NetworkRail

PWI Lunch and Learn - March 2022

Rail Management Hot Topics and Developments

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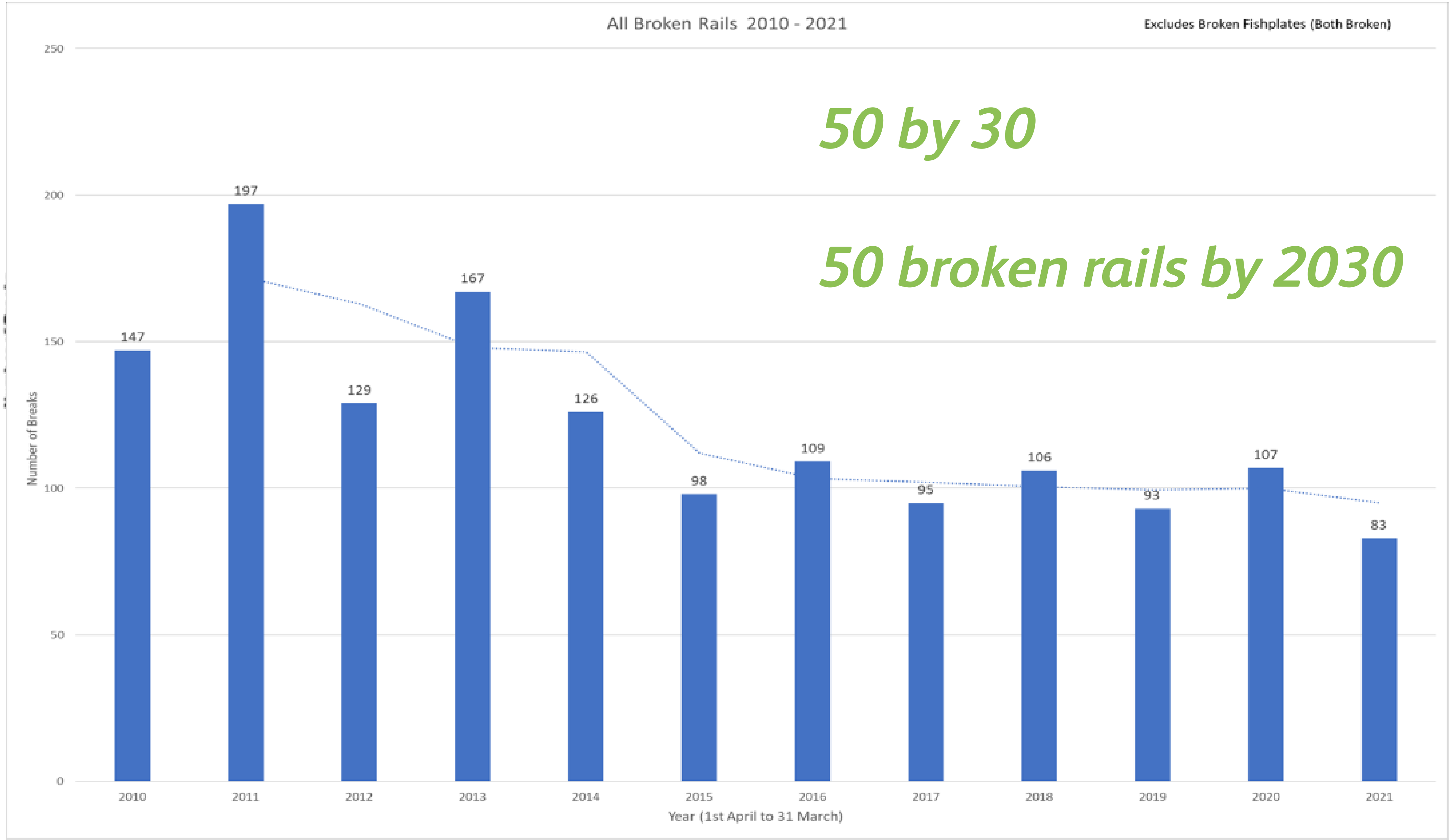
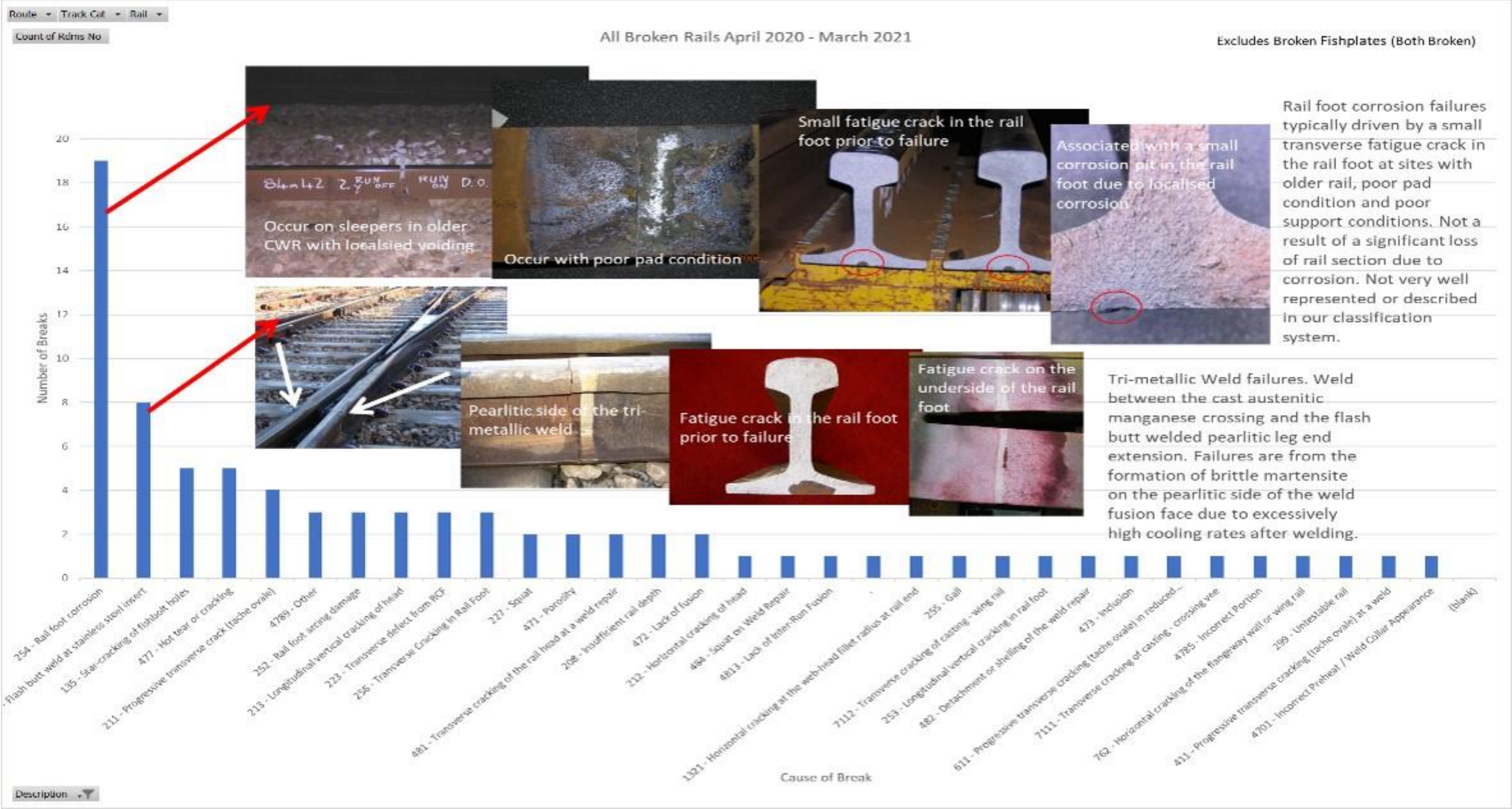
Providing technical leadership

Broken Rails since 2010 moving average

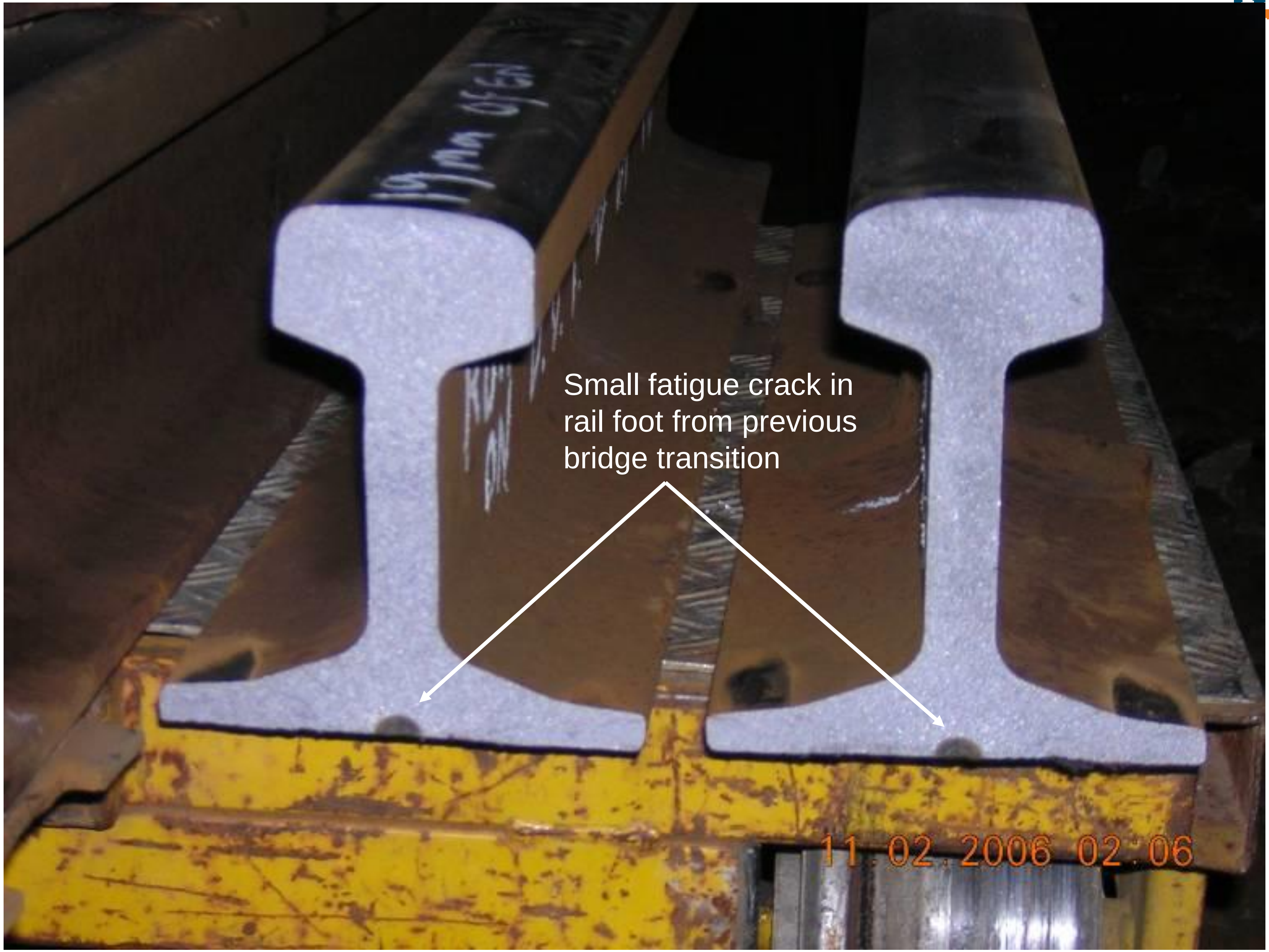


Broken Rails Cause - April 2020 to March 2021



Rail Foot Failures Account For Around 30% Of Annual Breaks

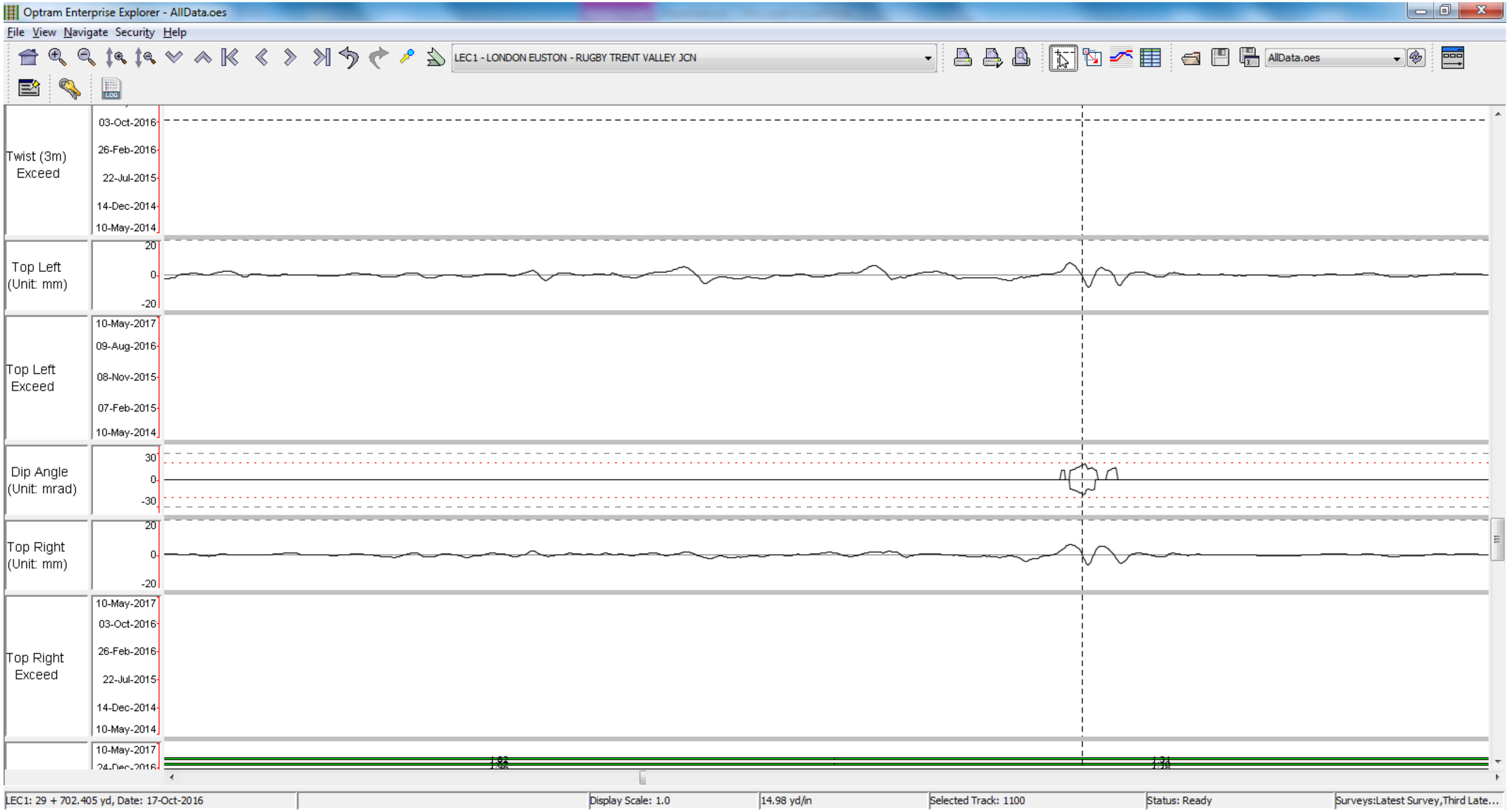
There has been a previous rail break at this location and the majority of rail breaks in the rail foot are caused by poor support conditions


Small fatigue crack in
rail foot from previous
bridge transition
11.02.2006 02:06

20-04-17, LEC1 1100, 29m 700yds
Northchurch, 1980, 113A rail.
Break initiated from the rail foot due to high dynamic loading from voiding sleepers and poor support conditions
No significant defect to detect by inspection.
Need to manage the conditions where this risk exists
40 years WCML 1500 MGT
Small Dip Angle in Plain Line

OFFICIAL

LEC1 1100 29m 700yds Northchurch
Dip in measured geometry trace



Broken Rail, RCF – January 2019 – Double Break - RCF

Sandy North Double Broken Rails 17/01/2022

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The rail was a CEN 56 rail section from 1988 supported by F27 sleepers and Pandrol clips. Up Fast line on plain line at 44 miles 63 chains. At the broken rail location, there is a small dip angle of between 10 to 15mrad, 1000 MGT

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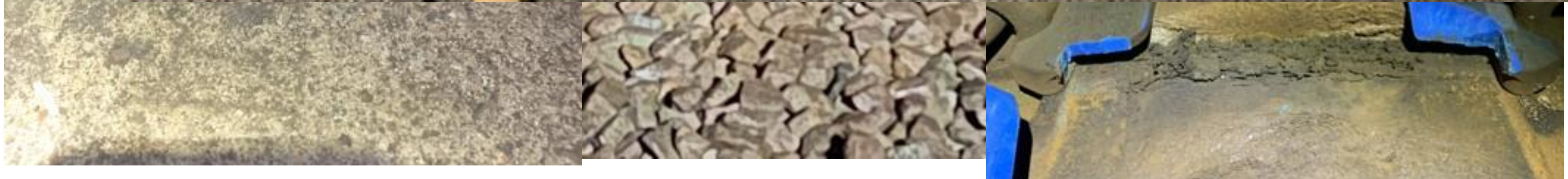

