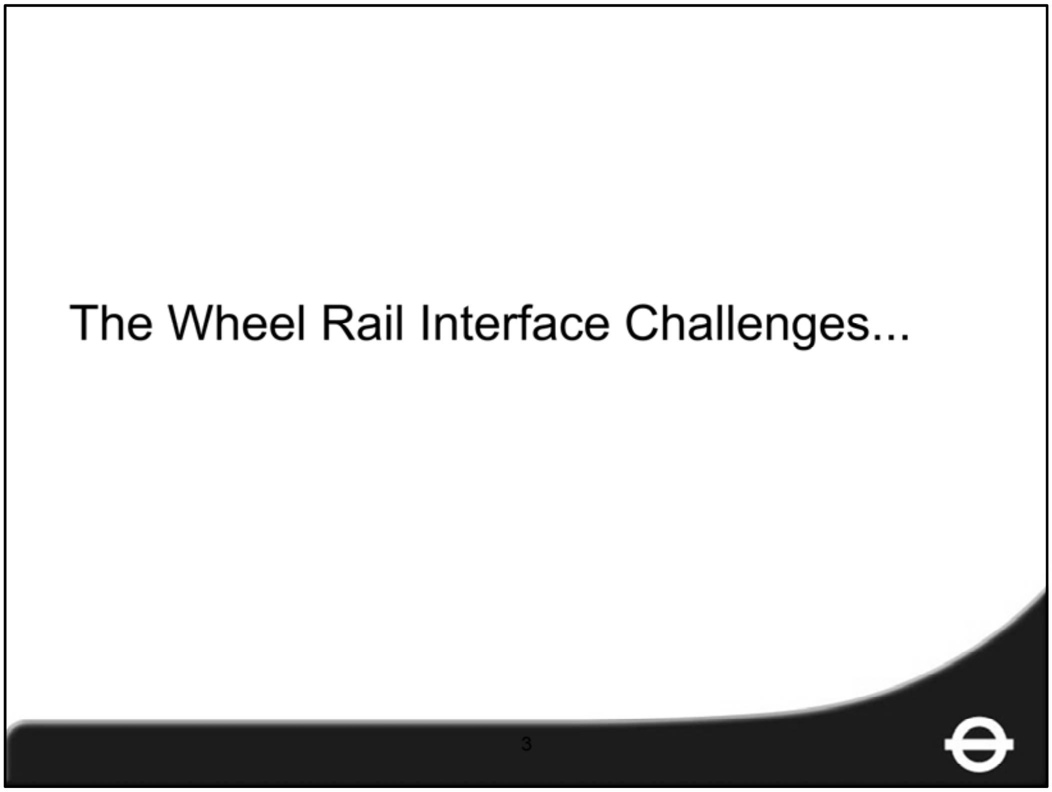
I’m Dominic Trueman, Principal Track Engineer at London Underground. I’m going to give a presentation on wheel rail interface challenges and management on London Underground.

Contents

- The challenges of effective wheel rail interface management on LUL
- Rail defect types on LUL
- Rail defect detection methods on LUL
- Examples of WRI solutions

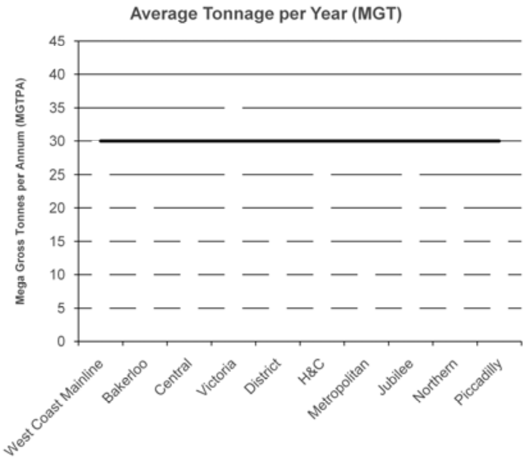
My presentation will feature the current challenges faced by LU, and the rail and wheel defects we are currently dealing with – and how we are addressing them. I must confess, this will be a bit weighted towards the rail aspect, but colleague Andy Vickerstaff who presents tomorrow will address the balance. The real aim of this is to share some of our issues, and our solutions, with you all and hopefully there will be some useful discussions after.



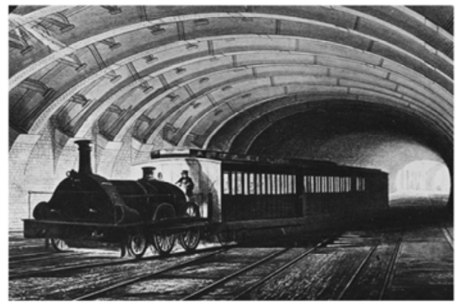
So the challenges…

High Tonnage

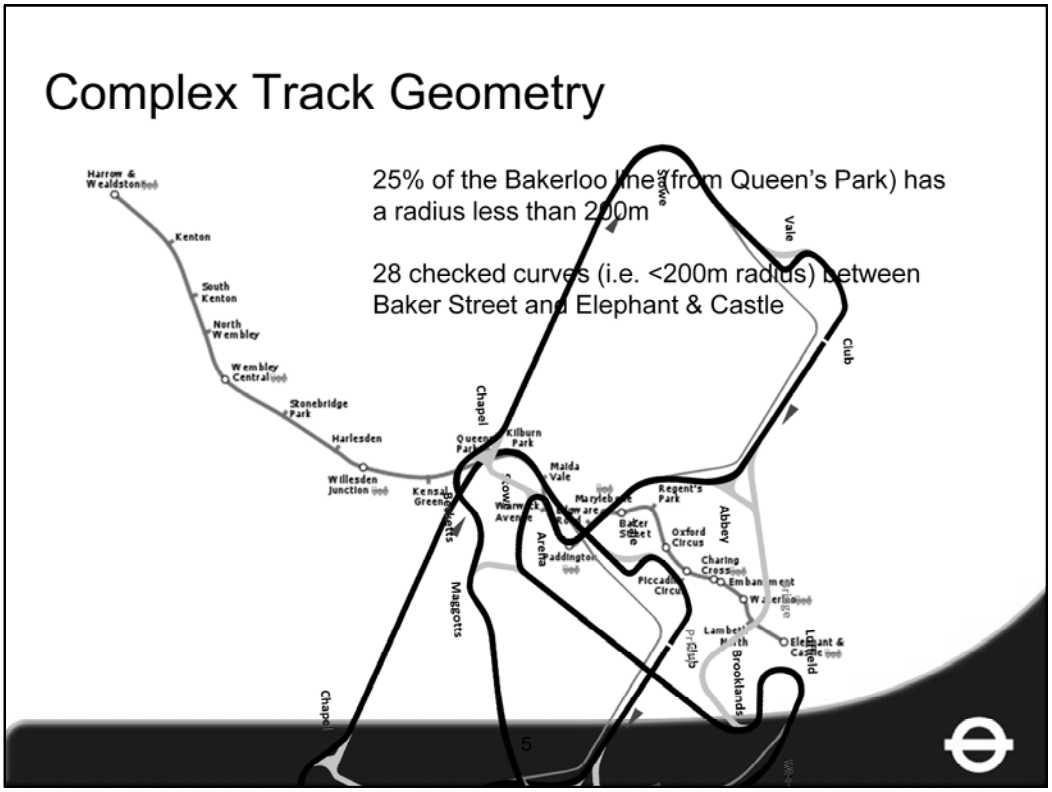
Running these tonnages:



