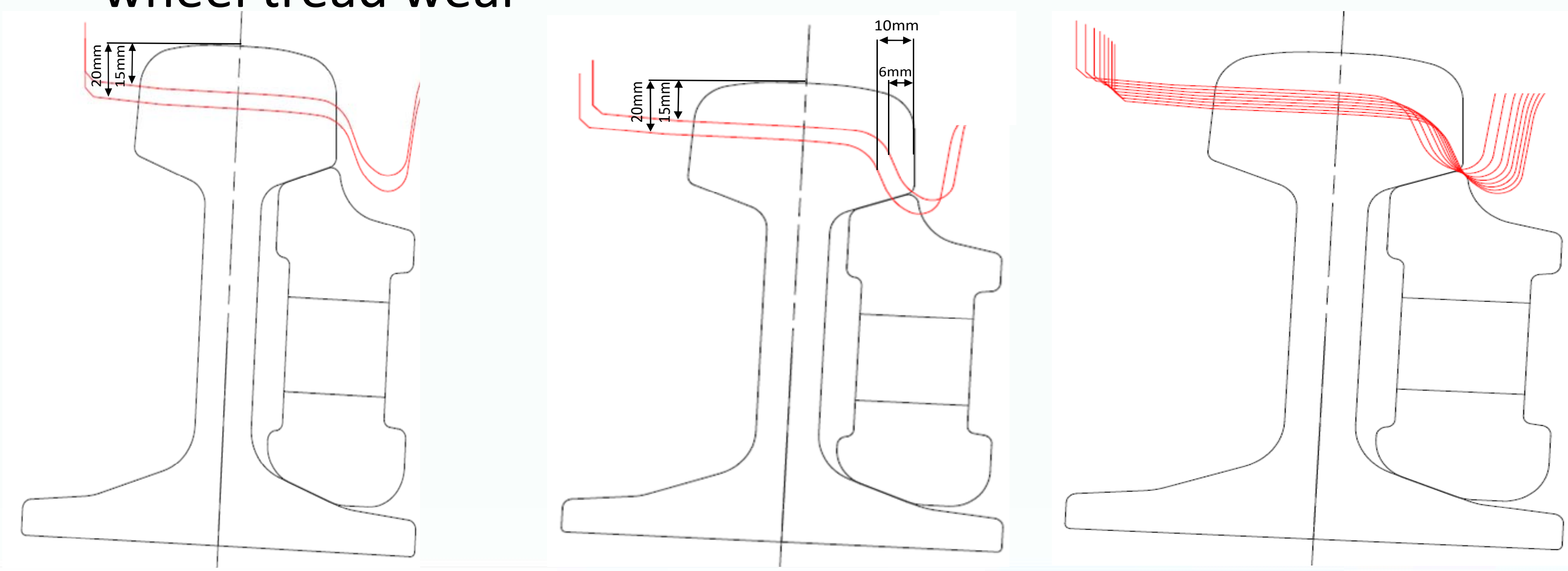
- Excessive levels of vertical rail wear can lead to safety and operational issues when the available groove depth becomes limited
  - Resulting in wheels running on the tip of the wheel flange for prolonged periods
  - Critical for Tram-Train schemes where a full flange wheel profiles are often required for S&C compatibility