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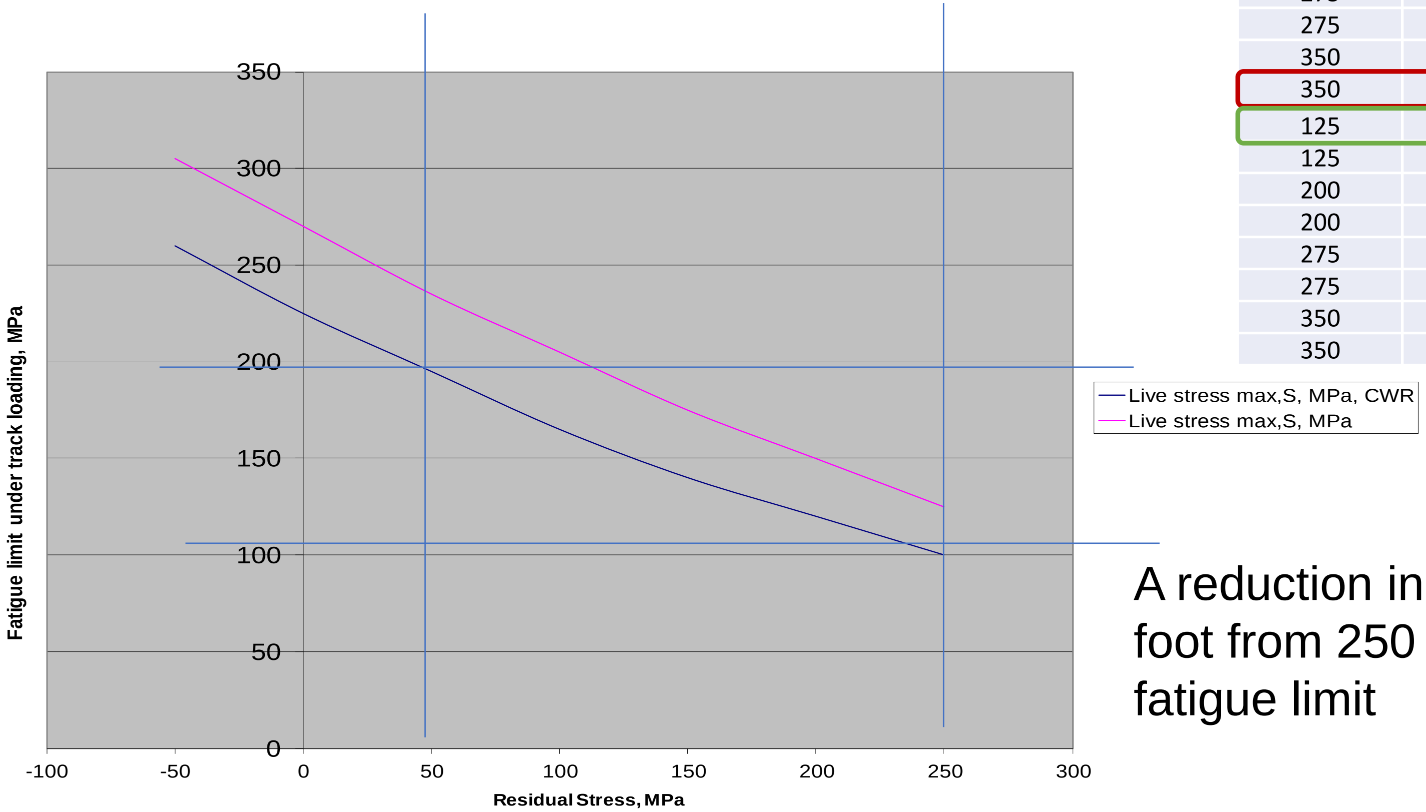
Predicted crack sizes at fracture for foot defects

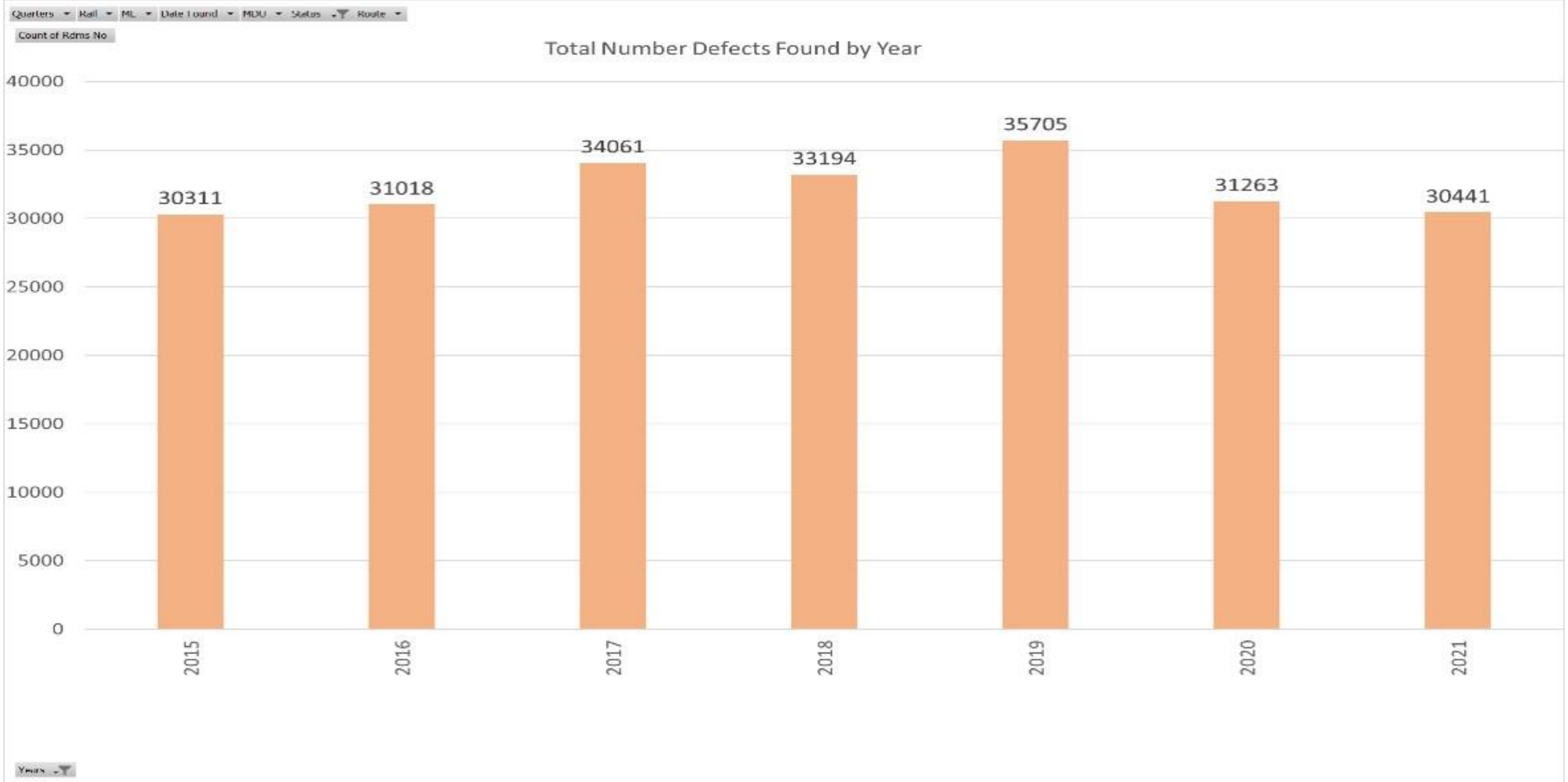
With current controls on wheel impact forces all rails can be expected to experience some loads above the fatigue limit. Because some extreme events may cause the initiation of a crack this may result in cycles below the constant amplitude fatigue limit becoming damaging, in which case finite lives will result.

Wheel Force, (kN)	Max live stress, (Mpa)	Residual stress, (Mpa)	Thermal stress, (Mpa)	Total foot stress, (Mpa)	Crit. crack radius (mm)
125	65.3	150	0 (27°C)	215.3	17.2
125	65.3	250	0	315.3	8
200	104.5	150	0	254.5	12.3
200	104.5	250	0	354.5	6.3
275	143.7	150	0	293.7	9.2
275	143.7	250	0	393.7	5.1
350	182.8	150	0	332.8	7.2
350	182.8	250	0	432.8	4.2
125	65.3	150	65 (0°C)	280.3	10.1
125	65.3	250	65	380.3	5.5
200	104.5	150	65	319.5	7.8
200	104.5	250	65	419.5	4.5
275	143.7	150	65	358.7	6.2
275	143.7	250	65	458.7	3.8
350	182.8	150	65	397.8	5
350	182.8	250	65 (0°C)	497.8	3.2
125	65.3	150	-65 (54°C)	150.3	35.2
125	65.3	250	-65	250.3	12.7
200	104.5	150	-65	189.5	22.2
200	104.5	250	-65	289.5	9.5
275	143.7	150	-65	228.7	15.2
275	143.7	250	-65	328.7	7.4
350	182.8	150	-65	267.8	11.1
350	182.8	250	-65	367.8	5.9

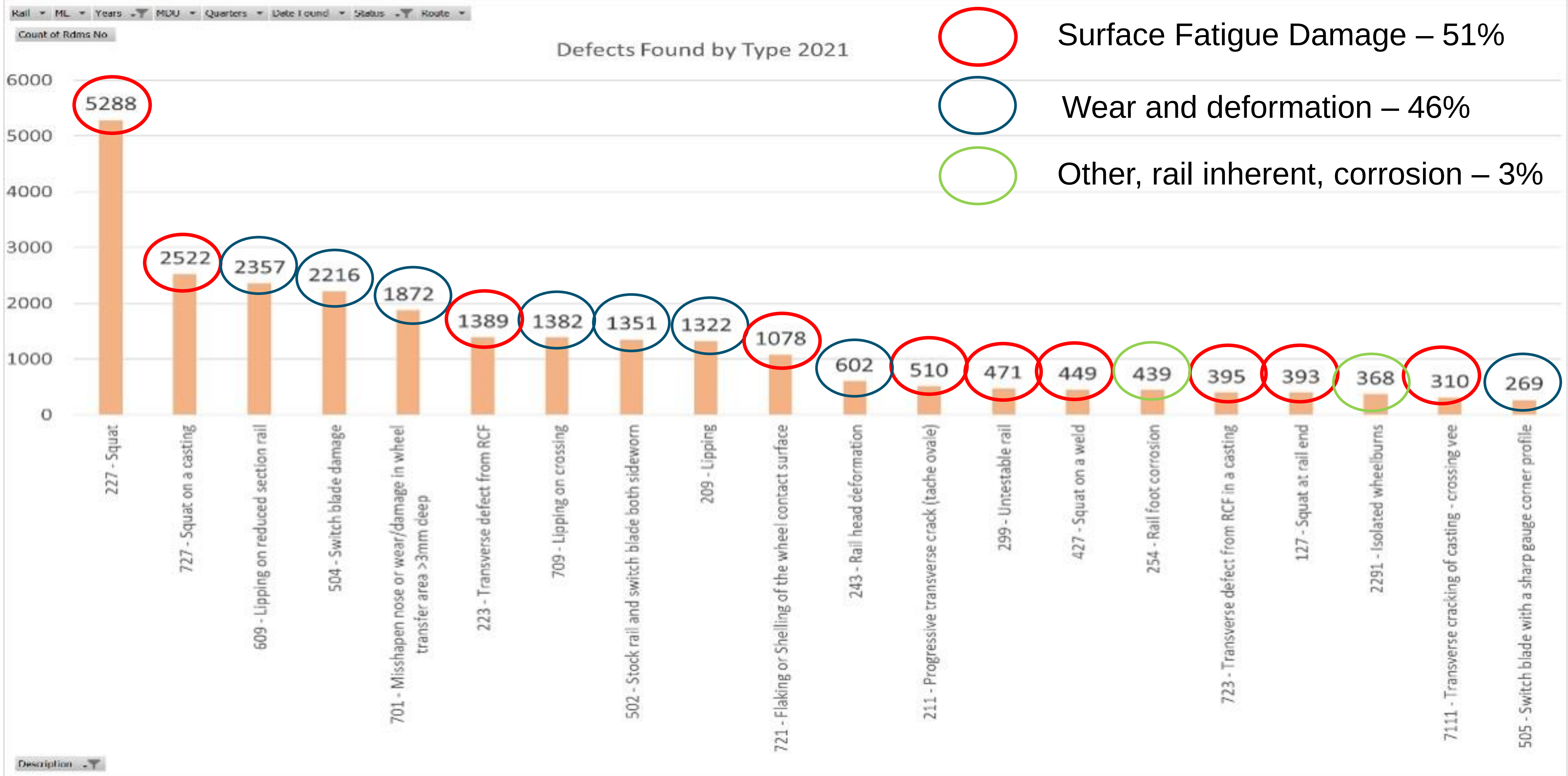


A reduction in the tensile residual stress level in the rail foot from 250 MPa to 50MPa would effectively double the fatigue limit

Total Number of Defects Found by Year 2015 to 2021



Top 20 Defects by Type - 2021



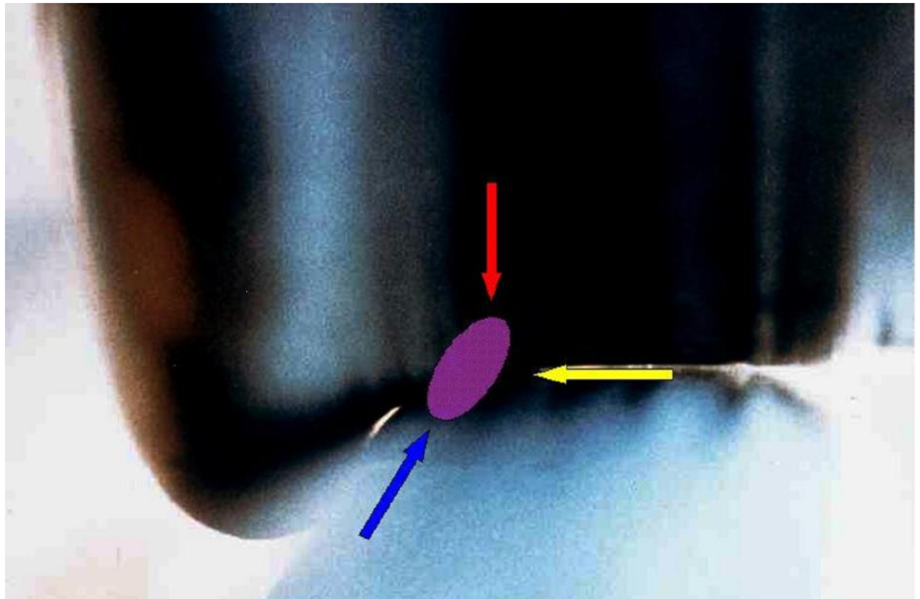
Surface Damage in the form of RCF, and Squats are the most common type of rail damage on modern railways

The contact patch

The contact patch between wheel and rail must transmit all the forces needed to support and guide the vehicle. It must also transmit all the forces from the train accelerating and braking.

In addition to vertical loads, longitudinal and lateral forces are generated in the contact patch

- They are generated by **all** vehicles
  - They are not just the forces created during traction and braking
  - They are created by vehicles as they ‘steer’ round curves



…We ignore them at our peril: they will not ignore us!

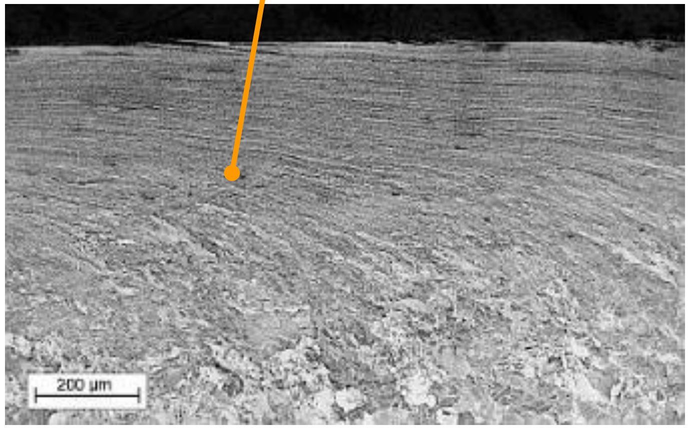
Mechanism for RCF initiation

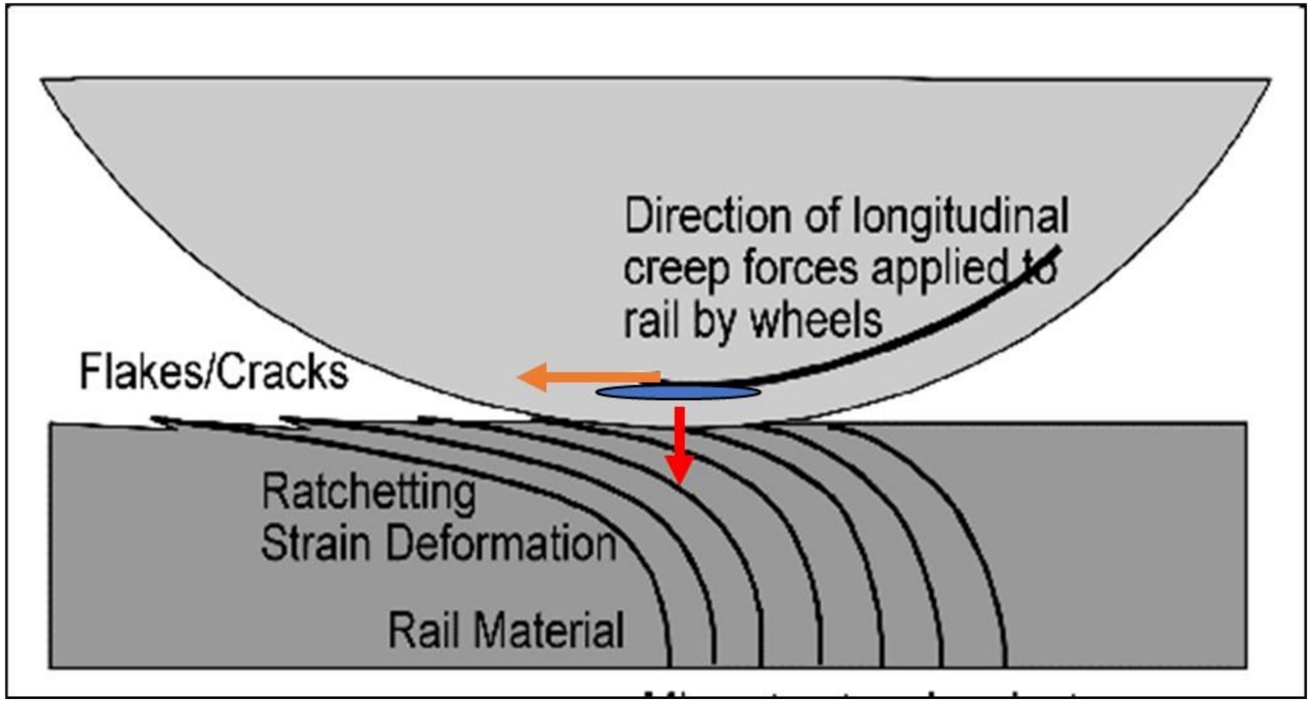
Material in the contact patch is subjected to very high stresses

- Hydrostatic compressive stress (vertical contact forces)
- Longitudinal shear force