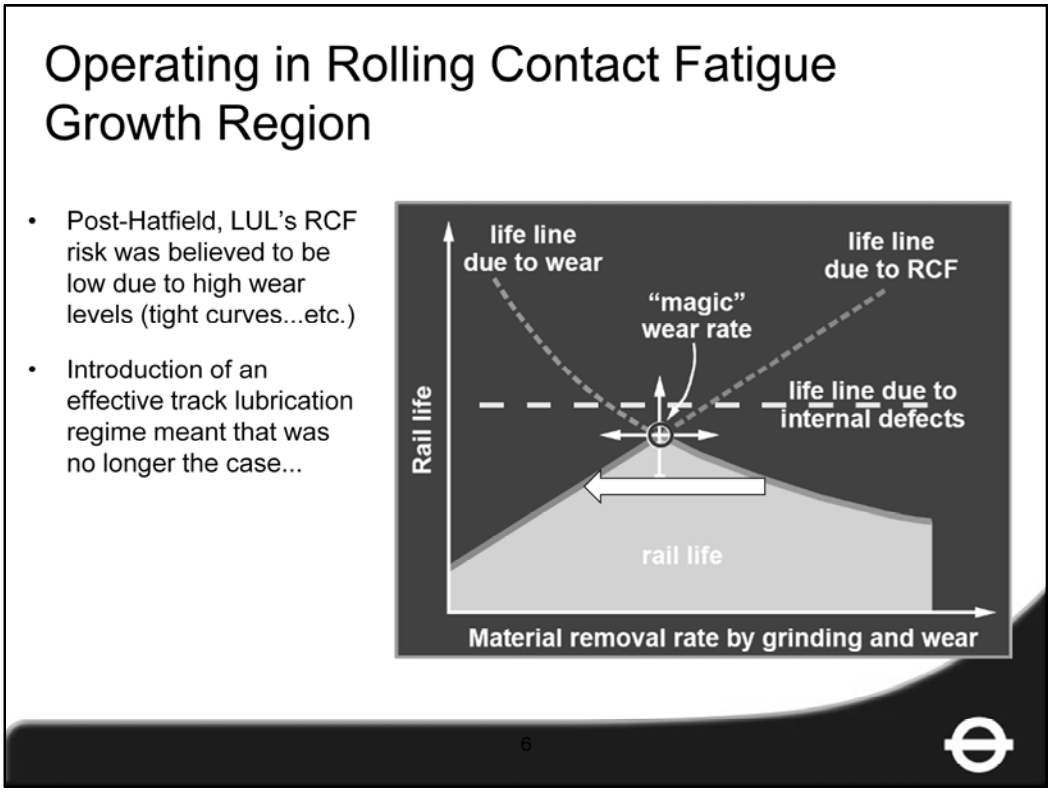
On a network this old:



What are the challenges facing London Underground? Mainly that we are running ever increasing track tonnages on aging Victorian/Edwardian infrastructure. I know that some mainline engineers think that LU is a glorified tramp service, so I will try to dispel that. On the graph I have used the WCML as a comparator – you will see that we are running high average tonnages on individual lines. This tonnage is driven by increase train weight and increased train frequency – 36tph on the Victoria line. This has significant implications considering mechanical fatigue cycles.



To add to this increasing tonnage, there is complex track geometry, which exacerbates the contact patch stresses. For example, on the Bakerloo line, 25% of the curves between Elephant & Castle and Queen's Park have a radius of 200m or less – 28 curves requiring check rails. For those of you who like Formula 1 overlayed Silverstone with the Bakerloo line – not to scale I know, but it gives you an idea of the complex track geometry.

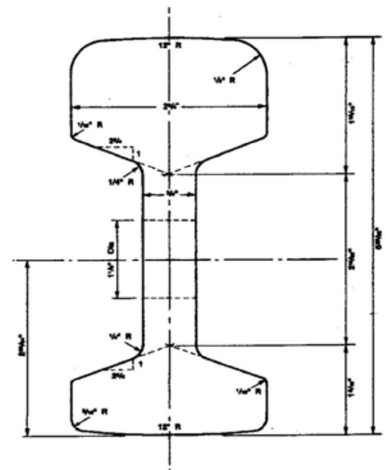


Another factor which contributes to a challenging WRI environment is the friction conditions of the rail. On the slide is a chart that demonstrates the limiting factors of rail life, wear and RCF cracking, which have an inverse correlation. It shows the maximum rail life can be achieve at the 'magic wear' rate, when the wear just wears away the RCF cracking. LU used to be on the right-hand side of the chart – rail life limited by high wear. Now that an effective lubrication regime has been introduced – the wear no longer removes the RCF cracking – as we will see later.

Rail type risk

High propensity of bullhead rail...

- 35% of the Victoria line is bullhead rail
- 87% of the rail defects have occurred there
- All the rail breaks in the last year (across LUL) have been in bullhead rail



RAIL SECTION – BS 95R.

Full description	BS95 Revised Rolled Bullhead Section
Weight	94.59 lb/yd.
Cross-sectional area	9.28 sq.in.

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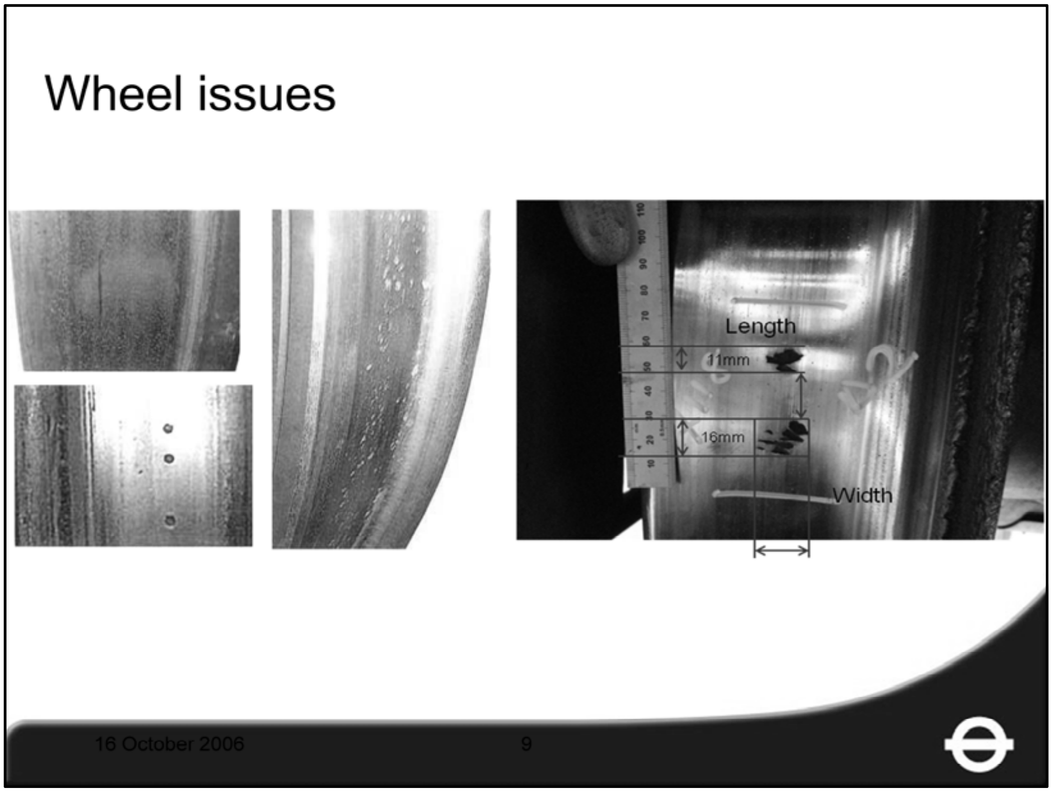
A real challenge is also the prevalence of bullhead rail. The bullhead rail section significantly more prone to rail breaks, the vast majority of rail breaks in the last 5 years have been in BH rail and all of the rail breaks in the last year have been in bullhead rail. Due to the complexity of deep tube track renewals, it is not easy to remove.

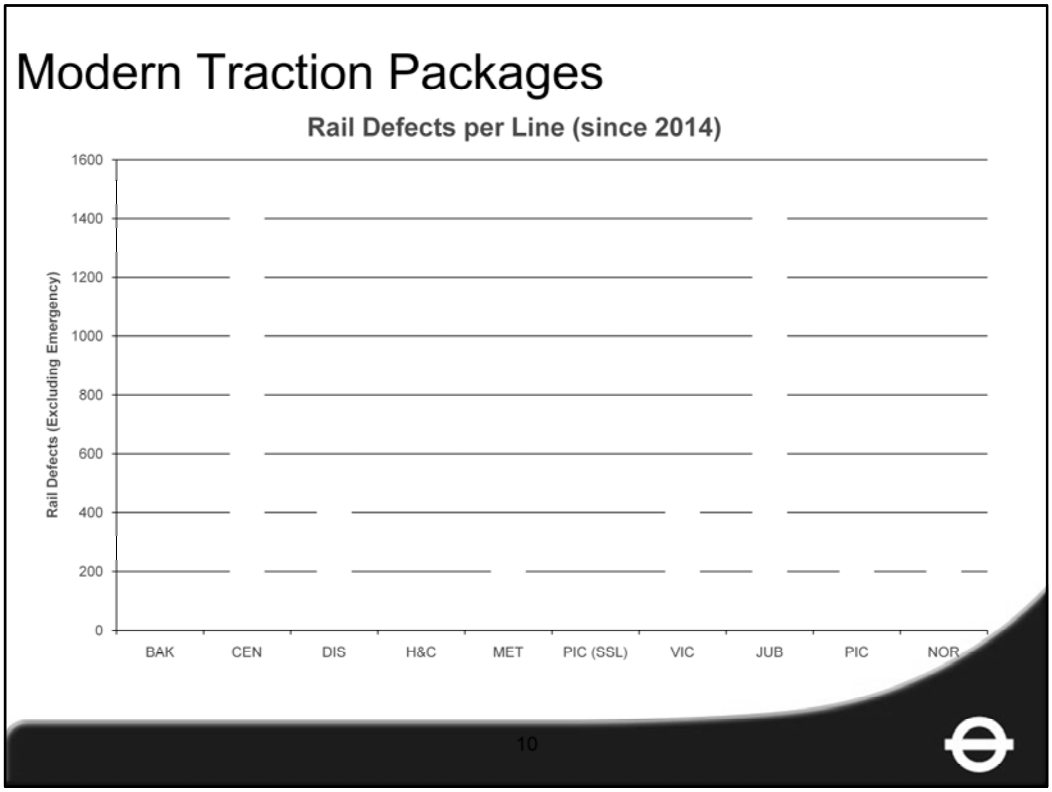
Access Issues

Limited engineering hours access to carry out grinding/milling

There is limited time to carry out rail head management –often less than 4 hours, which makes efficiency challenging.