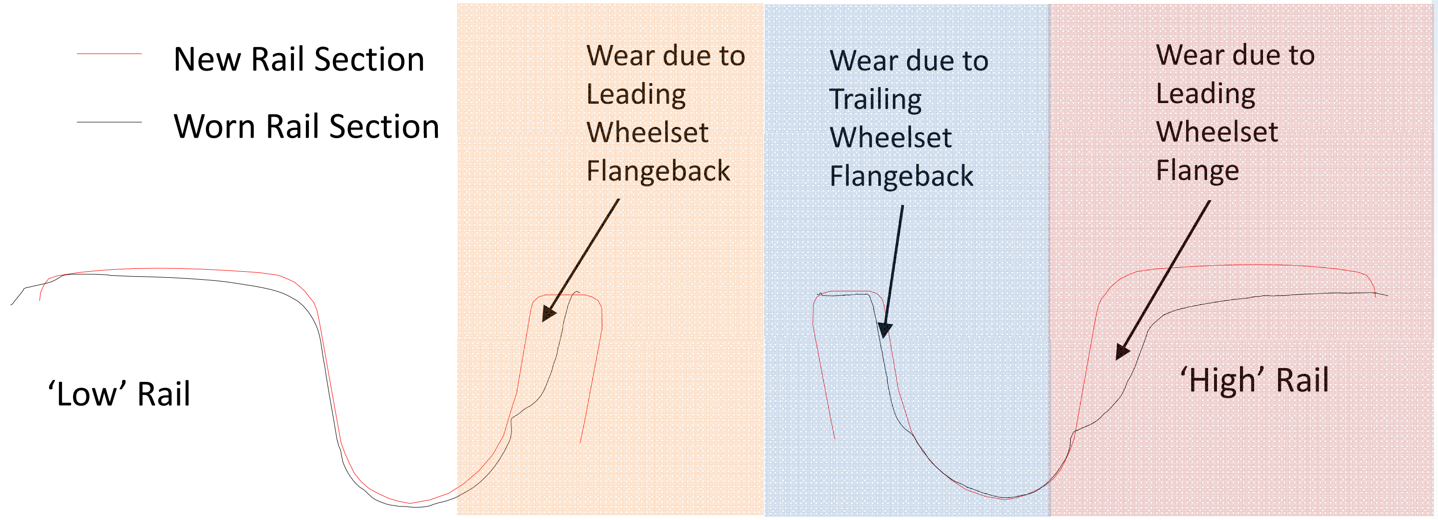


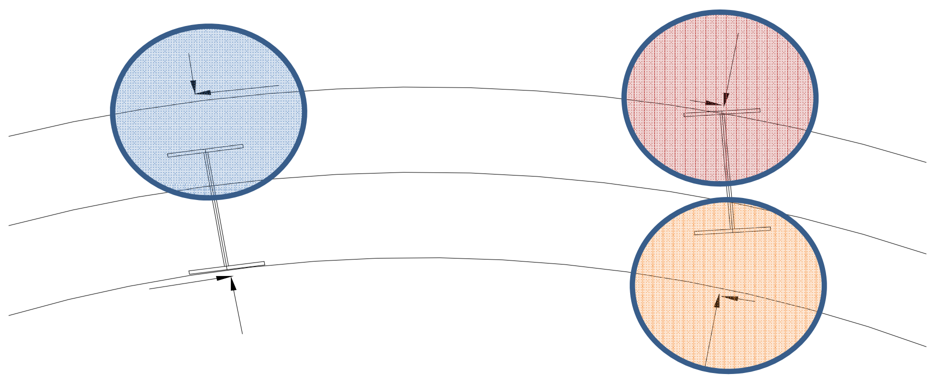
Geometric Compatibility

- Reduction in clearance between wheel and track components
  - Risk of striking fishplates and other track components
  - Clearance reduced due to rail vertical and side wear and wheel tread wear



Side and Keeper Rail Wear (1)

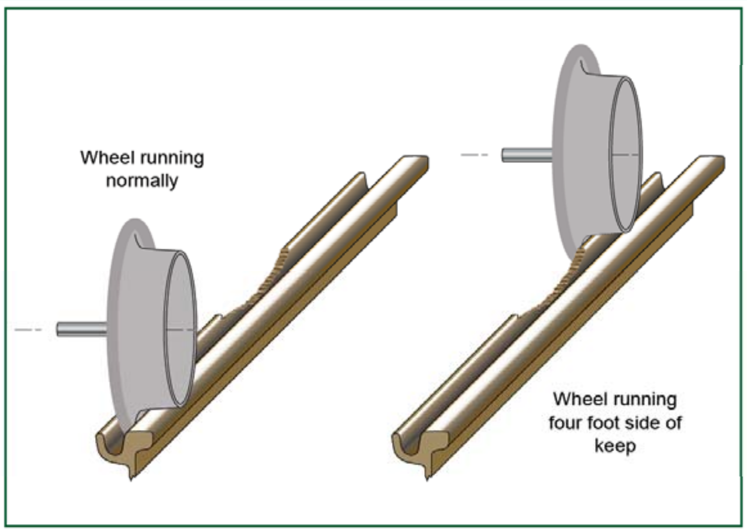




Wheelset Positions and Forces in a Tight Curve

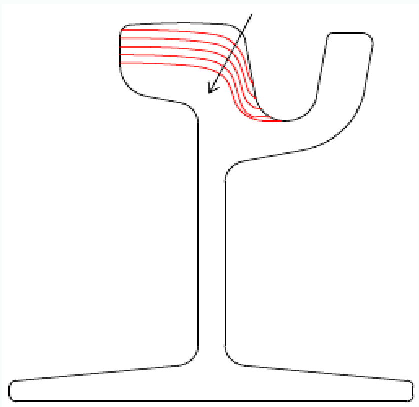
Side and Keeper Rail Wear (2)