Large plastic strains- permanent shear deformation

Severe plastic ‘shear’ deformation

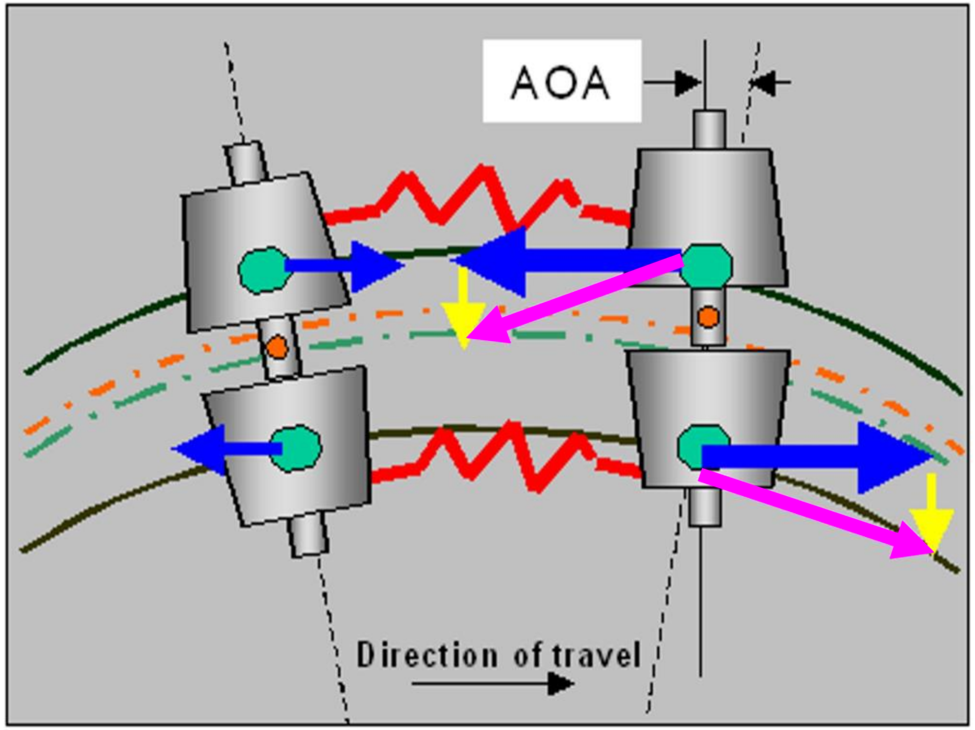




The surface angle of RCF cracks

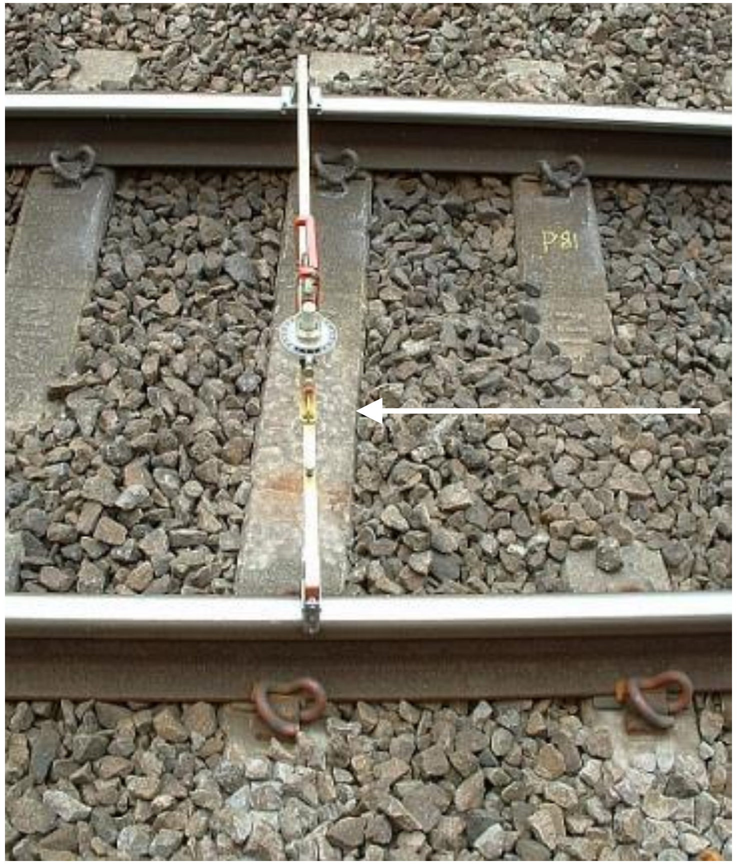
Cracks grow perpendicular to the resultant shear force

The angle of the cracks as predicted in analysis matches that observed in the field



Rail oriented Wheel/Rail forces

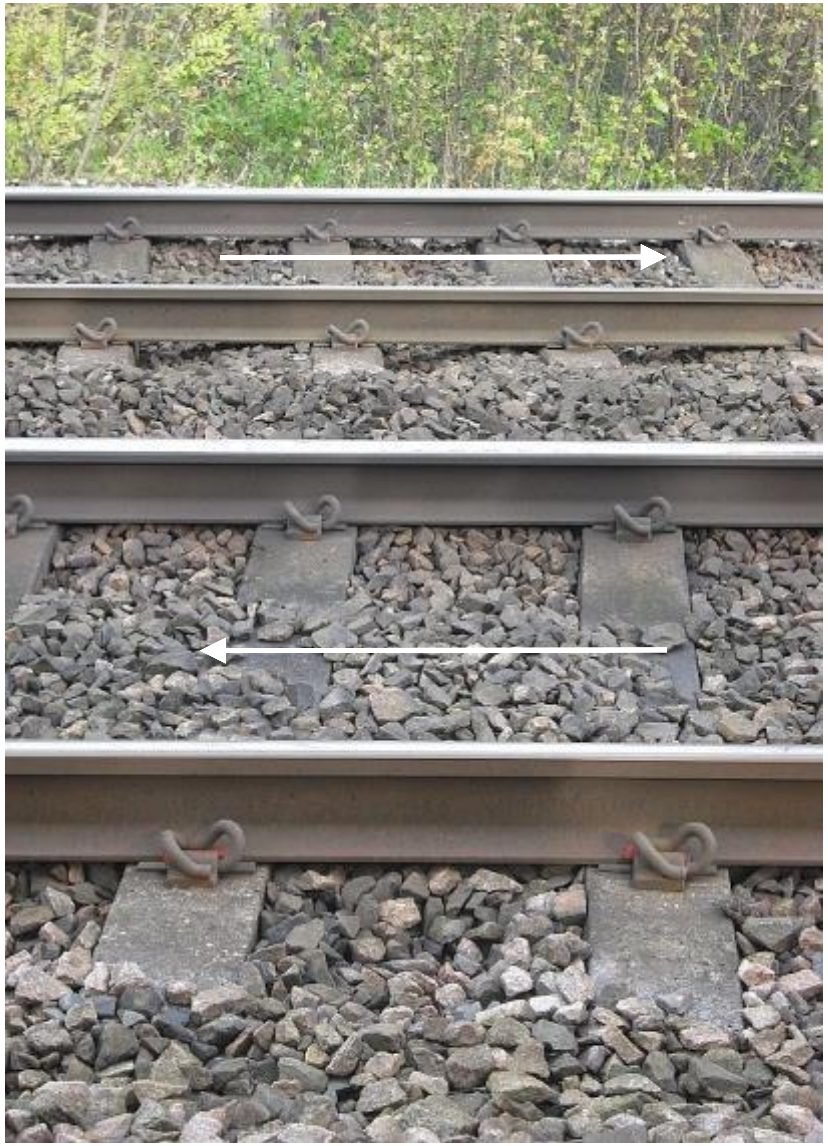
Longitudinal Forces from traction and curving are not Small



Outside of curve
('high' rail)

Traffic Flow

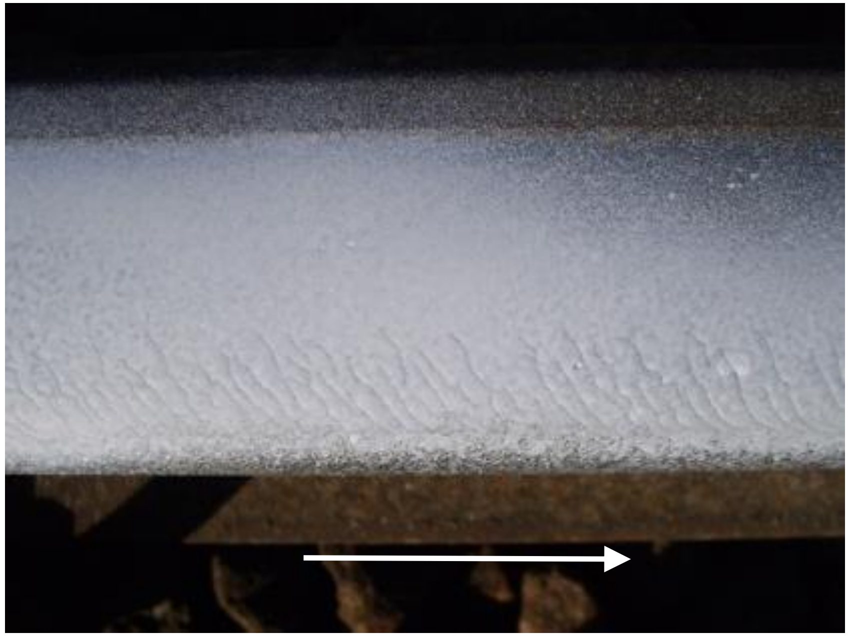
Inside of
curve
('low' rail)



- 1500m radius curve, 125mph track
- 'Outer' rail pulled back, 'Inner' rail pushed forward by curving forces

Damage caused by steering forces

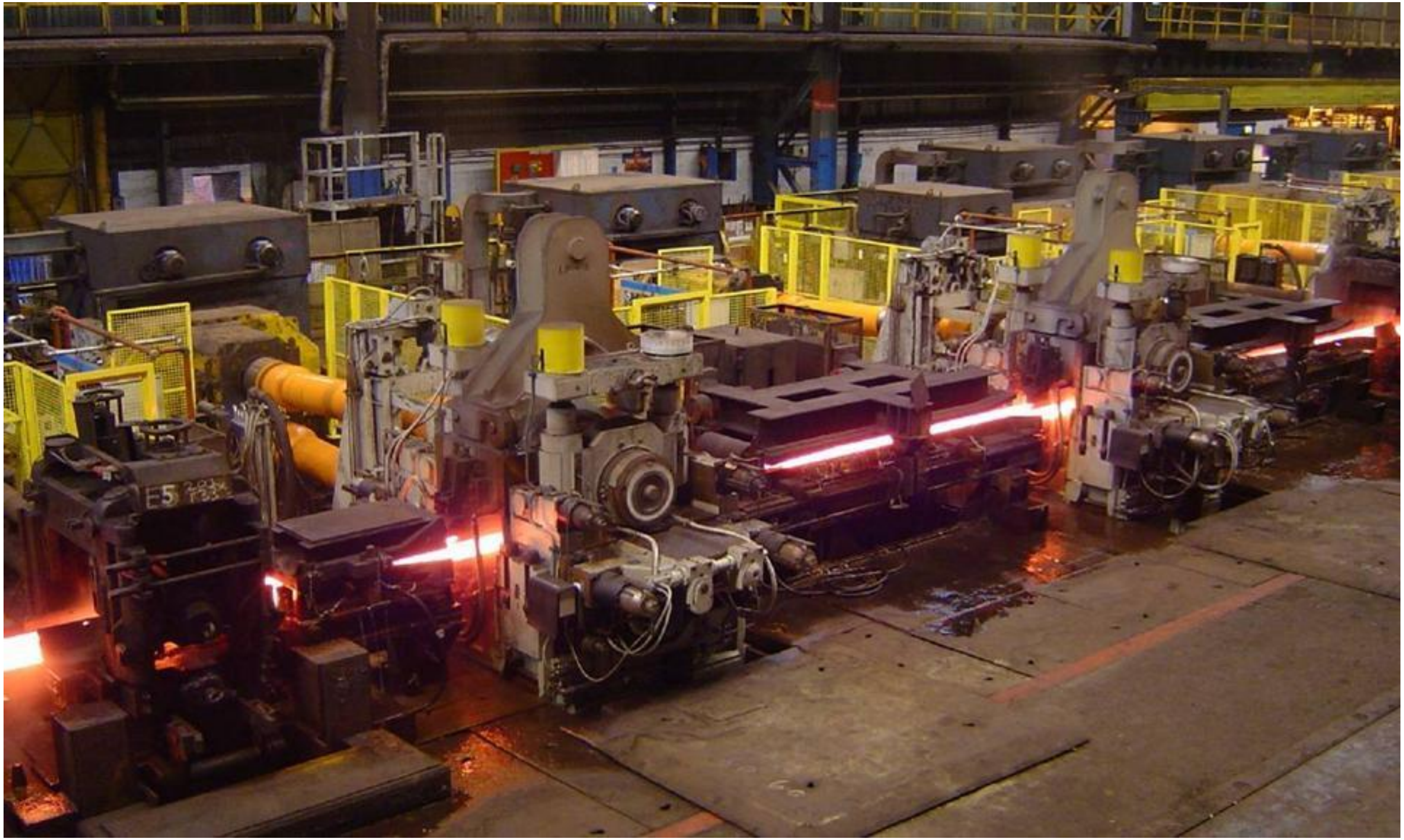
Rolling contact fatigue (high rail)



Damage caused by steering forces

Rolling contact fatigue (low rail)

Premium Rail Steel Developments



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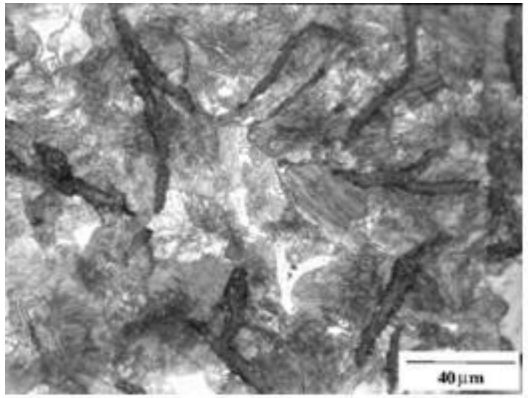
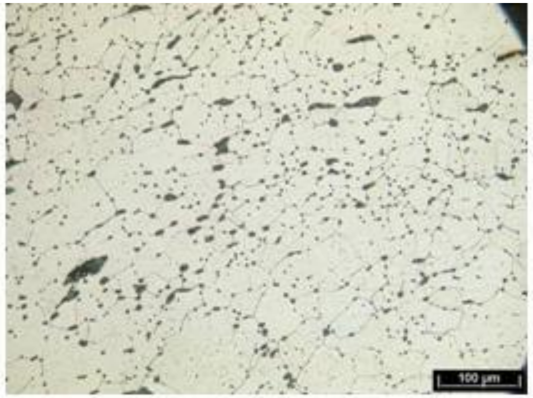
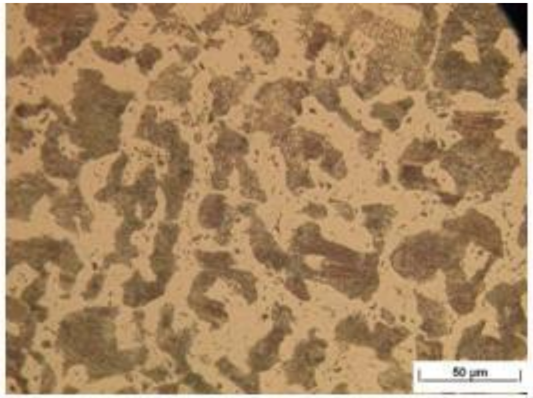
Metallurgical Developments – Rail Microstructures