High contact stresses isn't just a rail issue, as these photos of wheel defects show.

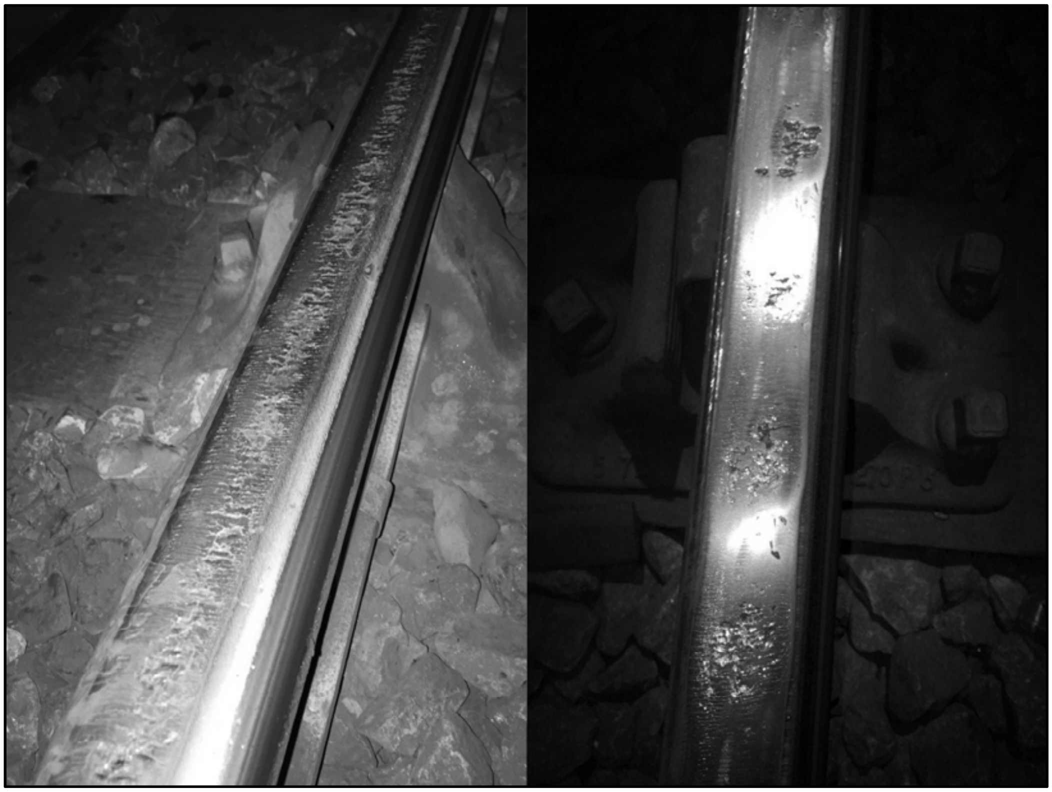


Modern DC-thyristor and AC traction packages are causing high numbers of squat-type defects. I will speak more about this defect type as will Stuart Grassie. But what is evident is lines with modern traction packages, automatic train operation and large open sections have significant numbers of these defects.

Business focus – moving people

Whilst as engineers we may this that wheel and rail profiles and maximising asset life is the most important thing – but really, moving as many people as safely possible is. But this means we must prioritise the availability of the assets, which means that the optimum engineering solutions is not followed. For example, with platforms like this, would you remove a train from service due to non compliant wheels?

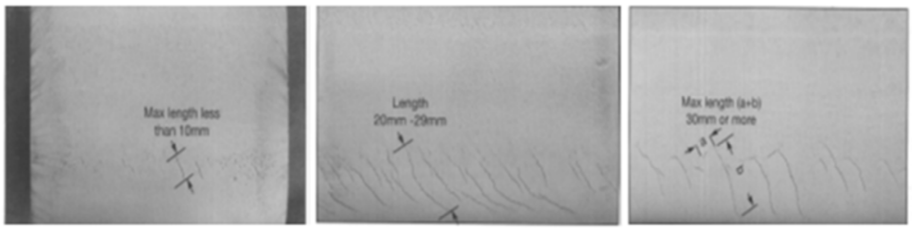
I’m now going to go through our significant defect types on LUL, discuss what are and how we are dealing with them. Rolling contact fatigue crack initiate due to the repeated plastic deformation of the rail in the contact patch region – know ratchetting. Growth is often due to hydraulic entrapment, which we tend to avoid in the deep tube – however, lubrication and frequent fatigue cycles mean it is a significant problem.



The photo of the left shows the damage that occurs when hydraulic entrapment does take place – serious breaking away of the rail head. On the left is a more recent phenomenon, possibly exacerbated by heavier rolling stock. It is RCF cracking which forms in corrugated patterns. Either due to vehicle dynamics, or significant slip/stick of the wheel, the contact stresses oscillate – causing intermittent patches of severe cracking.

Past management of RCF

- Quantity of RCF on the network unknown
- Visual inspections
- RCF severity determined by length of crack



Light | Heavy | Severe

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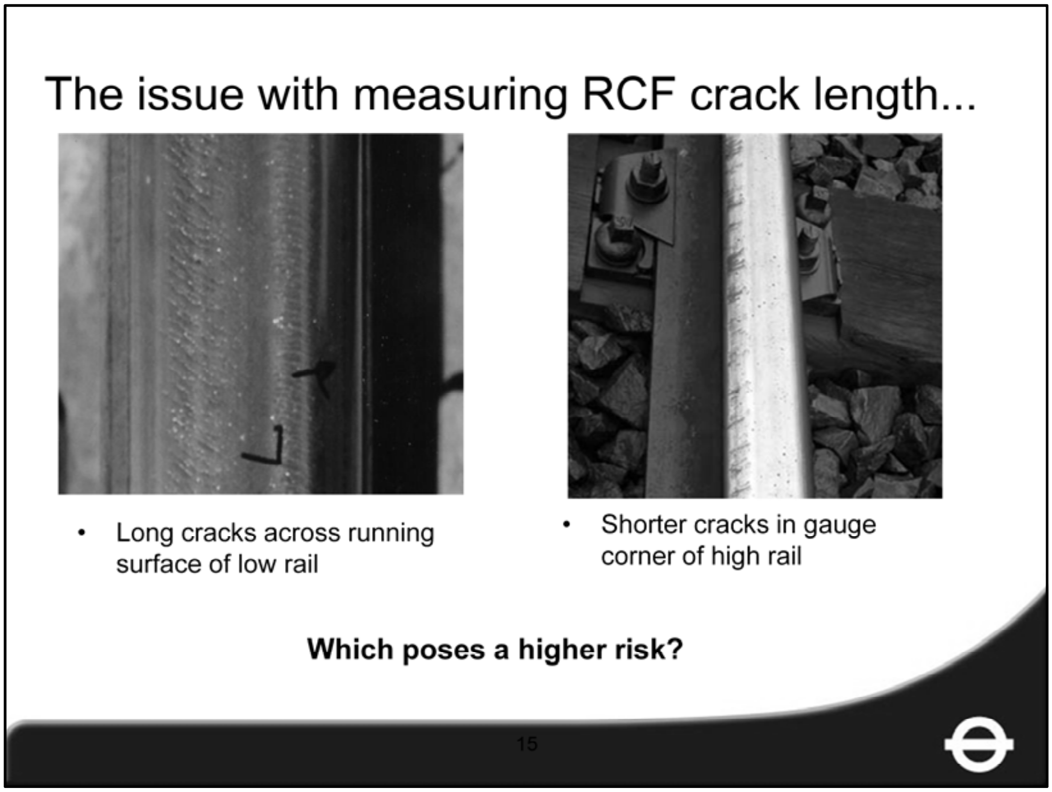
LUL has really moved forward with it's RCF management over the last few years. Previously the amount of RCF on the network was unknown and the inspection that was carried out, was visual – basing the severity on the length of crack/



However, there is an issue with using crack length. Take the example here (which isn't from LUL – apologies) – we have long, fishscaling (as I call them) cracks, which would be classified as severe. On the right there is short gauge corner cracks which, based on length would be light/moderate – which poses most risk?