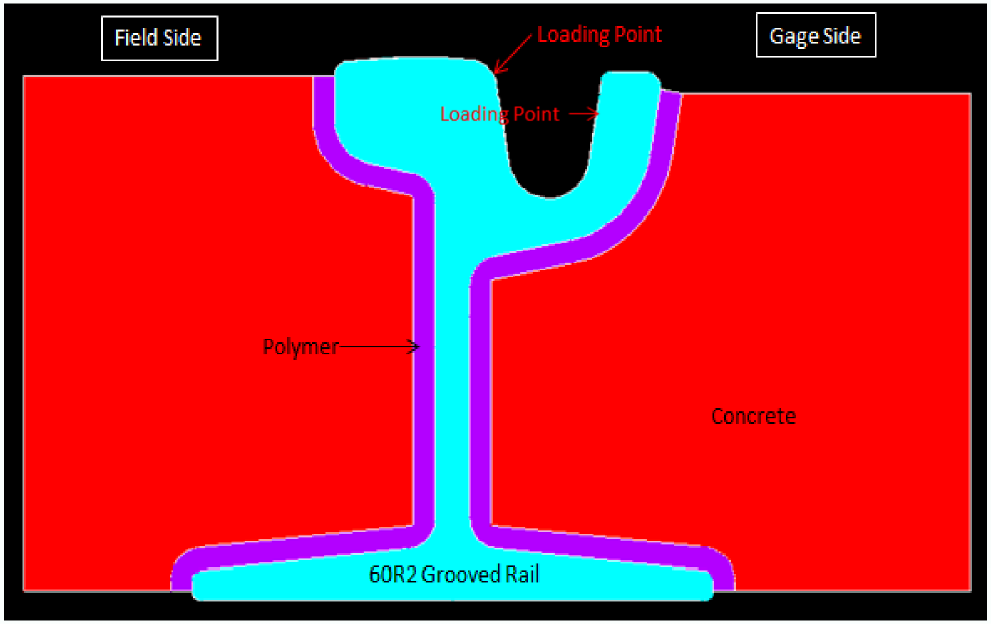
- Excessive wear to keeper rail should be avoided:
  - Wear of keeper rails could eventually lead to failure, increasing the risk of derailment, as wheel flange strikes broken keeper
  - Controlling rail sidewear, wheel flange wear and dynamic gauge spreading (through application of tie bars) will help to reduce keeper rail contact
- The permissible levels of rail side and keeper wear can be effectively determined using a combination of wheelset fit and geometric assessment

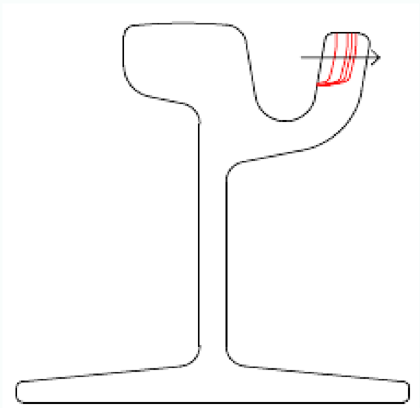


Grooved Rail Structural Integrity

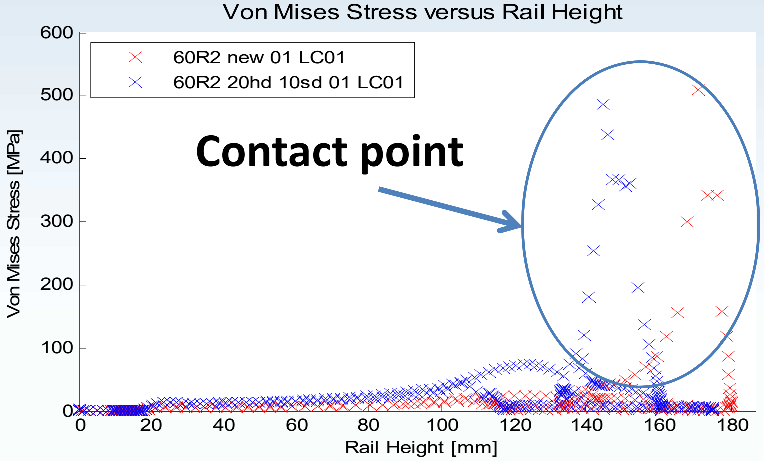
- Structural integrity of new and worn rail sections assessed under typical loads using finite element analysis
- Wheel-rail contact conditions and forces derived from vehicle dynamics simulation