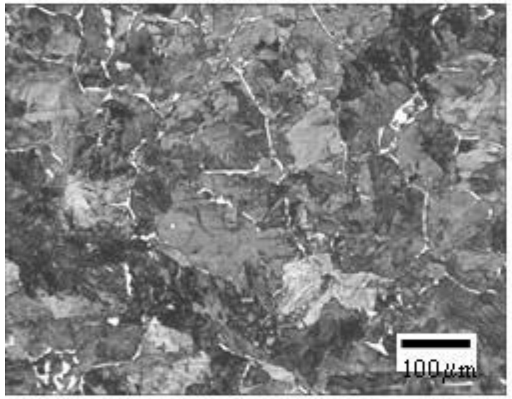
1767 Cast Iron ~ 3%C; 200HB



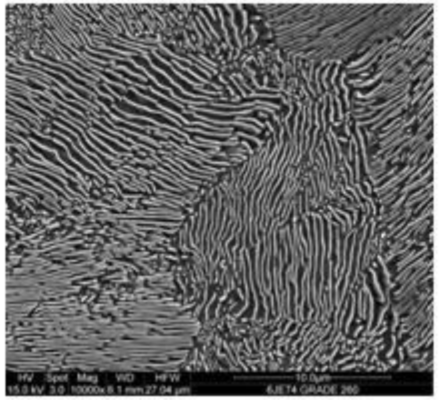
1808 Wrought Iron 0.05%C; 174HB



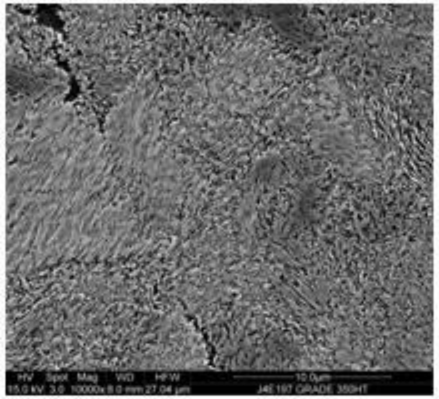
1857 Bessemer Steel ~ 0.25%C; 182HB



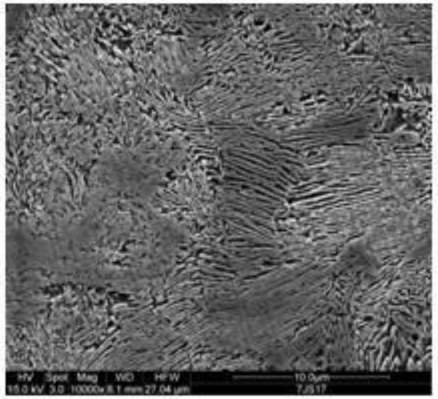
1950 BS11 Normal (R220); ~0.55%C, 230HB



1970 Grade A (R260) ~ 0.8%C, 280HB

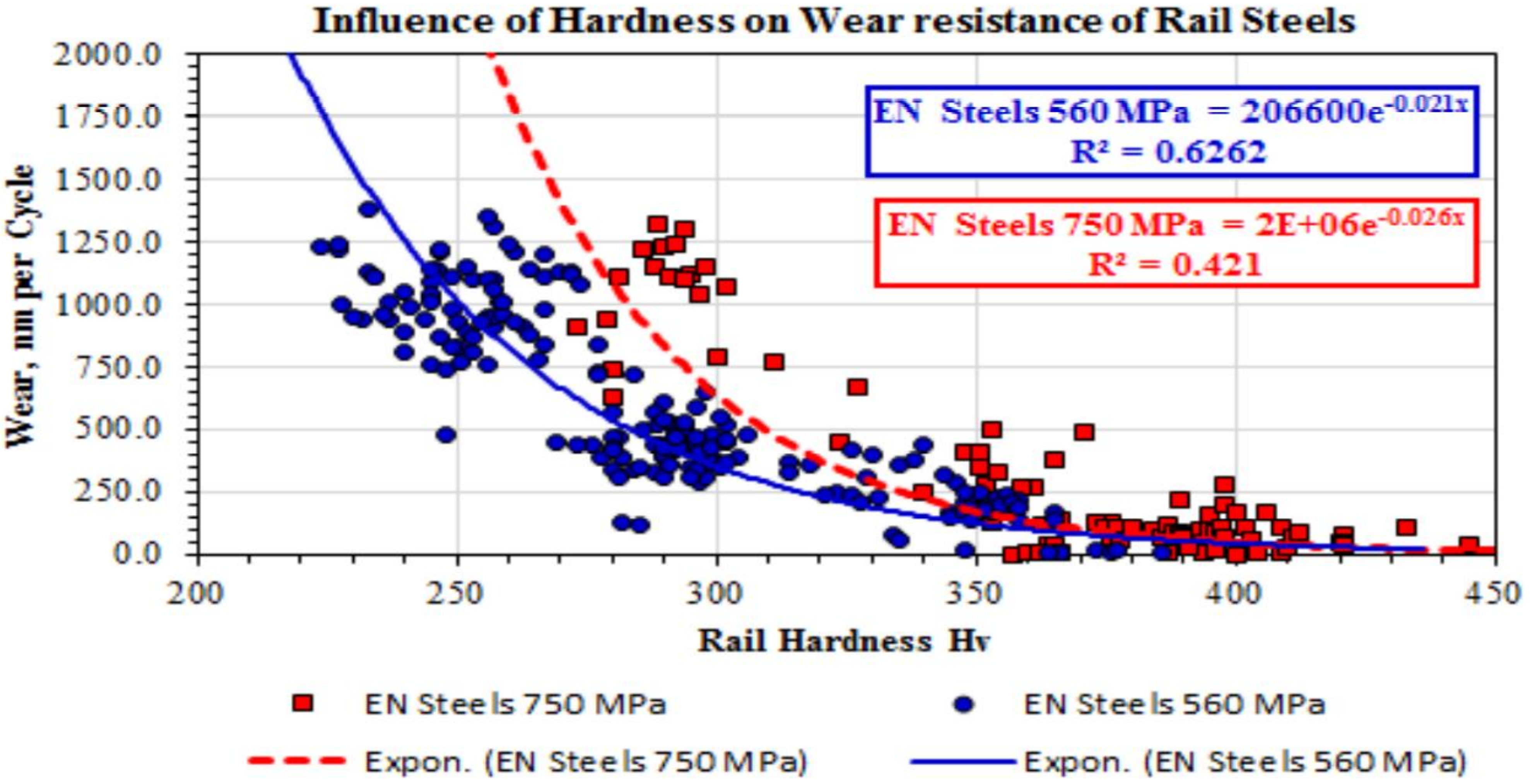


1985 MHT (R350HT) 0.8%C, 350HB



Current HE Grades (R400HT) ~0.9%C; >400HB

Wear and Hardness



Rail Steel Development – Do we know what we want?

Grade R260 is by far the most dominant grade used in metros and mainline track throughout Europe and probably accounts for over 90 % of rails in track in Europe

Grade R350HT is the original heat treated rail steel which has the same composition as the standard R260 grade, but used accelerated cooling to refine the pearlite and increase hardness and tensile strength

Grade HP335 is a naturally cooled hypereutectoid steel from British Steel. It does not require additional heat treatment and offers significantly reduced energy costs during manufacture. It has been engineered to increase the volume fraction of cementite through an increase in carbon content, with an increased strength of the pearlitic ferrite by harder, finer carbide precipitates ensuring that this hard phase is the dominant phase at the wheel/rail interface and offers a reduction in wear and increased resistance to RCF

400 MHH Alloyed, cooled, straightened, heat treated – low residual stress

Bainitics BLF320 / 360

?????

Horses for courses? Where, what and why?

Rail Steel Conundrum

Harder

Harder, reduces wear and deformation

Higher strength alloys and hardness with expensive alloying additions

Higher carbon more likely to suffer thermal transformation

Higher carbon / alloying reduces weldability

Higher Strength and Hardness – Costly Heat Treatment / reheating adds significant cost,

Cooling rates critical

Higher residual stresses from manufacture

Reduced ductility and toughness

Less wear

More grinding? Less controlled grinding

Life restricted by surface damage?

Softer

Lower strength and resistance to surface damage

Potential for lower residual stress

More natural wear to reduce fatigue damage build up on running surface

Reduced cost of manufacture

More weldable

Opportunity to weld repair

Lower strength but increased ductility and higher toughness

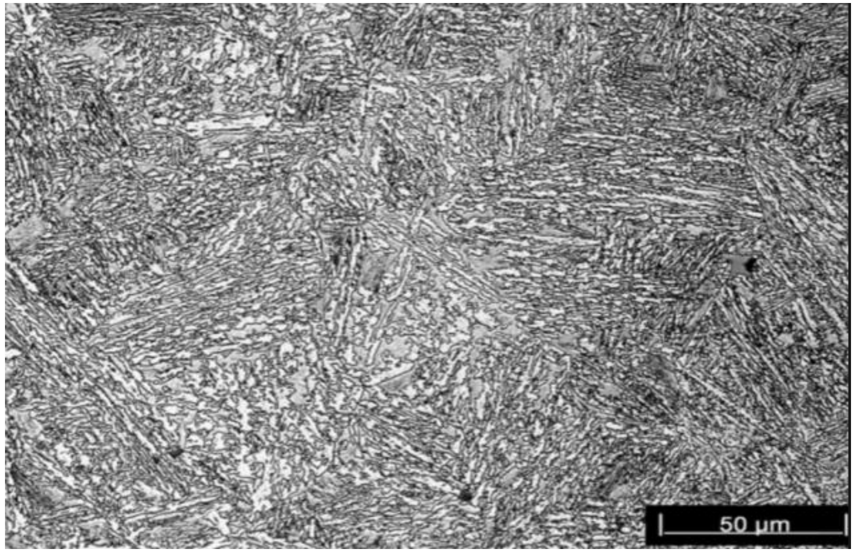
More natural wear and profile deterioration - more grinding

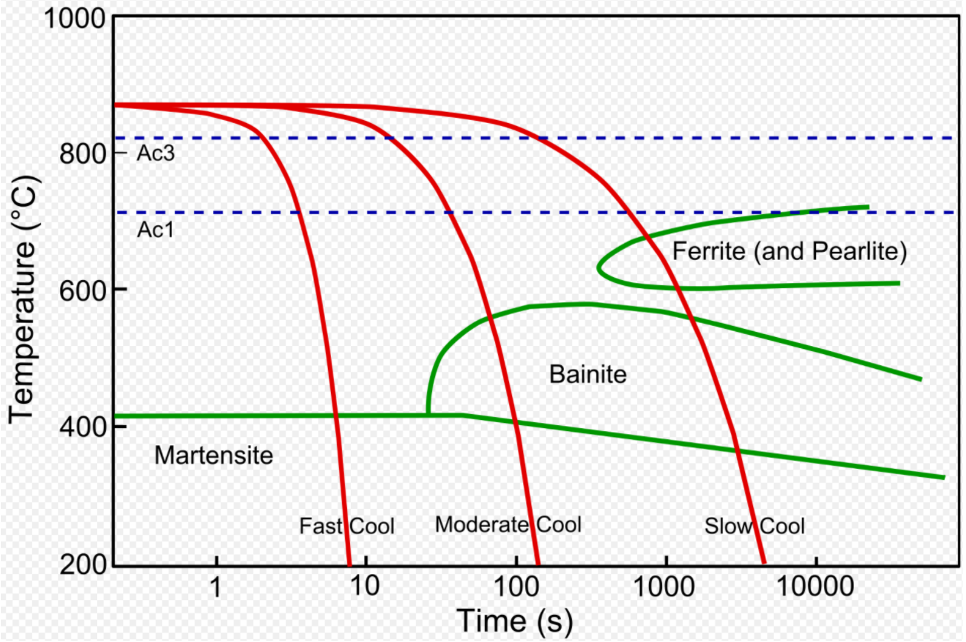
More plastic deformation and lipping

Life restricted by wear?

Pearlitic, Martensitic and Bainitic Steels

Different sections of a route on any network have different magnitudes of susceptibility to the key rail degradation mechanisms and a methodology for identifying the damage susceptibility of these sections is important in realising the optimum choice of rail steel and maintenance requirements.





Bainitic Rail Steels – British Steel

Not something new but offer a significant change and difference in performance to the more common pearlitic rail steels

Improved RCF performance provided by low carbon, carbide-free Bainitic Low Fatigue grades leads to lower life cycle costs through reduced maintenance requirements, especially under extreme traffic conditions where surface damage could significantly reduce the asset life

Two grades - BLF320 and BLF360 (previously known as B320 and B360) – are available to provide extreme contact fatigue resistance to critical track locations and have been used by SNCF in high speed switchblades and movable points, and routes with high traffic density.

BLF grades have been in mainline use for over ten years proving exceptional RCF resistance in the most challenging conditions. In extended monitoring programmes spanning rail lives in excess of 1,000MGT, British Steel BLF rail has never required grinding to control RCF.

Bainitic Rail Steels

Not something new but offer a significant change and difference in performance to the more common pearlitic rail steels

Grade BLF320 is a low carbon carbide-free bainitic steel from British Steel. It is a highly alloyed composition with additions of Si, Mn, Cr, V, and Mo to yield a carbide free microstructure comprising bainite and austenite on natural cooling following hot rolling. Although wear resistance of the grade is similar to R260, it offers excellent resistance to RCF and has given a long grinding-free life in a 4000 m radius curve in the Eurotunnel, carrying > 100 MGT per year. The grade is weldable using flash butt and aluminothermic processes and the low carbon content also facilitates weld repair techniques.

Grade BLF360 is a slightly higher carbon version (0.25/0.35 %) of the BLF320 grade, also developing a carbide free microstructure comprising bainite and austenite on natural cooling following hot rolling. The slightly higher hardness provides increased resistance to wear compared to Grade BLF320, while maintaining the high resistance to RCF. This grade has been approved by SNCF for use in high speed S&C. The higher resistance to RCF has been demonstrated in several trial sites in France, Germany, and Switzerland. However, critical and subcritical Heat Affected Zone regions of both flash butt and aluminothermic welds that can occur in this grade can be susceptible to cracking. This has severely restricted the realisation of the benefits of improved RCF and wear resistance offered by this grade.

Rail Steel Properties

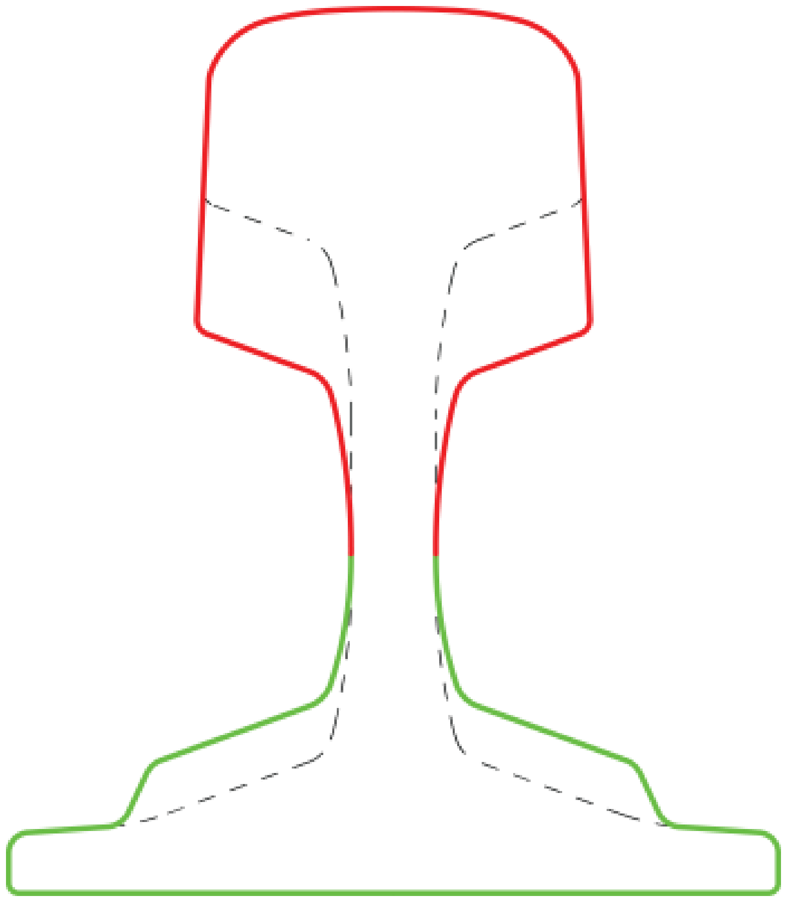
Steel Grade Category	Steel Grade	Composition (Liquid), % by mass						UTS, min.	Elongation, min, %	Hardness Range (HBW)
		C	Si	Mn	P max	S, Max	Cr, max	Mpa		
Standard	R260	0.62-0.80	0.15-0.58	0.70-1.20	0.025	0.025	0.15	880	10	260 to 300
	R260Mn	0.55-0.75	0.15-0.60	1.30-1.70	0.025	0.025	0.15	880	10	260 to 300
Hard Heat Treated	R350HT	0.72-0.80	0.15-0.58	0.70-1.20	0.02	0.025	0.15	1175	9	350 to 390
	R350LHT	0.72-0.80	0.15-0.58	0.70-1.20	0.02	0.025	0.3	1175	9	350 to 390
Hardest Heat Treated	R370CrHT	0.70-0.82	0.40-1.00	0.70-1.10	0.02	0.02	0.40-0.60	1280	9	370 to 410
	R400HT	0.90-1.05	0.20-0.60	1.00-1.30	0.02	0.02	0.30	1280	9	400 to 440
British Steel As-Rolled Hypereutectoid Steel	HP335	0.87-0.97	0.75-1.00	0.75 – 1.00	≤0.02	0.008 – 0.025	≤ 0.10	1150	7	335 minimum
British Steel As-Rolled Carbide-Free Bainitic Steel	B320 Contains 0.10-0.20% Mo	0.15-0.25	1.00-1.50	1.40-1.70	-	-	0.30-0.70	1100	13	320 min
	B360 Contains 0.10-0.20% Mo	0.25-0.35	1.00-1.50	1.40-1.70	-	-	0.30-0.70	1200	12	360 min

Jay Jaiswal – University of Huddersfield
New Rail Design

Developed profile – result of parametric evaluation of a matrix of cross-sectional designs

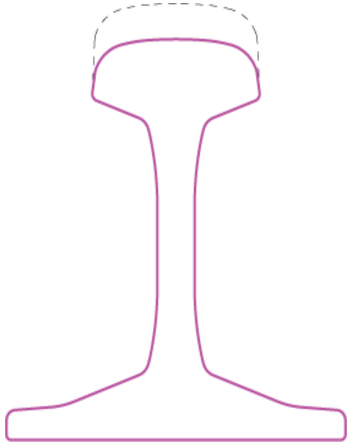
Key features compared to 60E2:

- Head & foot width, rail height, crown profile, web thickness, foot tip thickness maintained – no implications for gauge, sleeper seat, and fastenings
- Head height increased 50 % - area by ~63 %
- Foot area increased by 38 %
- Web area reduced by 31 %
- Overall increase concentrated in the head, (part affecting performance and life span)
- Location of neutral axis unaltered

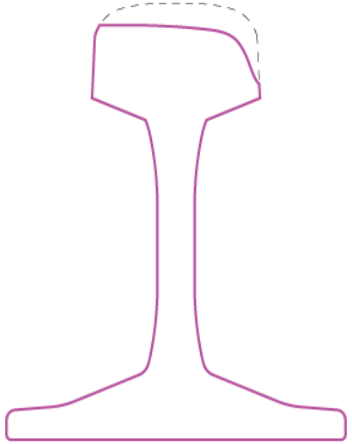


Design for Rail Wear

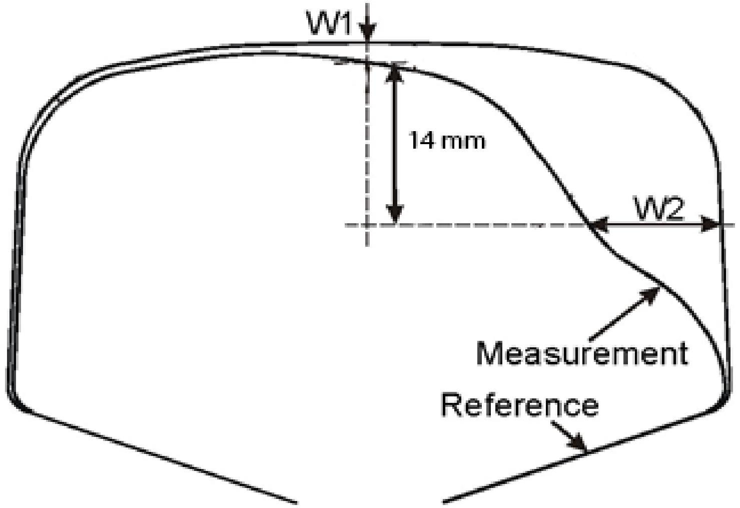
Worn profiles on reference 60E2



60E2 WV14

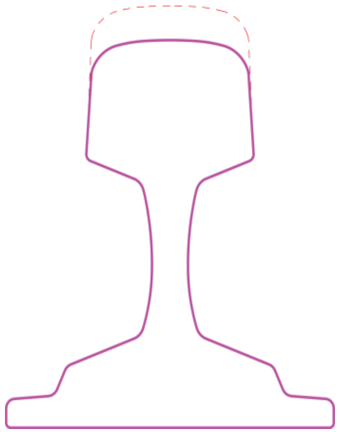


60E2 WVL14

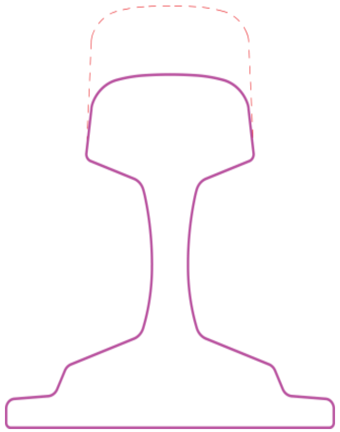


$$W = W1 + W2$$

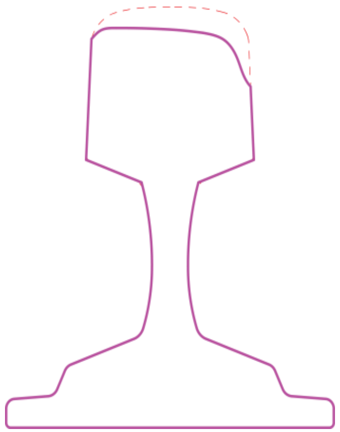
Worn profiles of the designed HDFTO



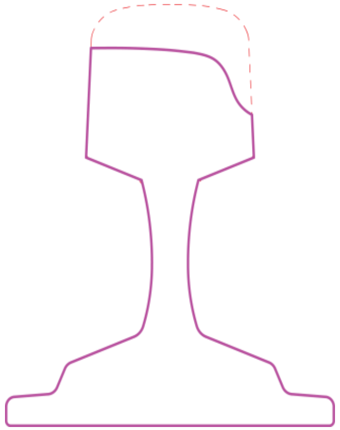
HDFTO WV14



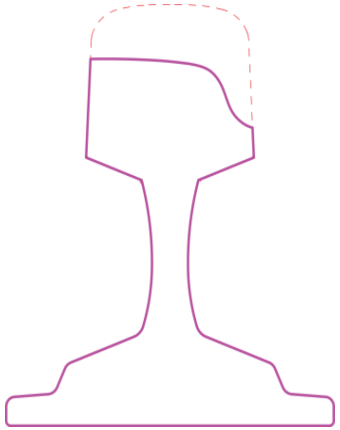
HDFTO WV28



HDFTO WVL14



HDFTO WVL28



HDFTO WVL35

Its not just broken rails in colder weather. Too hot can be equally risky.
Track Buckles