MRX Technologies Rail Surface Crack Measurement Operator Propelled Unit (RSCM OPU)

- Rail Surface Crack Measurement Operator Propelled Unit
- Magnetises the rail
- Determines artifact **depth**, track position and position on the rail head
- Records deepest artefact up to 7mm in 1m

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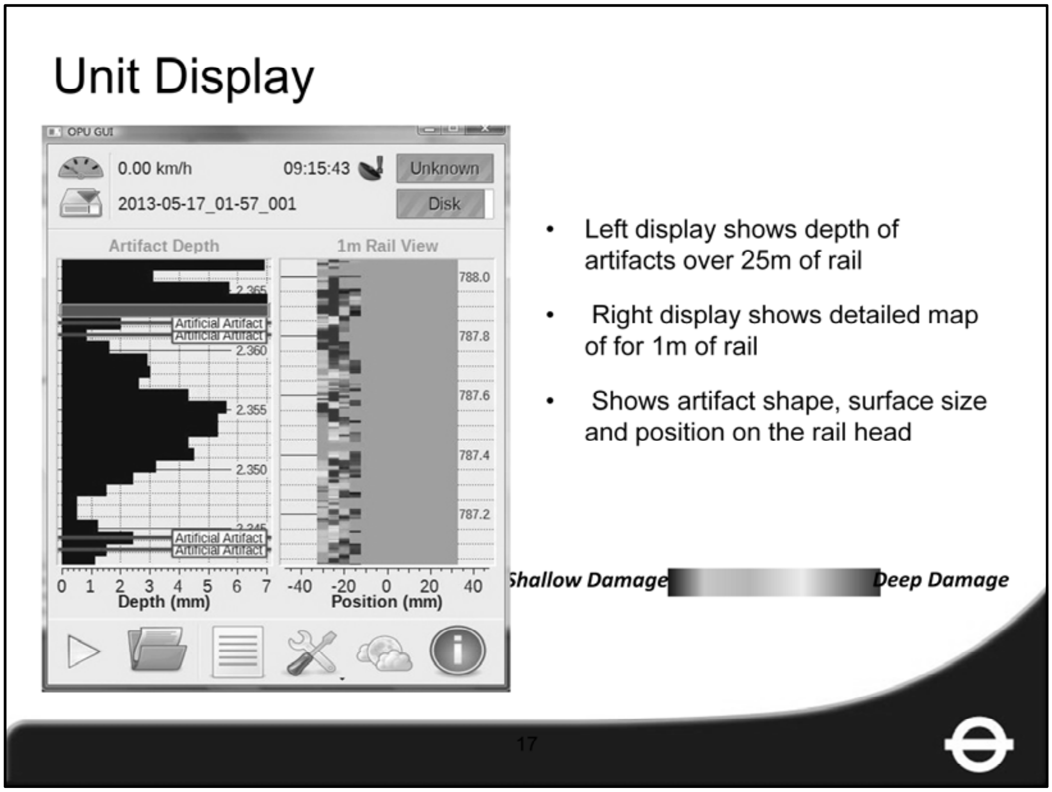
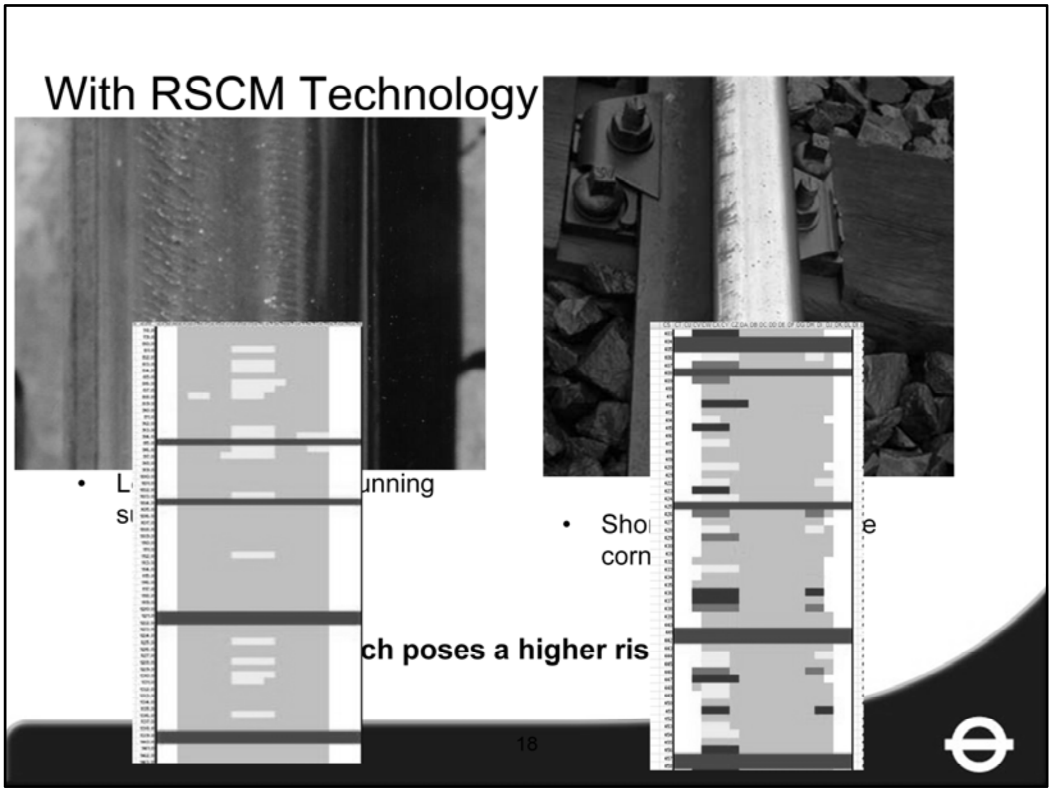
So we introduced a device from MRX Technologies, which utilizes magnetic flux leakage to assess the depth of RCF cracking. It provides the deepest crack in a metre section of rail – up to a depth of 7mm. Unlike eddy current systems I have seen, it measure depth into the rail head – which is the key.

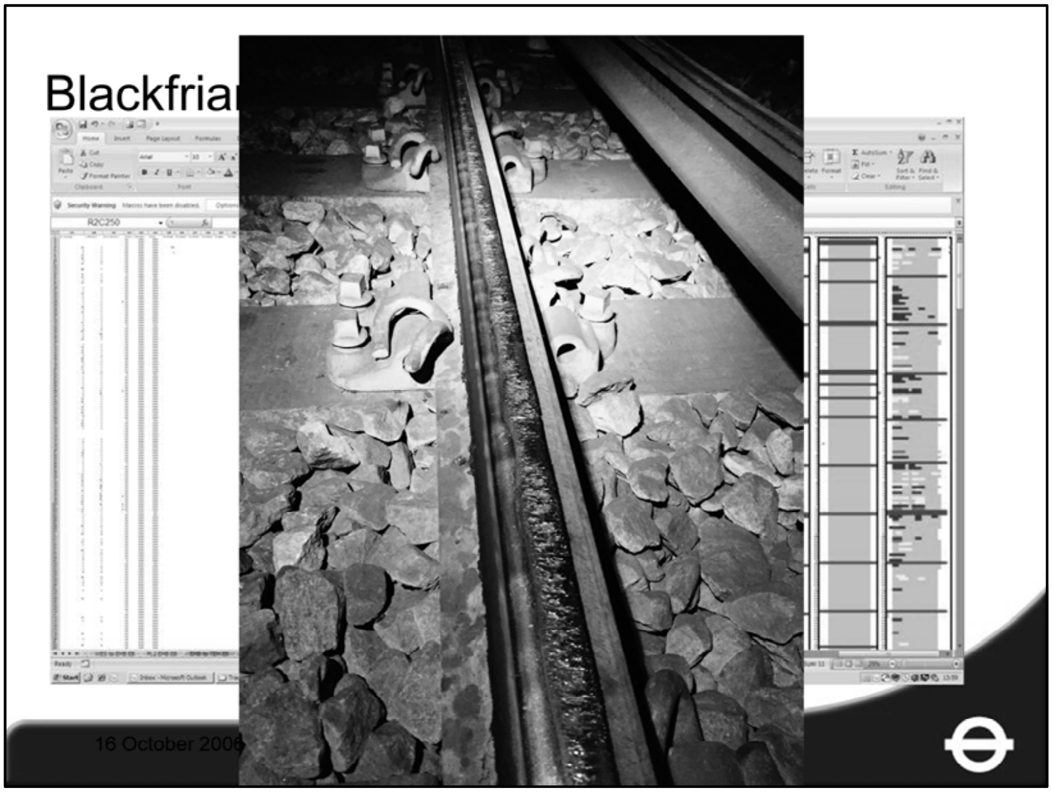


This is the display which shows, on left hand side, the depth of RCF cracking per metre. On the right hand side, it shows the location of the RCF cracking in a certain metre. This example shows the cracking is up to 7mm in the gauge corner.