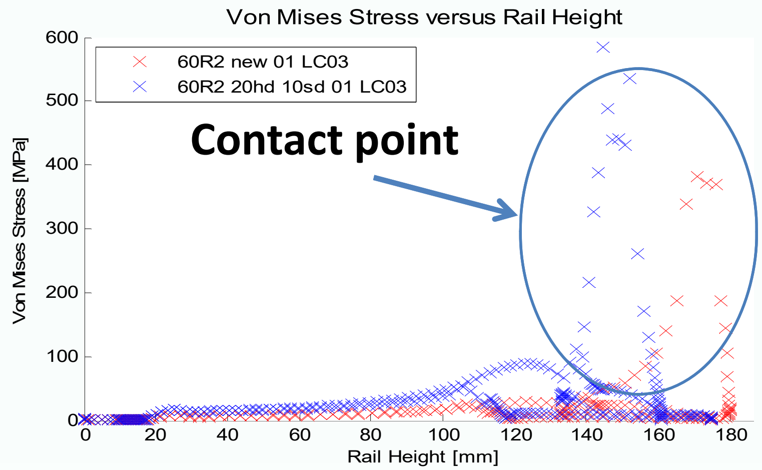


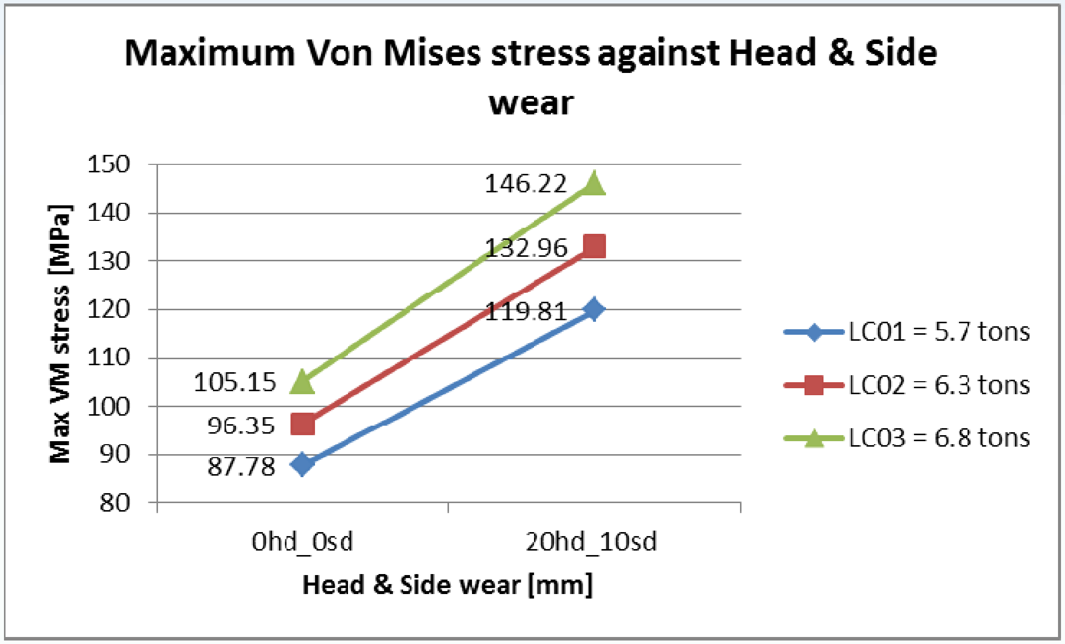




Vertical and Side Rail Wear

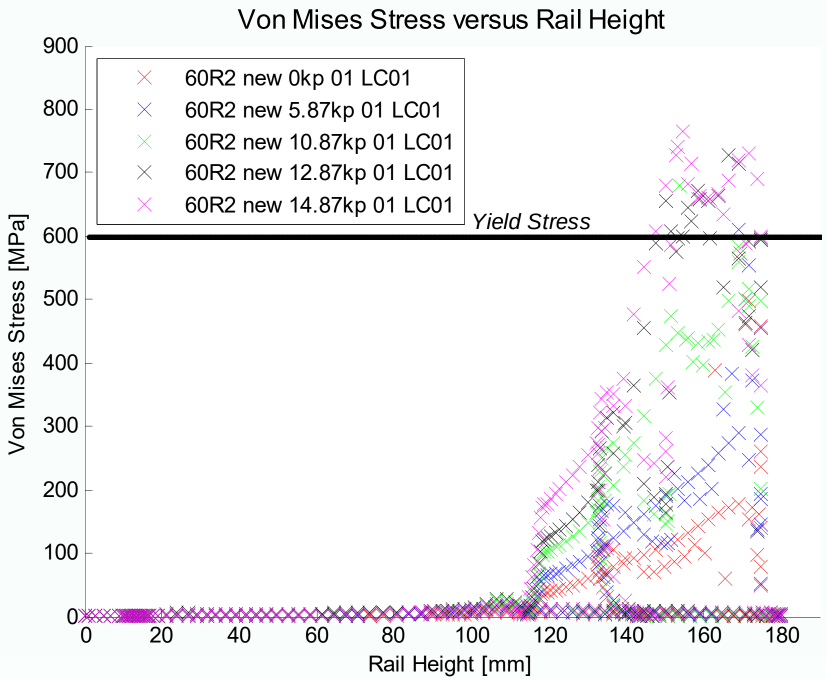


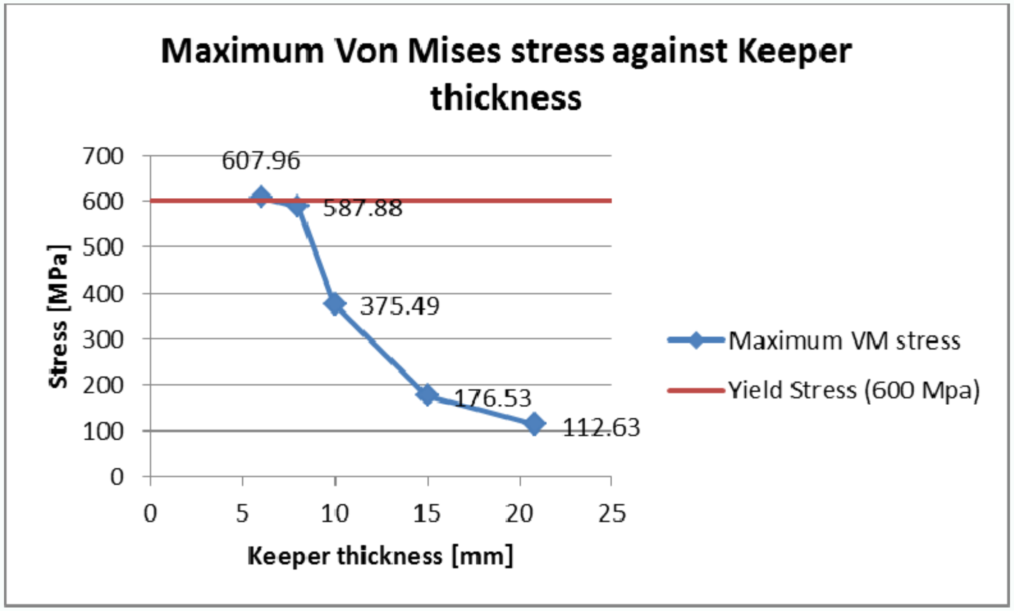




Keeper Rail Wear

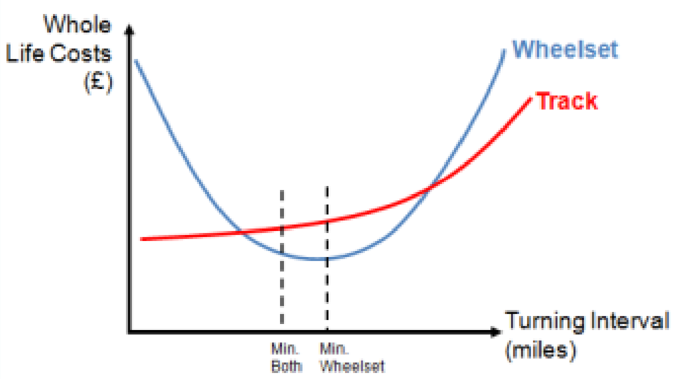
- Initial results suggest that structural integrity of the keeper is maintained until thickness reduces to <8mm
- To be confirmed through experimental testing





Wheelset Maintenance

- Worn wheel profile shapes may be designed to reduce initial wear rates, but further savings can be made through effective management of wheelset maintenance
- Optimisation of wheel reprofiling interval, through assessment of maintenance/inspection records can significantly improve wheelset life
- Mileage-based reprofiling tends to be undertaken more frequently, but resulting in less material removal on the lathe and more consistent contact conditions