Huddlesford July 2003

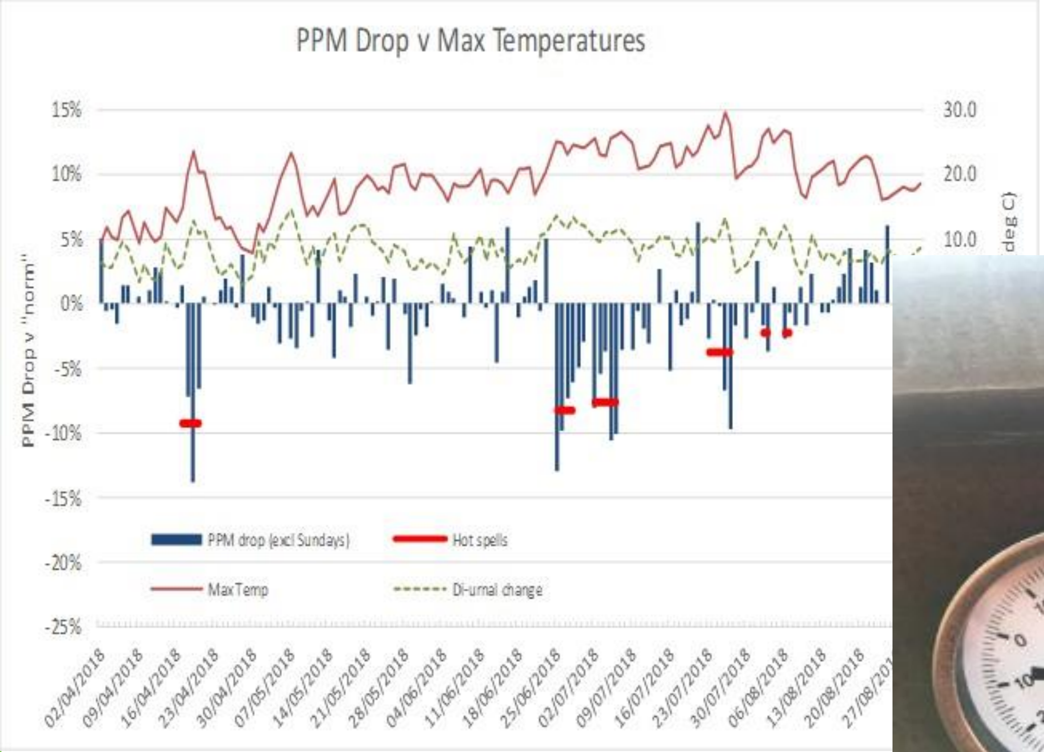
35 to 40% of all buckles in or within 100m of S&C, 70% of high speed buckles in or within 100m of S&C

Hot Weather Performance Impact summary

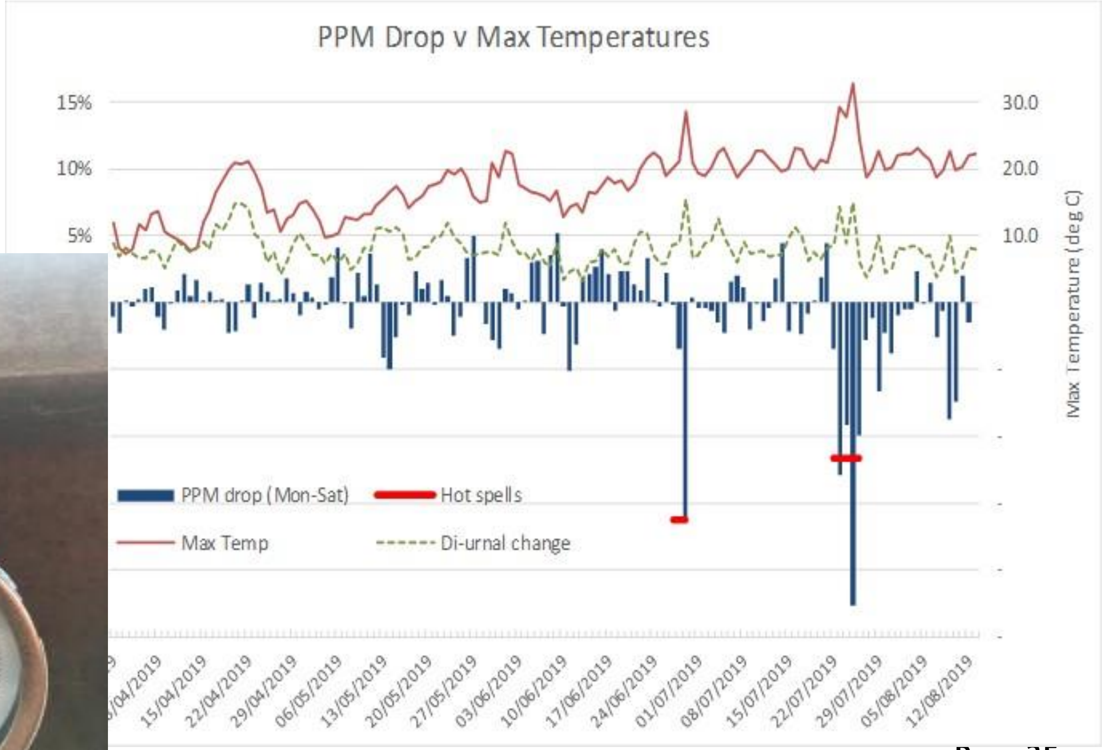
The brief but intense spells of hot weather in June/July 2019 was particularly evident on train performance, with sharp drops in PPM on the days with sharply higher temperatures. In contrast 2018 performance had a profound effect over a longer period due to the continuous spell of hot weather.

Overall the hot weather, especially in P5, caused an extra 25 % loss in PPM related to heat speeds and track related failures(buckles/rough rides) - (0.71 % of PPM loss)

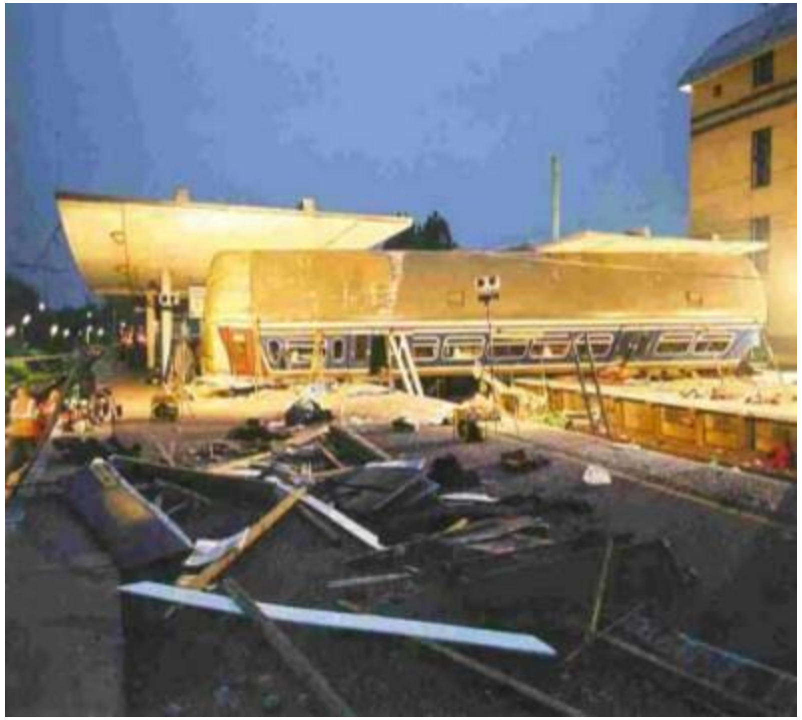
2018



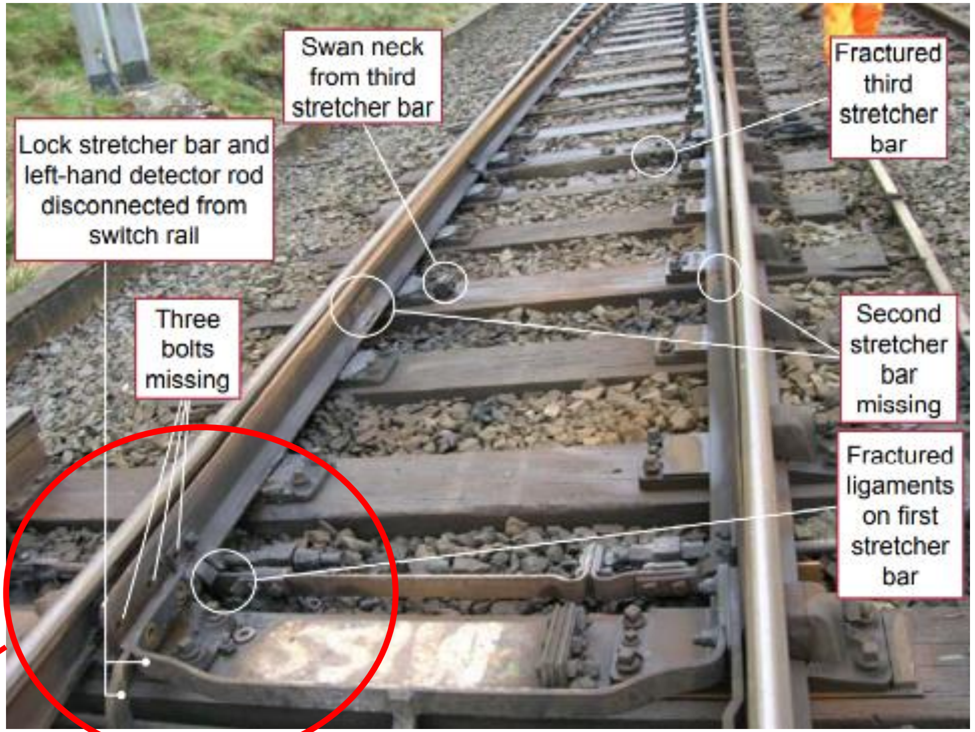
2019



Not Just Broken Rails and Buckles
Potters Bar May 2002
Fastening integrity is equally important



Lambrigg – February 2007



What can we do better?

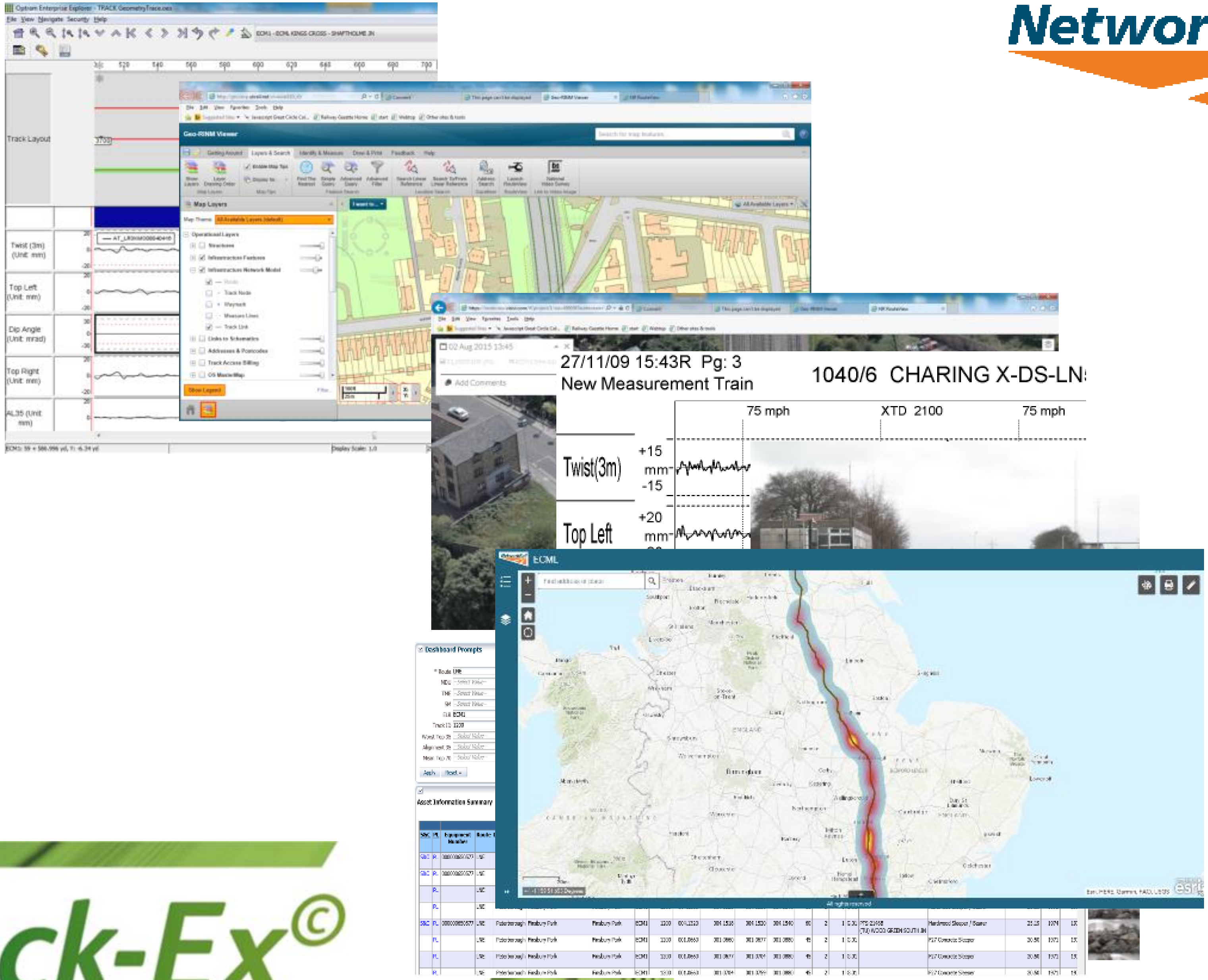
- As an organisation we're currently data rich but intelligence poor

- Better understand the local condition(s) of our asset
- Use data from different sources to focus in on potential risk sites
- Improve information systems to enable data to be easily correlated together
- Understand areas at higher risk of failure or require different maintenance regimes
- Better manage support conditions particularly at geometry faults, rail defects, transitions / wet beds / voiding
- Understanding where multiple conditions / risks occur together
- Consider enhancing or new minimum actions for higher risk locations

- We current fix a wet bed by digging out ballast and reinstating new ballast to support the track. We intervene at dip angles and other geometry faults.
- Should changing the rails be part of the rectification work?