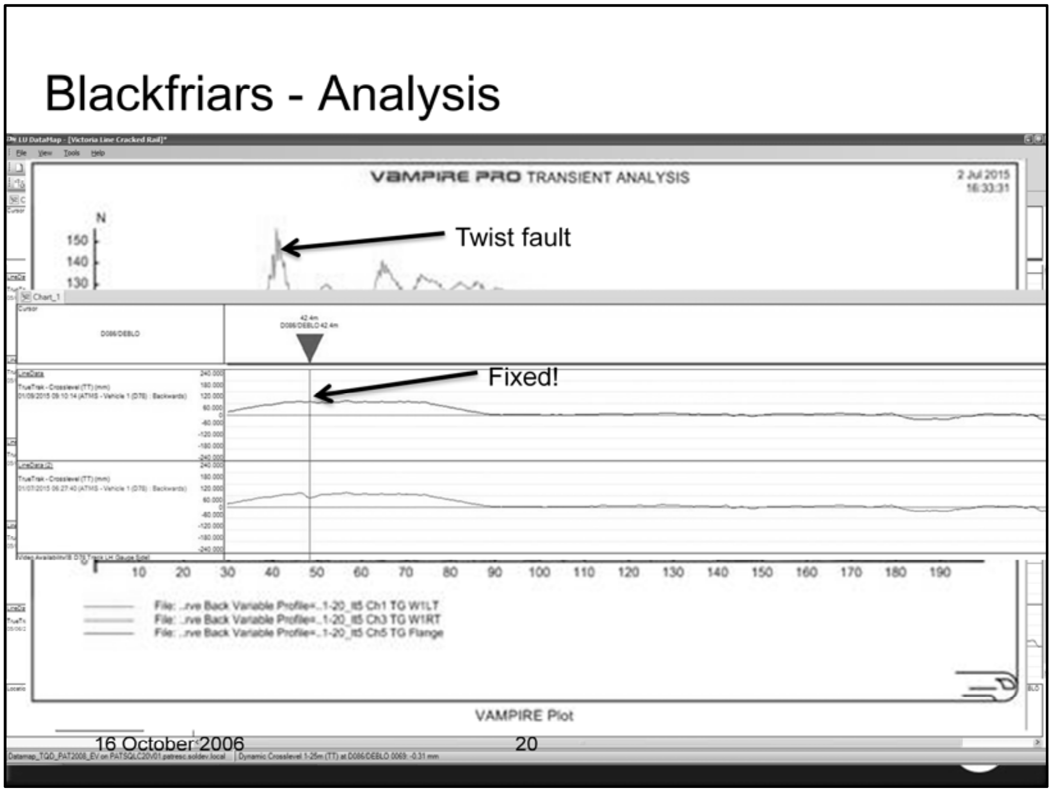


If we go back to the previous example…

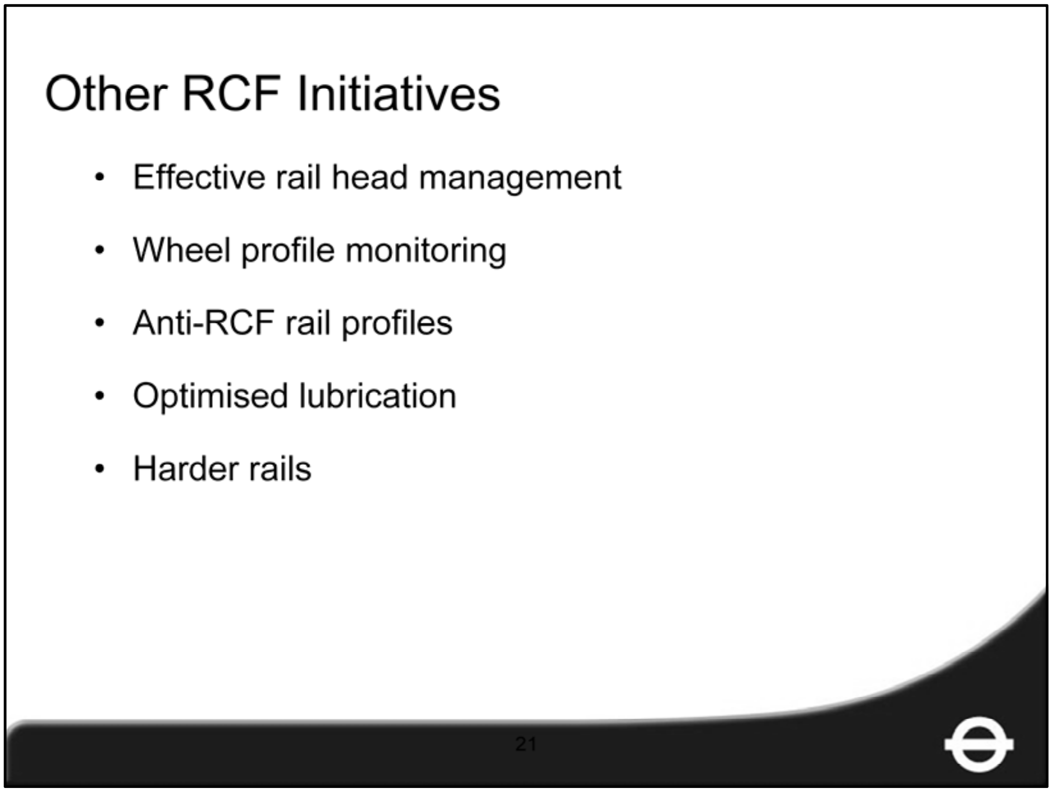
This information allows us to make risk-based, predictive decision of our rail head management. Rerails and grinding are now being driven my appropriate condition data.



Here's an example of the use of this data. It picked up some severe gauge corner and ToR cracking between Mansion House and Blackfriars. A site visit showed the severity of the cracking. It's worth noting this was the type of corrugated RCF cracking.

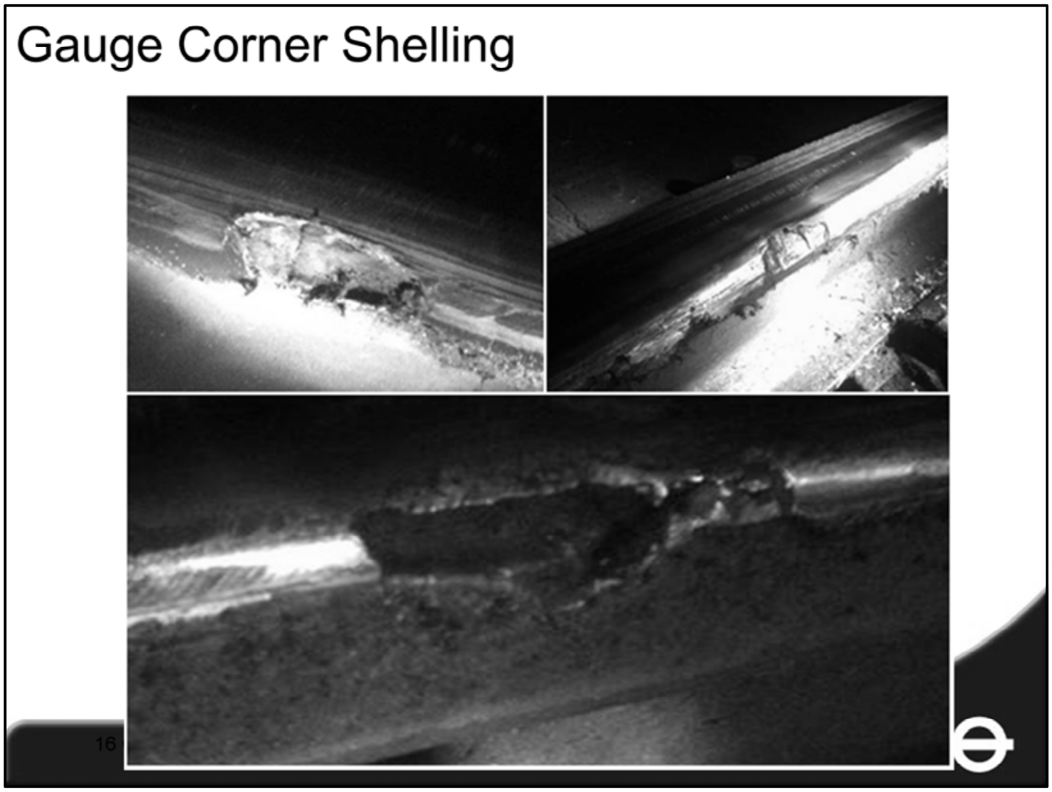


Utilising data from our Automated Track Measurement System – essentially a service train with TRV equipment – we identified a twist fault on the high rail. We modelled this track geometry in the vehicle modelling program Vampire, which identified oscillating high rail stresses, correlating to where the RCF was. With this information we were able to instruct rectification work and we are now monitoring the site for (hopefully) reduced RCF cracking.