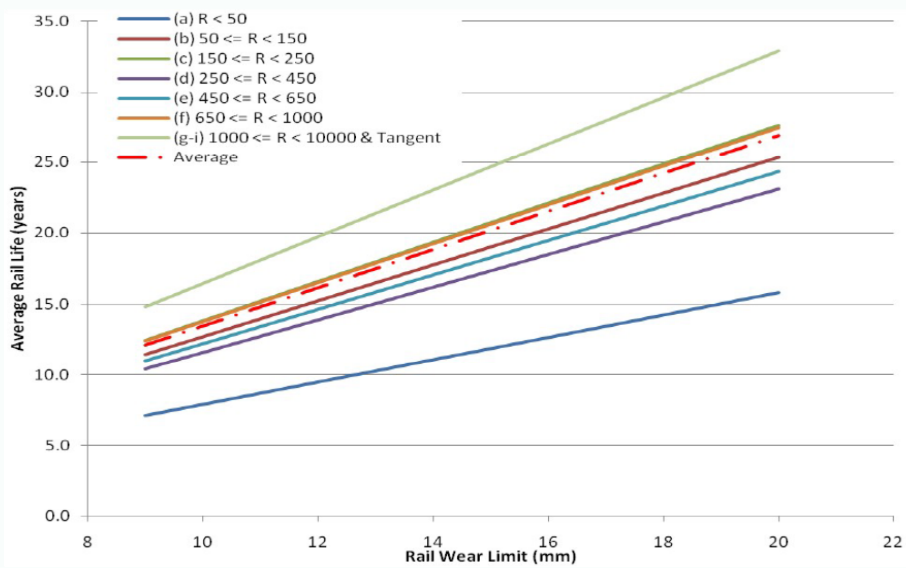


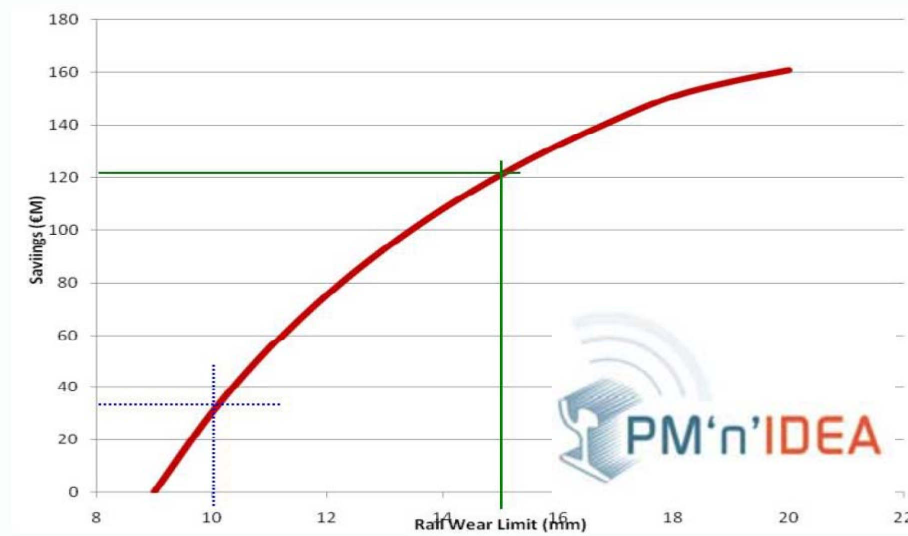
Economic Drivers

- Previous studies have shown that effective management of the WRI can provide significant benefits and cost savings for light-rail systems
  - Improved planning of future maintenance and renewals
  - Reduction in disruption to passenger service
  - Maximising the life of the rail section (reduction in premature rail replacement) and wheelset
  - Reduction in carbon footprint

Wear Limits on Rail Life

- EU project *PM'n'IDEA* demonstrated the financial impact of a change in vertical wear limit on various segments of a UK light-rail network (≈ €90M over 30 years)
- Justification for establishing optimum limits for rail wear





Conclusions

- Significant variation in design conditions and maintenance limits adopted on light-rail networks
  - Lack of detailed guidance
- Opportunities exist to optimise the WRI on light-rail networks through selection of optimal:
  - Wheel-rail profiles
  - Rail steel grades
  - Maintenance limits and practices
- Tools to assist in management of the WRI, which combine vehicle-track degradation data and prediction models, are currently under development as part of UKTram 'Low Impact Light Rail' project

Thank-you