Tools

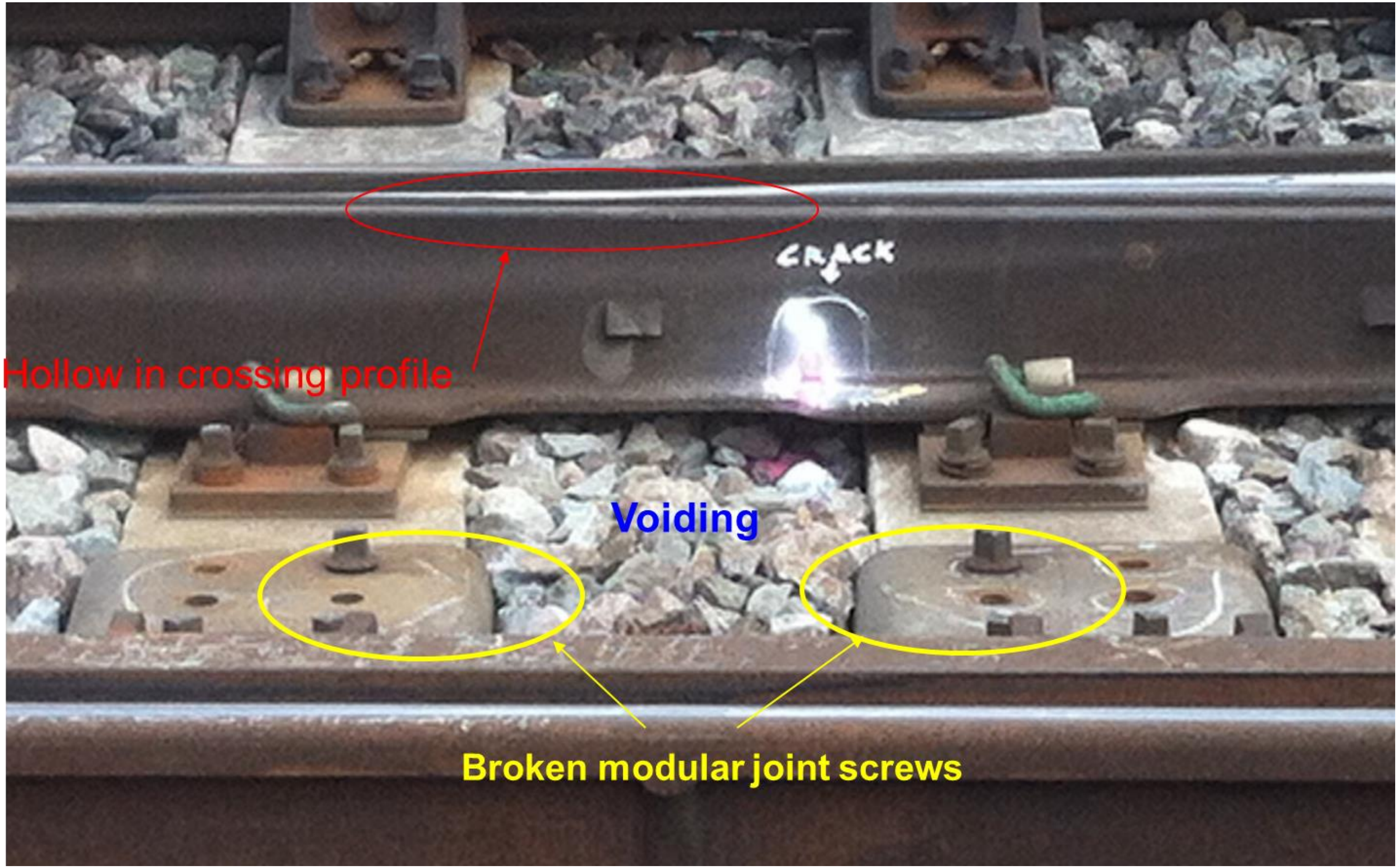
LADS
RINM
Route View
Geometry Traces
Supervisors Inspections
(INM) age of rail
Track-Ex – vehicle dynamic models
DST Track Decision Support Tool
PLPR
AIVR
Rail Health
Insight (In Development)



Track-Ex©

A powerful prediction tool to support track engineers

Cracked Crossing - Underlying issues – poor formation and voiding – component condition



Infrastructure Improvement Programme - Insight

We collect data from across the network, using measurement trains, remote condition monitoring, helicopters, and handheld devices but we lack the tools to turn this data into actionable information.

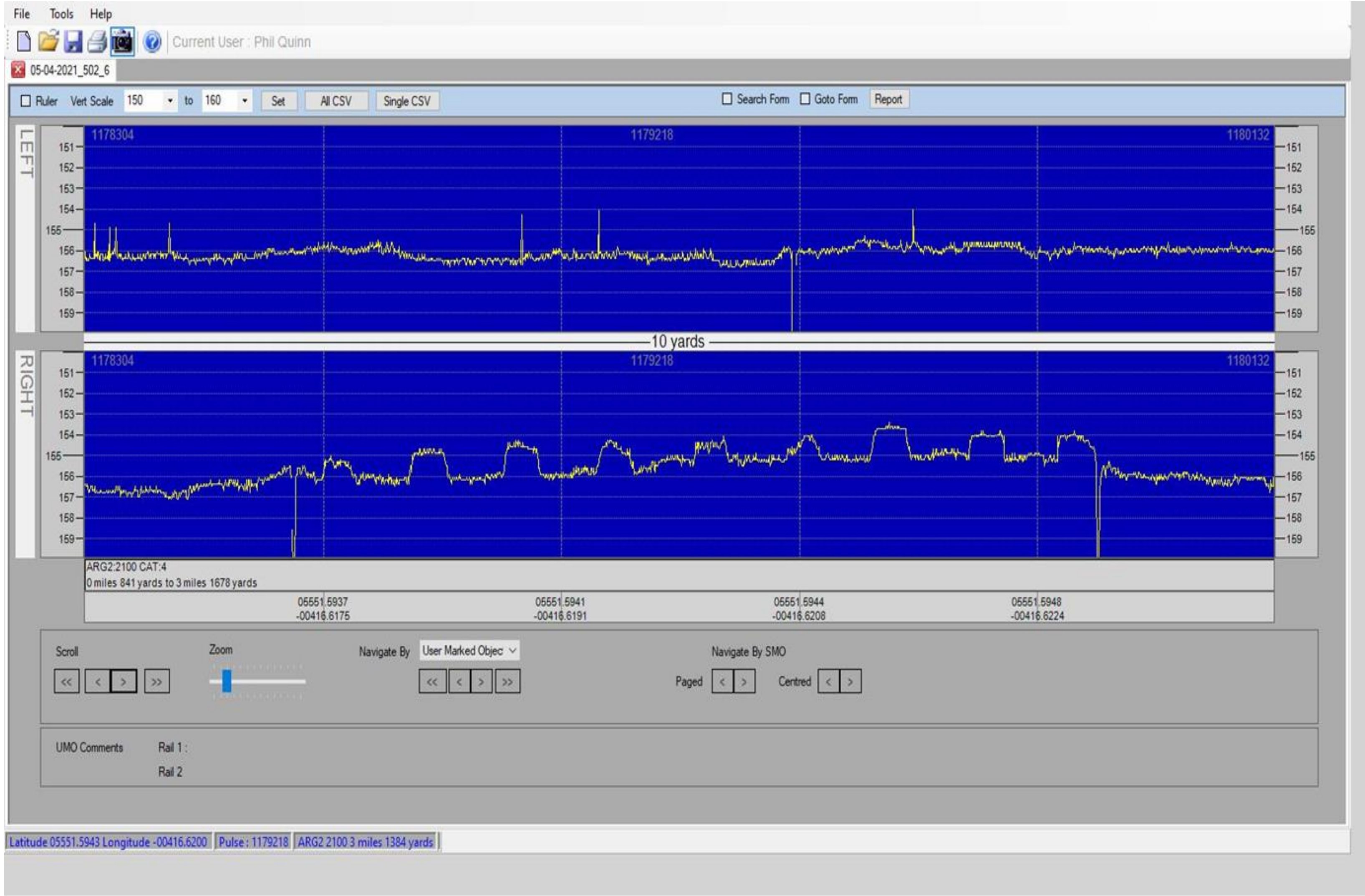
II is using data science, analytics, and algorithms to **extract meaningful information from the wealth of data already collected to support decision making.** We're trailblazing the use of cloud computing to store and process this vast amount of data and looking into new and innovative ways to understand our network.

Intelligent Infrastructure (II) is a five-year digital transformation programme (2019-2024), focused on turning data into intelligent information. It will enable us to move towards predictive maintenance and will improve services for passengers and freight customers.

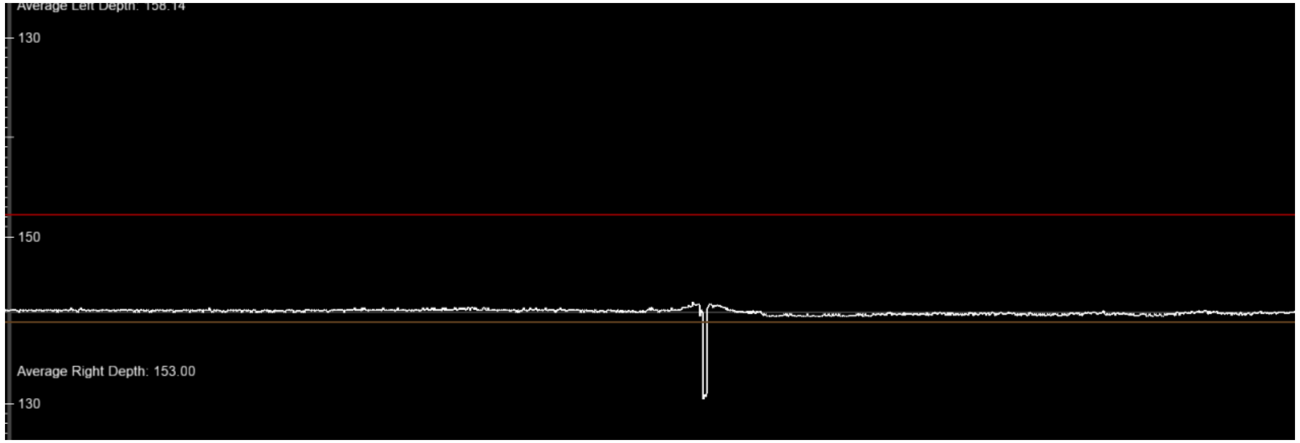
Applying analytics to leverage existing technology

Using existing data sources to inform maintenance schedules to target interventions through predict and prevent

Insight - Combining Data – Rail Depth from UTUs



Insight - Rail Depth from Ultrasonic Test Trains



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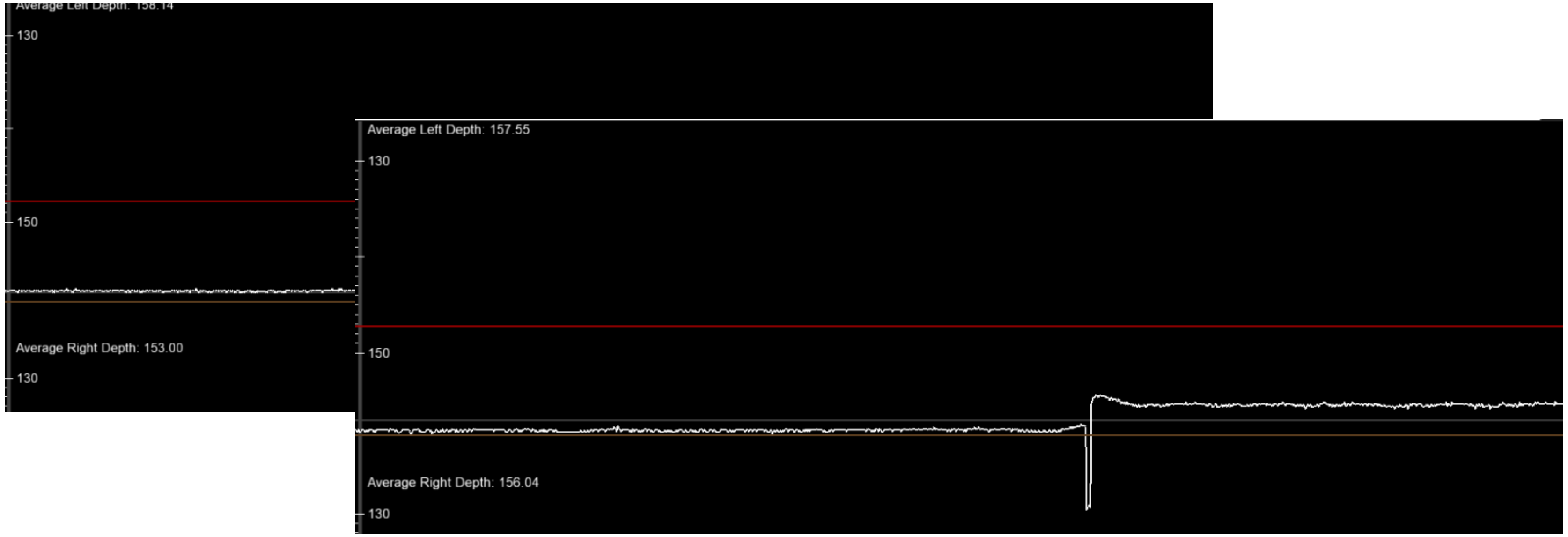

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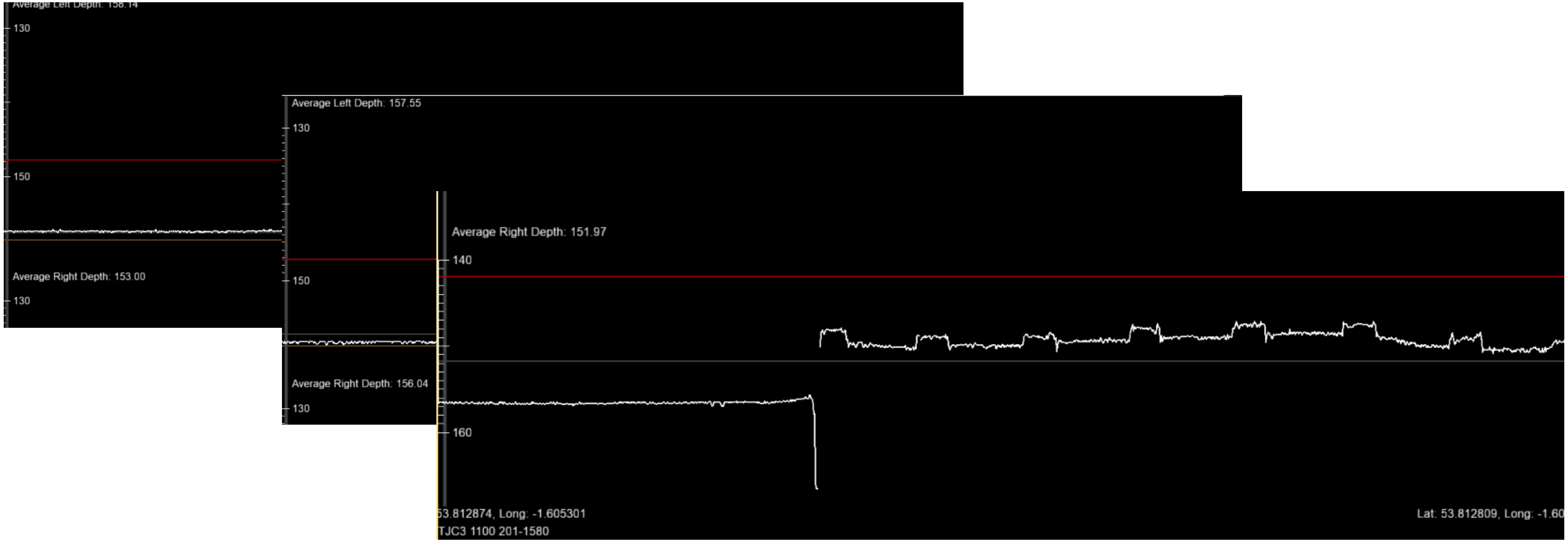