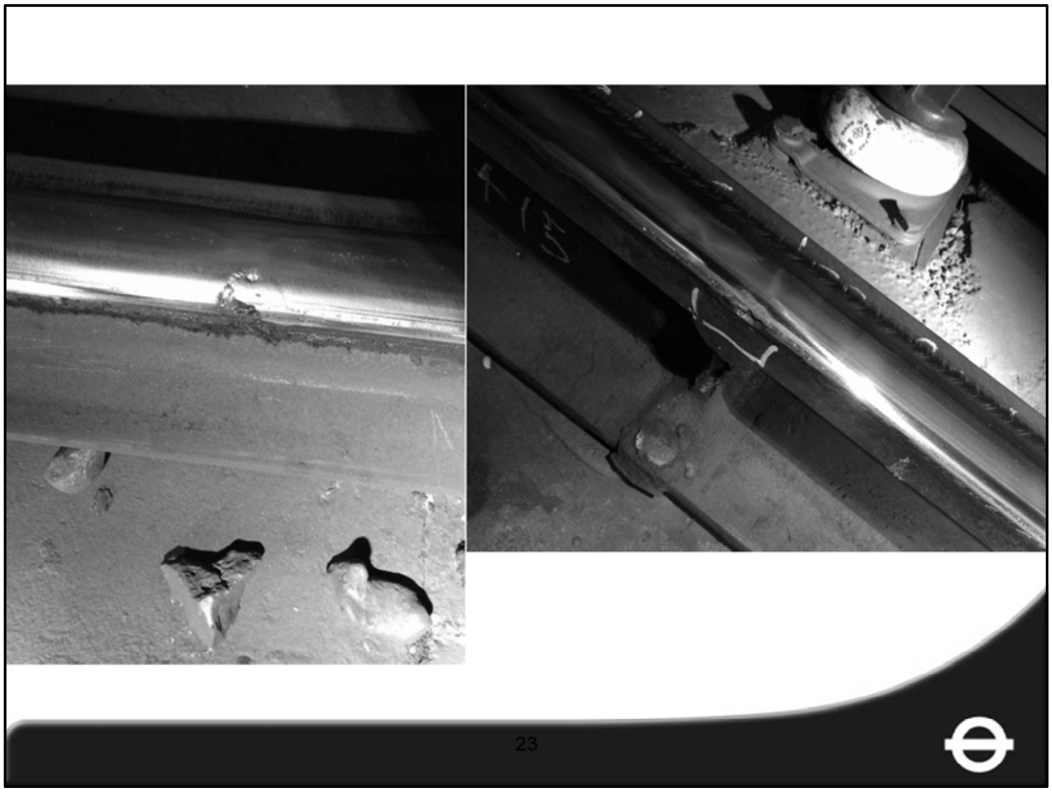


As I have mentioned, this data allows us to monitor our rail condition, but we are also monitoring our wheel profiles to ensure that the system is managed. As my colleague Andy will mention, it isn’t a perfect situation yet – but we are moving in the write direction.

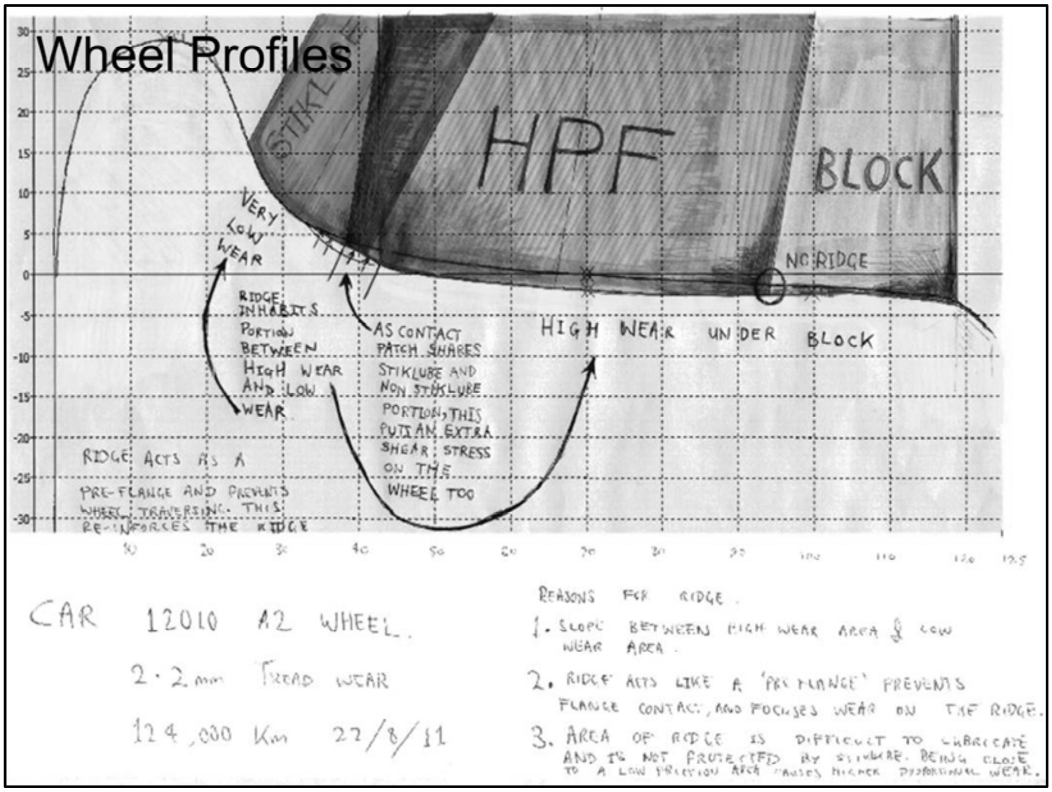
We are also implementing anti RCF rail profiles (on the District line) as well as utilizing Vampire to optimize our lubrication location and output.



Gauge corner shelling is a recent problem, where large chunks of rail break away from the rail head. The are formed when a transverse defect grows into the head, before growing horizontally before breaking out. We were suffering a significant number on the Victoria line. Often in transitions too.

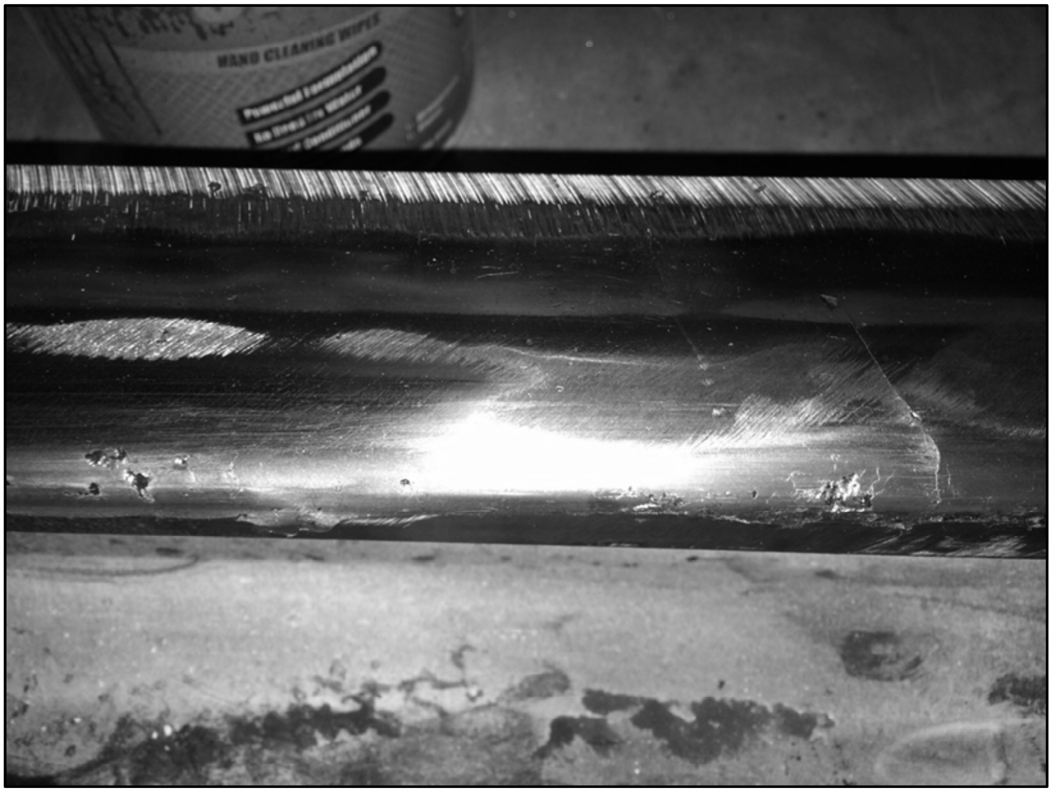


It is worth noting that these formed in areas of both RCF and no RCF.



So the wheel profiles of the Victoria line trains, and a trend was noticed. The wheel profiles of the trailer car wheels had a double root flange – a lump in the corner between the flange and tread. Why was this, and why only in the trailer cars? What we did know is that this notch was causing significant gauge corner stress – and this supports why they occur in transition – when this corner hits the gauge corner with most force.

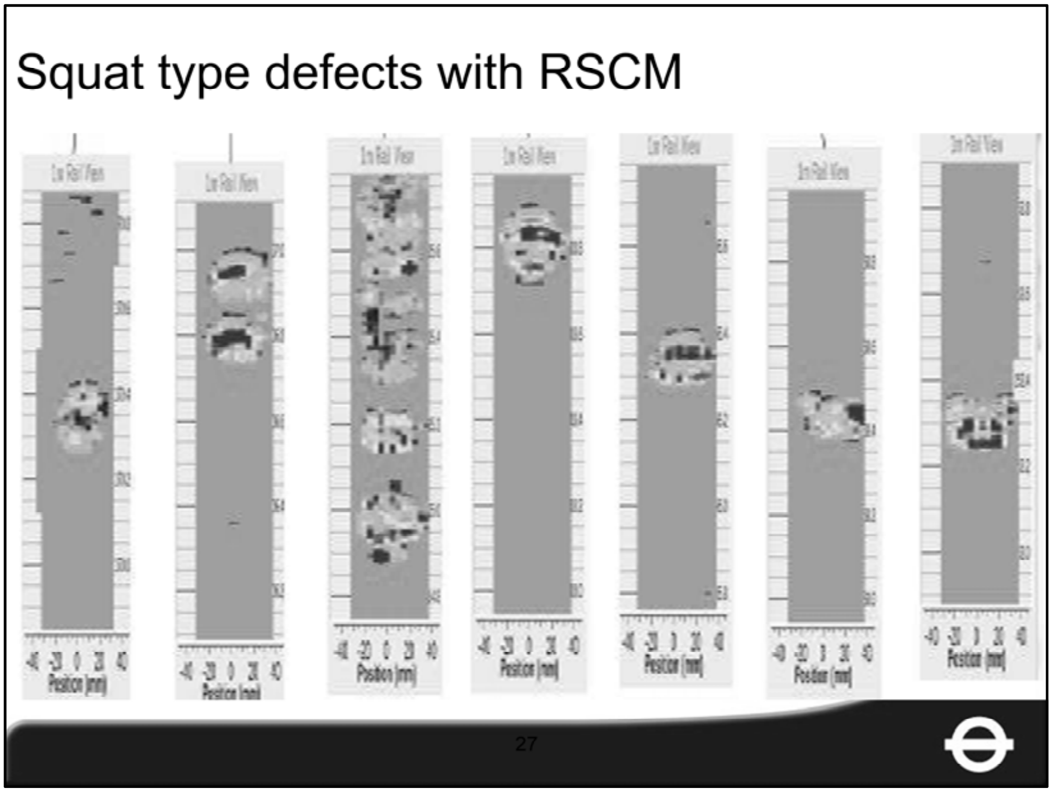
It came down to the application of thread breaking and the overlap of the stiklube and HPF sticks on the wheels. This has led to the removal of the lubrication and HPF sticks on the trailer car as well as wheel turning. As a result, we are seeing improved wheel profiles and reduced defect numbers.



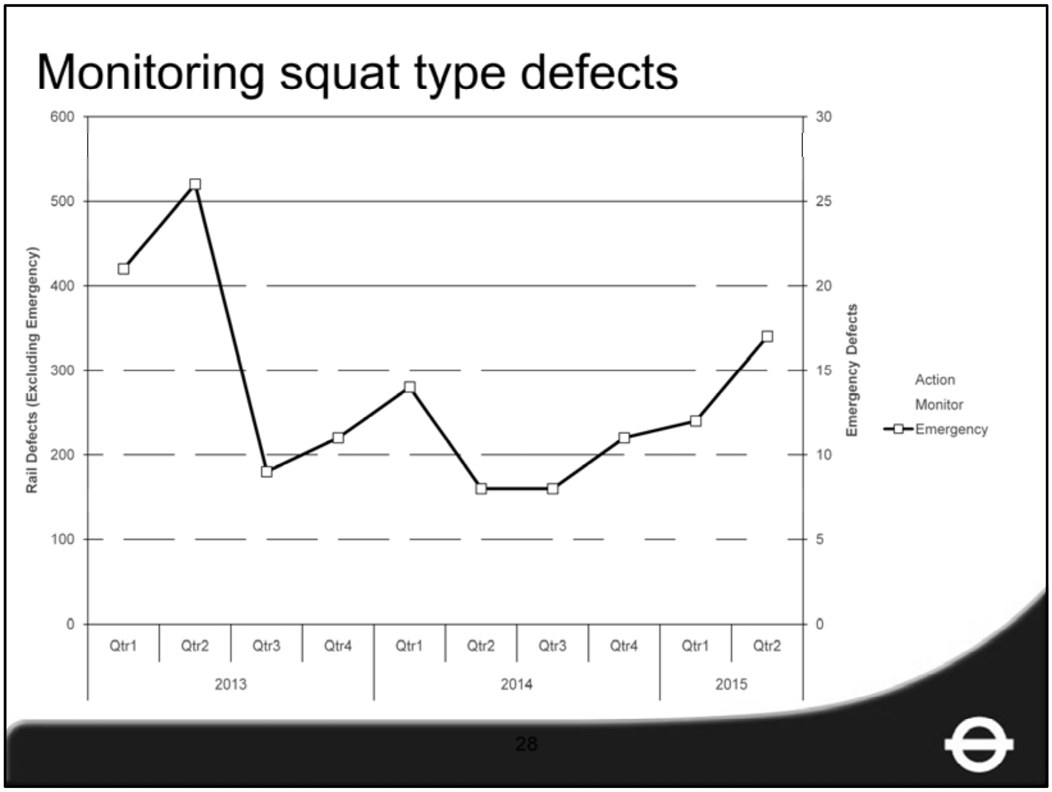
However, sometimes the cracks don't break out and go through the head – this is why wheel profile management is so key.