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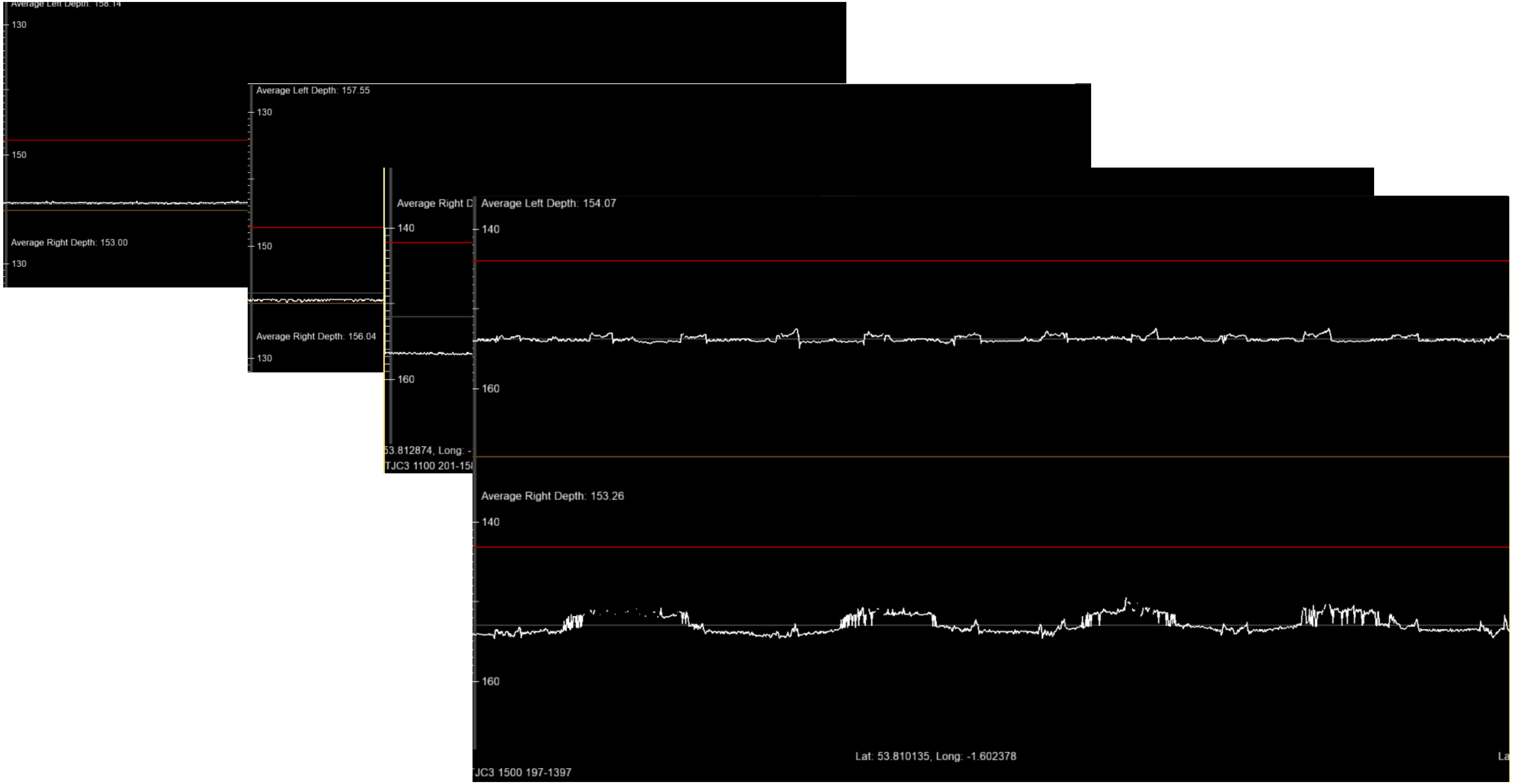
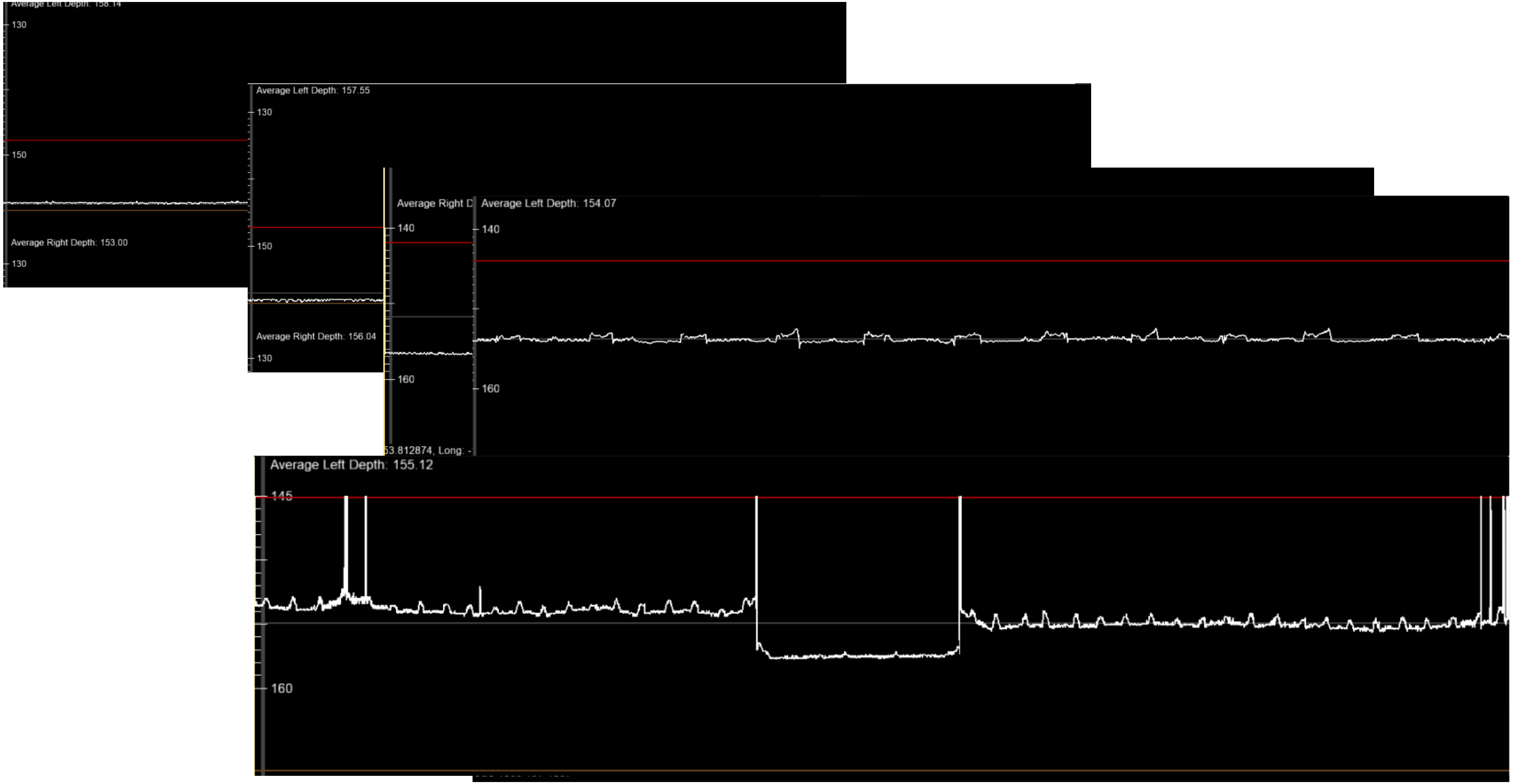
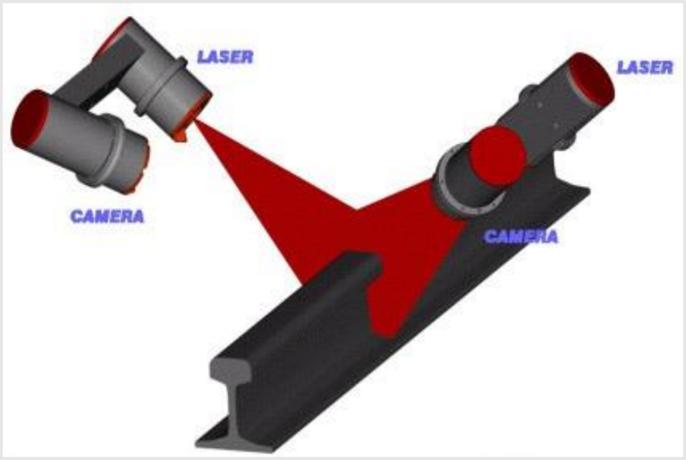
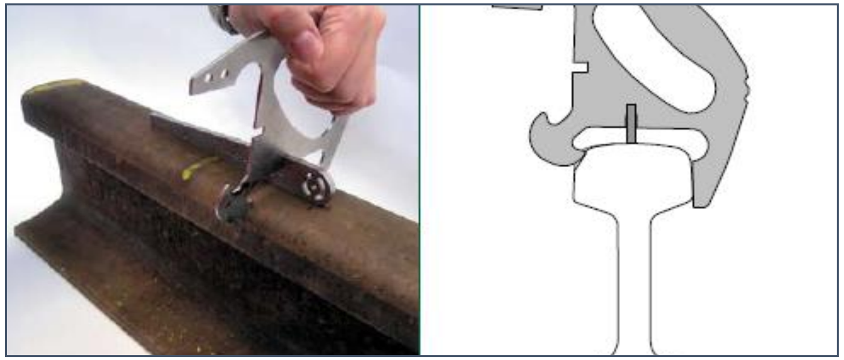


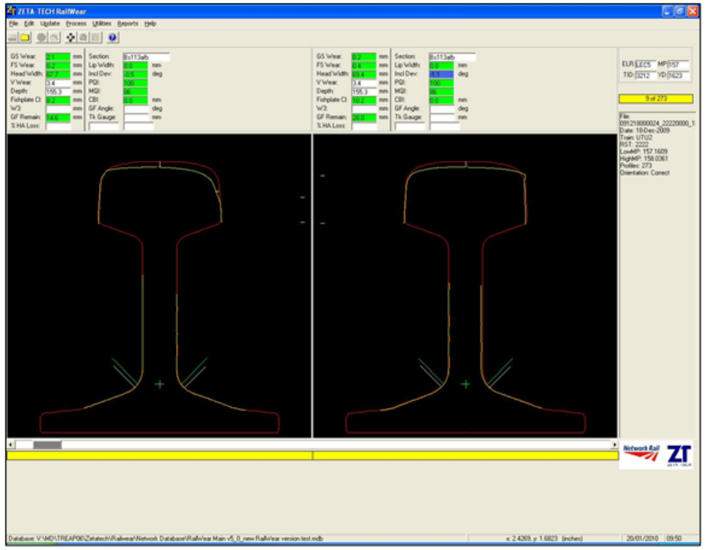
Insight - Rail Depth from Ultrasonic Test Trains

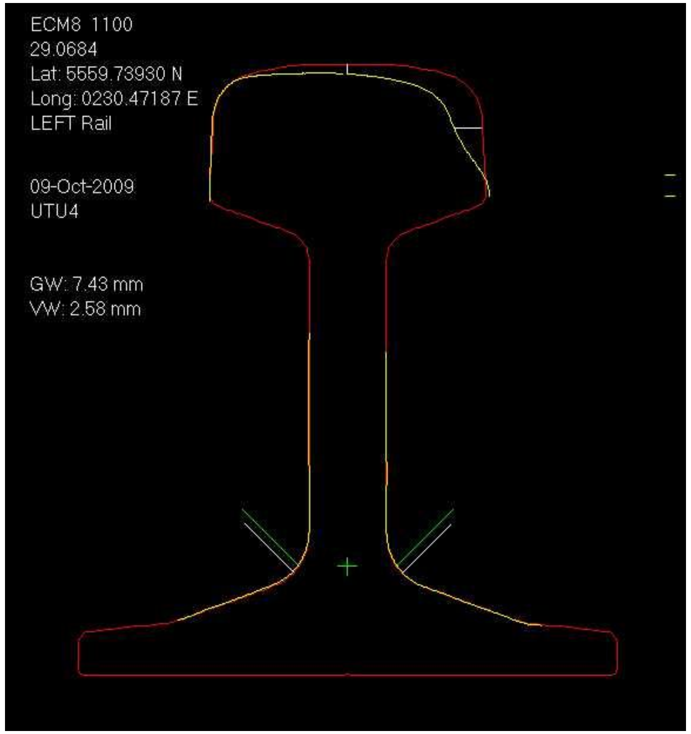


Insight – Combining Data - Rail Wear



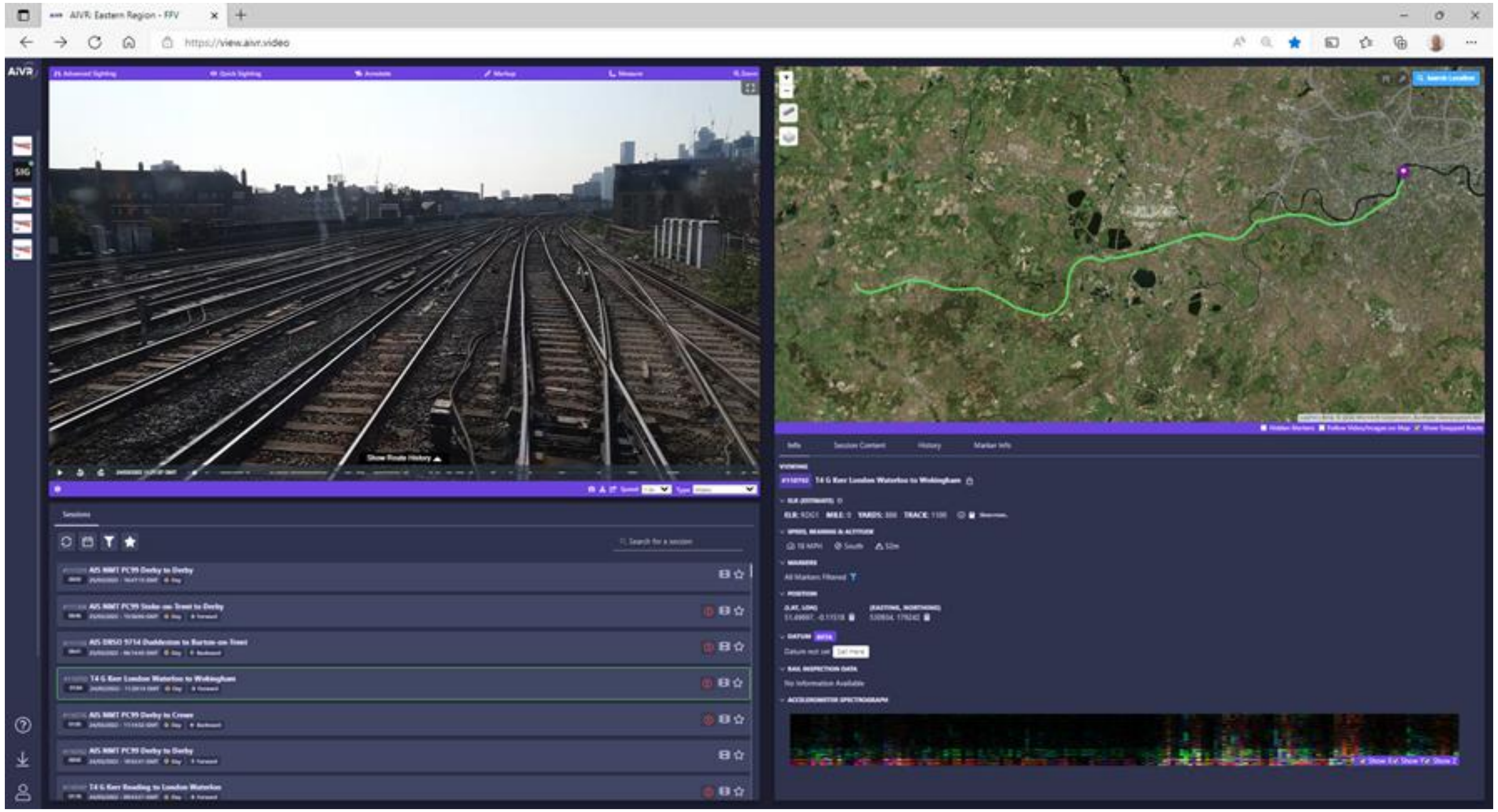




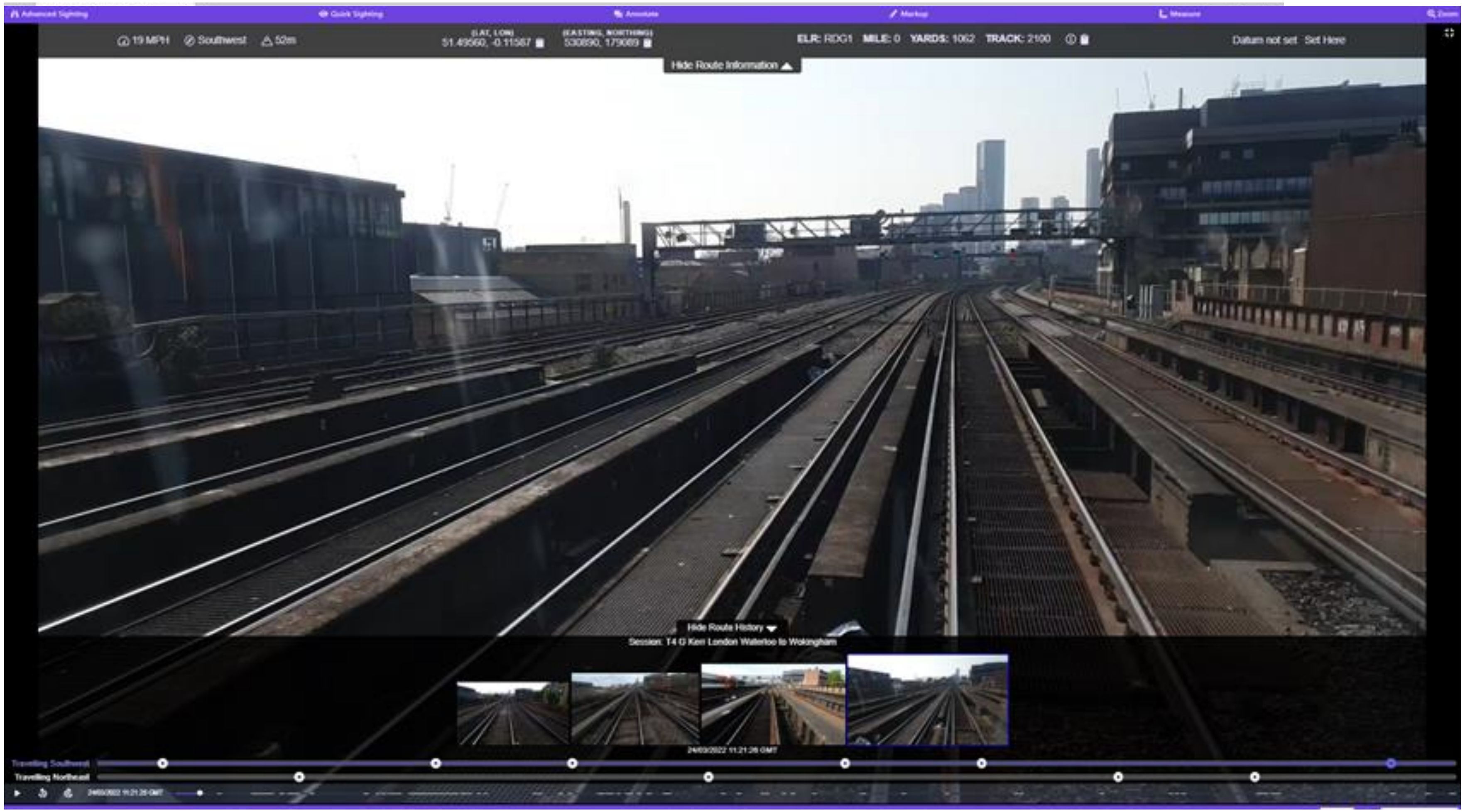


- Uses Laser Light Source and CCD cameras
- Records at track speeds
- Full profile i.e gauge plus field side
- Operational on all UTU’s
- Accurate profiles at around 2m intervals
- Matched to standard “as new” rail templates by software
- Remove/ reduce requirement for manual inspection.
- Safer
- Significant time saving for maintenance staff
- Advantages in ‘Red Zone’ areas.
- Improved rail management.

AIVR Automated Intelligent Video Review – One Big Circle



AIVR Automated Intelligent Video Review – One Big Circle



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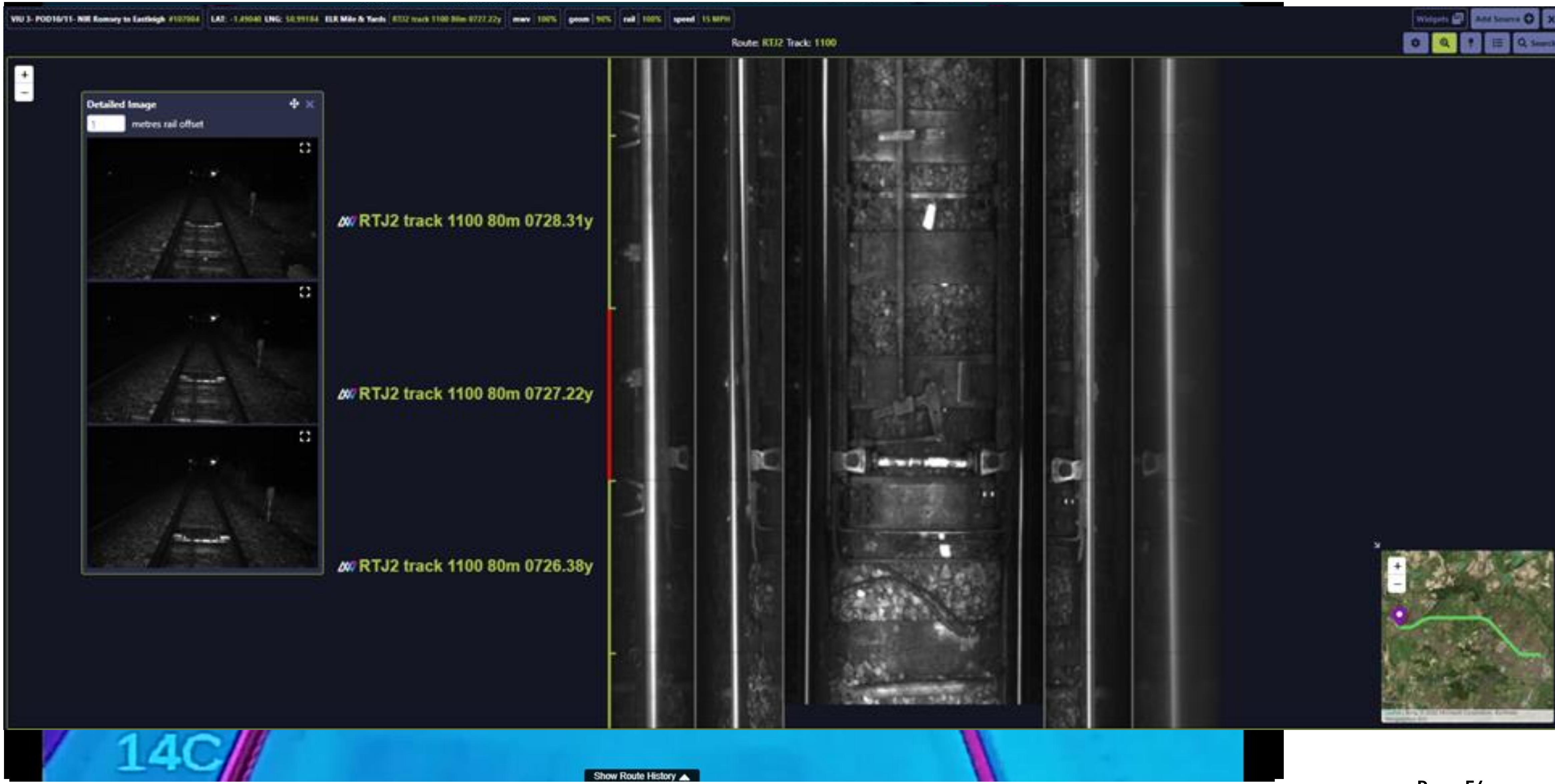

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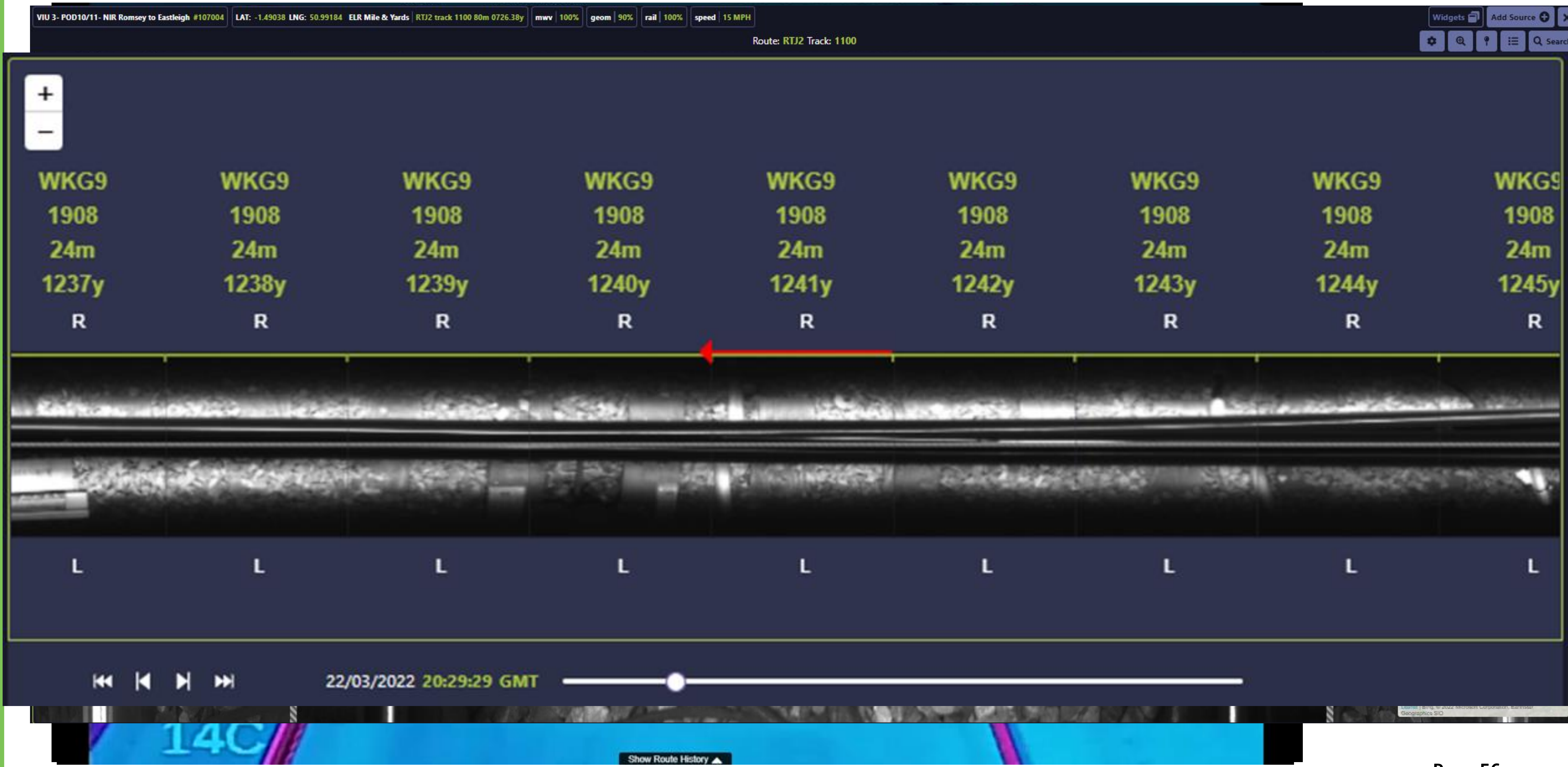

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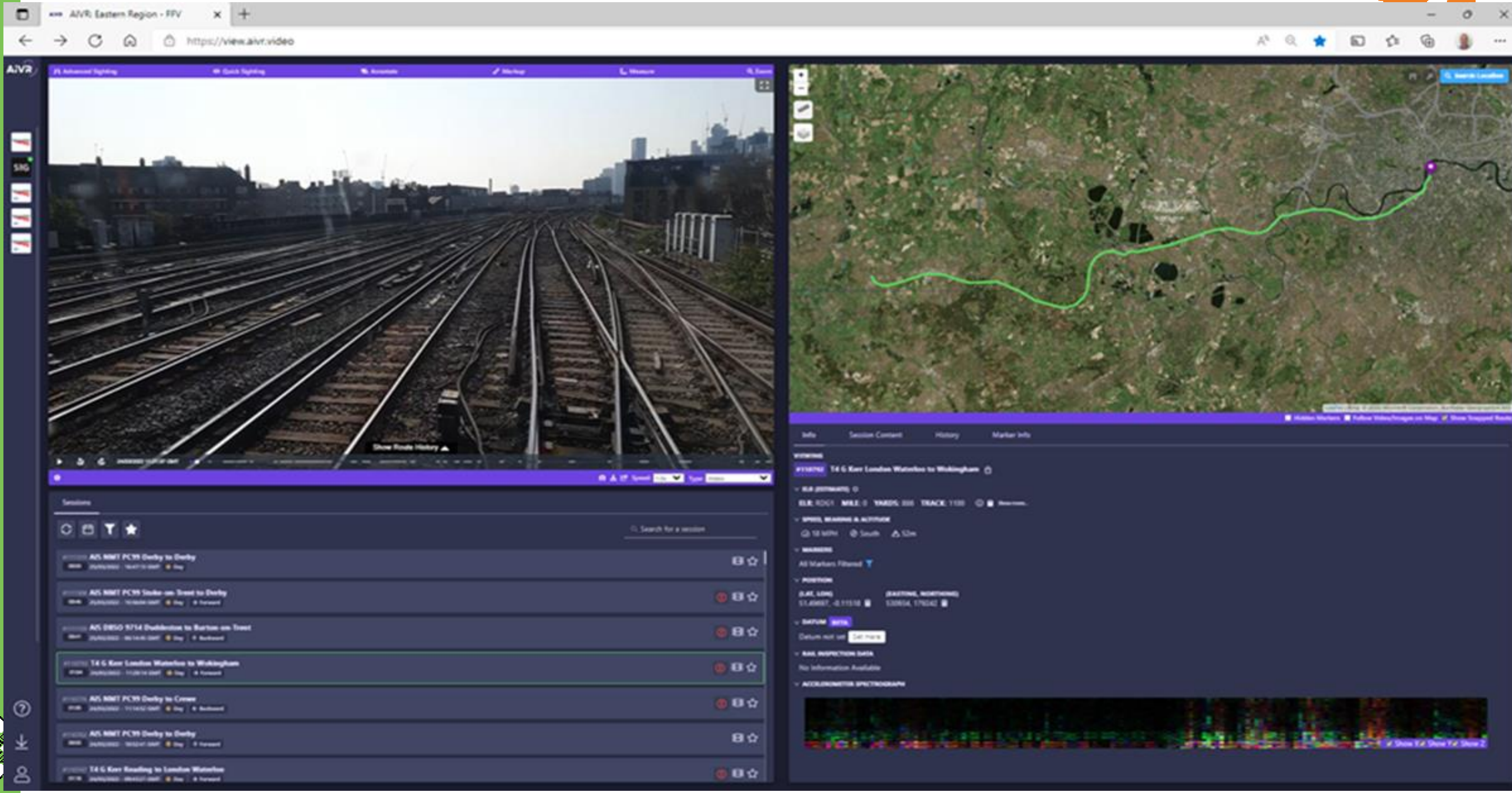

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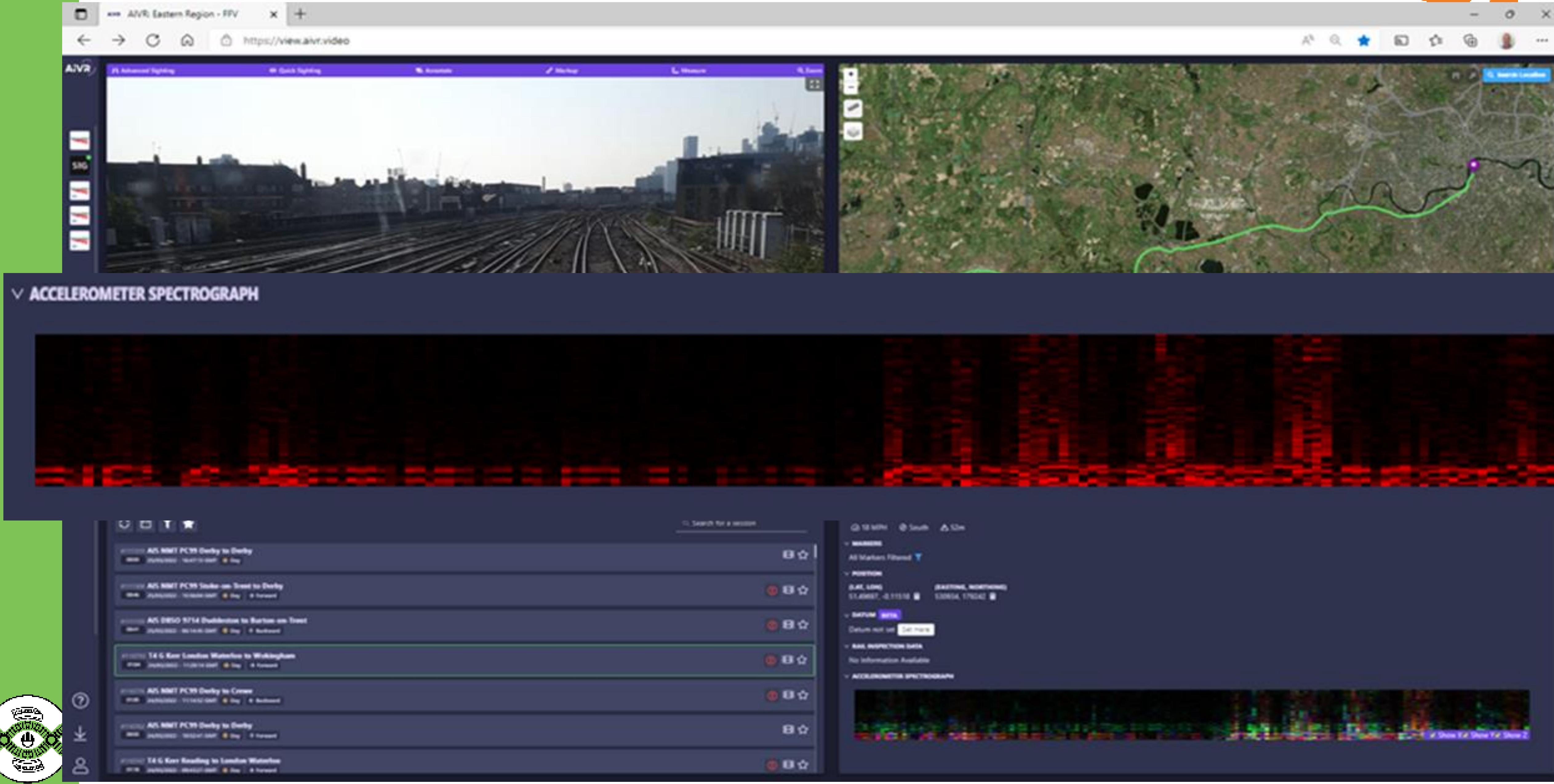


Conclusions

- Use of multiple data streams to better manage risk
- Greater use of automated and train based inspection and monitoring systems
- Insight to provide aligned data and highlight areas at increased risk
- Reduce the number of UTU suspects that require verification by linking UT and imagery, we send operators out to too many suspects where no actionable defect is present
  - Consider lower intervention dip angles for specific components
    - 10mrad for welds, 10 to 15mrad for crossing noses
    - 20mrad for glued IBJs, 20mrad for adjustment switches
- Better control of the tensile residual stress in the rail foot from manufacture so risk of foot defects and breaks are reduced
- Change the way we consider rail in service – today's geometry fault maybe tomorrow's rail defect or break
- Consider rail replacement as part of the repair of significant long term geometry faults. Reduce the risk of foot failure by changing the rail then seek an effective repair for the geometry fault
- Focus on the support conditions, stiffness and resilience of the track system – improve ways of effectively repairing and maintaining the track support structure

Future Thoughts

Track does not look after itself – neglect it at your peril. Track very rarely fails safe

All rail failure modes are in competition and the rail will 'fail' by the mechanism resulting in the shortest life. Historically low incidence of foot failures may indicate that the life of a rail has normally been limited by other failure modes

There are huge benefits in not renewing rail and components prematurely and extending the life of the asset but this can slowly change the risk profile and failure modes

Have developments in metallurgy and better management of surface damage and wear resulted in rails lasting longer increasing the risk of foot failures which are now becoming prevalent due to higher cumulative tonnages increasing fatigue damage and more significant corrosion pitting over time?

The understanding of precise crack growth rates, critical defect sizes and fatigue life is difficult where the applied strain range varies as widely as in the case of the rail, and where cycles both above and below the constant amplitude threshold occur on an ageing asset with increased wear and corrosion damage. Residual stress values are variable particularly around welds and can change significantly over time through deformation and wear under traffic

Monitoring and understanding the condition of the track particularly as it becomes older and more worn with higher cumulative tonnages becomes more critical

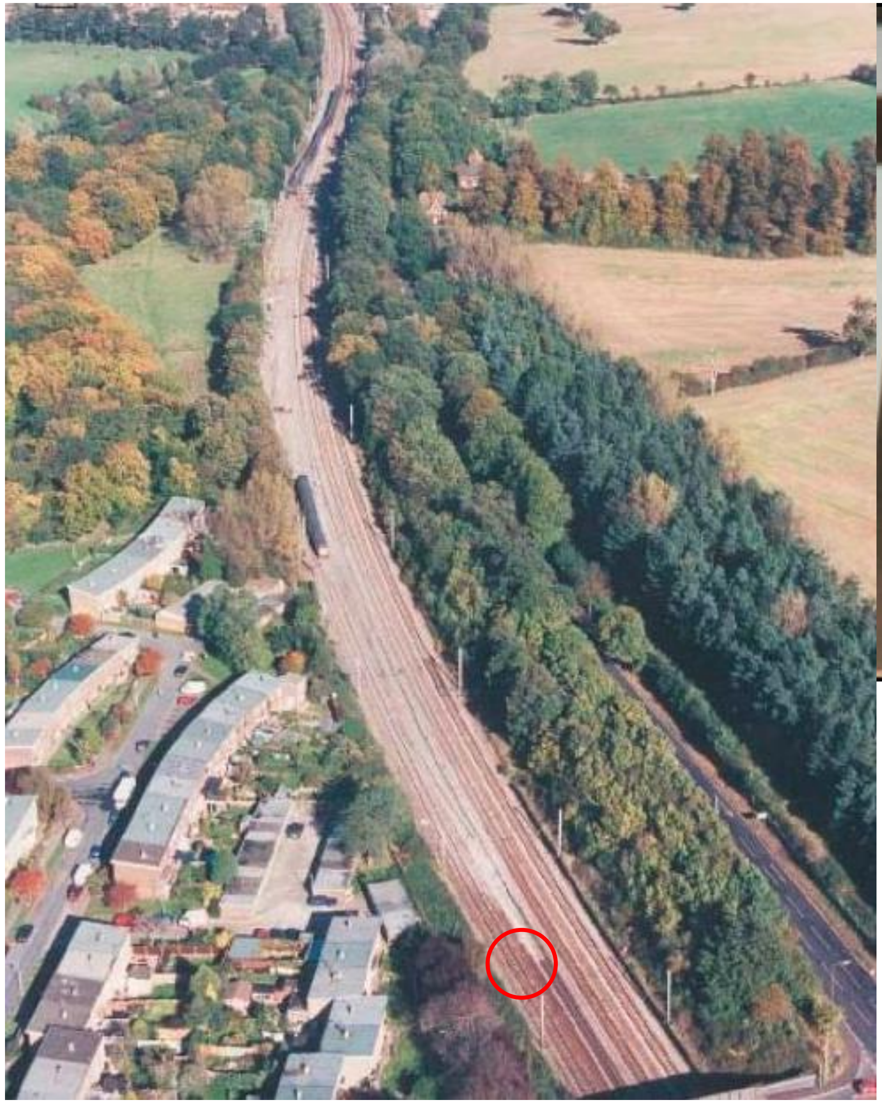
Many of the controls against broken rails are underpinned by inspections carried out effectively at the required frequency. If a defect or condition is not identified it will not be managed or controlled

Inspections need to identify defects and conditions in a timely way so that there removal can be planned before failure occurs

Why we need to be concerned?

NetworkRail

Hatfield - 12.23 Tuesday 17 October 2000



NetworkRail

everyone
home safe
every day

Many Thanks For The Invitation To Present Today

Technical
Authority

Providing technical leadership