Squat Type Defects

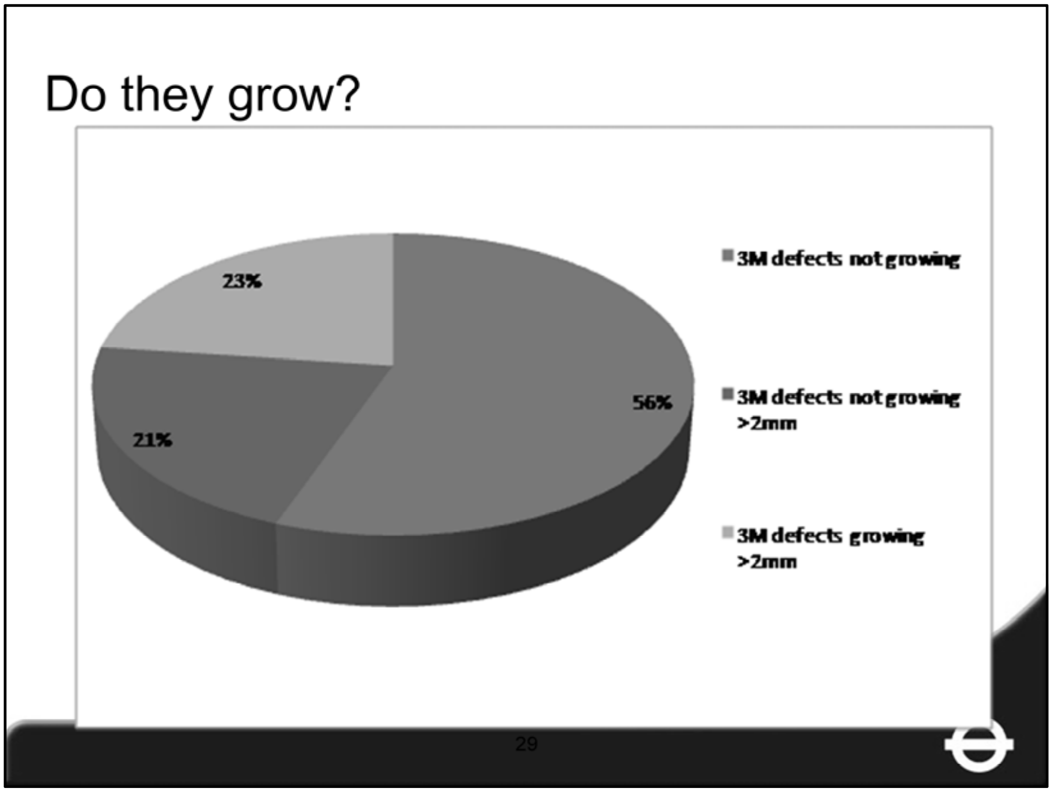
As I mentioned earlier we are getting significant numbers of squat type defects due to modern traction packages. The modern WSP causing the wheels to microslip under acceleration which creates thermal and mechanical stresses which lead a subsurface layer of martensite forming, from this, cracks form. I'm sure Stuart will go through this in more detail (and accuracy than me!). Per km we suffer more than NR do, possible due to ATO.



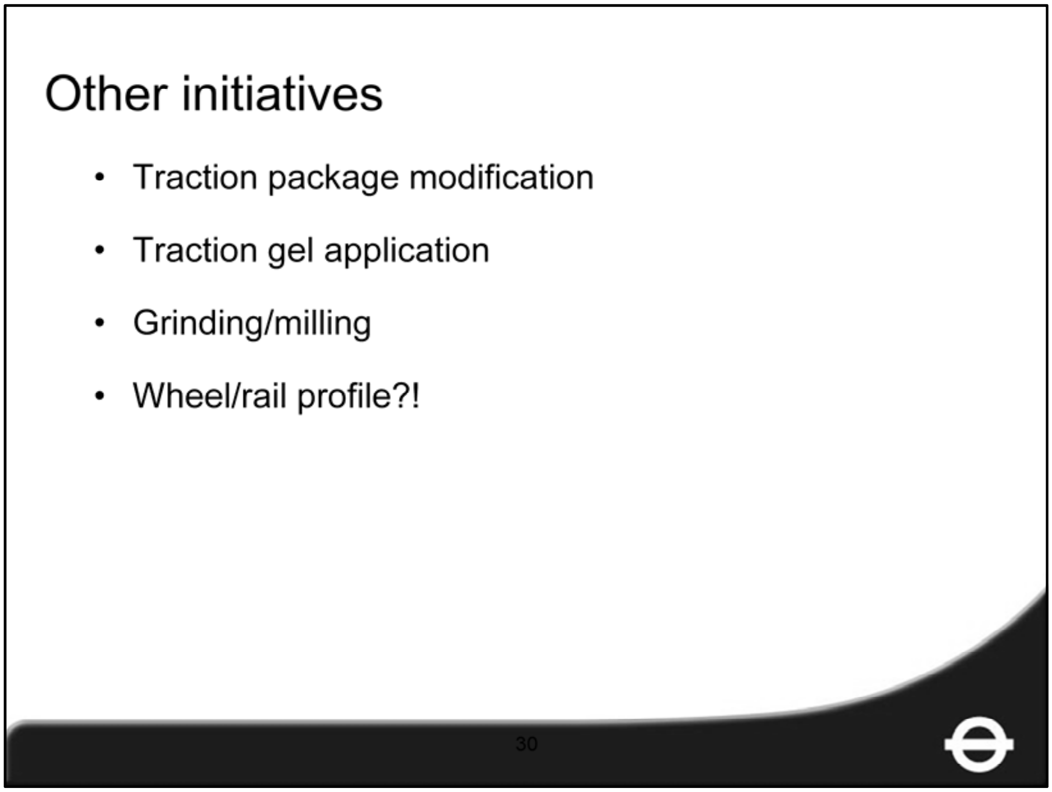
This is a slide just for interest before I go on. It is the magnetic flux leakage images of the squats – you can see in most, the two cracks which form from the squat – the red marks. This was fascinating to see for someone who likes his rail defects. Also I think the one on the right looks I bit like a smiling bear.



What can we do with these squats? Traction package changes are difficult and expensive (although we are trying) and so we needed a rail management solution. So we started to monitor them rather than remove them. The chart shows the increase in defects which we are monitoring since mid 2014.



And what did we find out? This data is from pre-2014 which supported a wider roll out. They are referred to as 3M defect as that is the code applied for a monitor defect. As you can see, 56% didn't grow and 21% showed growth less than 2mm between tests – considering the manual nature of U5 hand probe testing, they were considered not to be growing. Only 23% were growing and non grew to an emergency state between tests. More recent analysis has shown that a smaller percentage are growing.

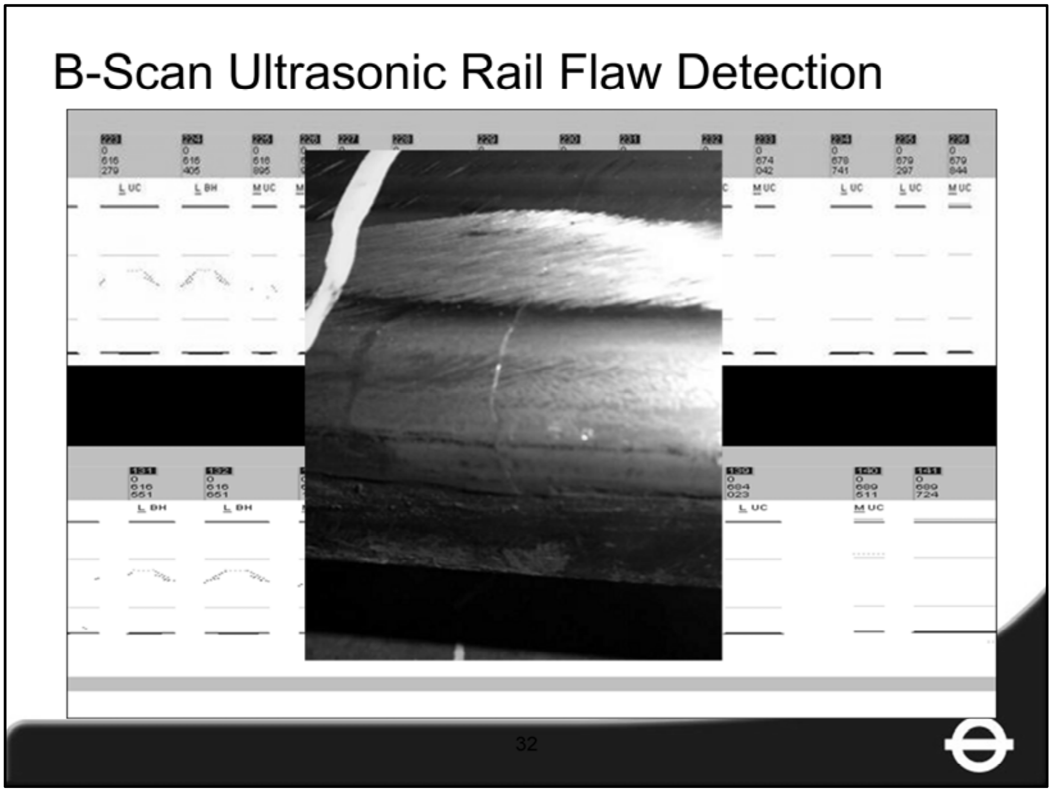


What else can we do to prevent squat type defects? Modify the traction package…We are working with Bombardier and PPC to see if we can adjust the slip control of our S-stock trains. It’s early days so watch this space. We have also tried applying traction gel – normally used for leaf fall, at squat prone areas, to reduce the slipping – unfortunately this has had mixed results, but as it’s my brainchild I’m hoping for some more conclusive data after winter.

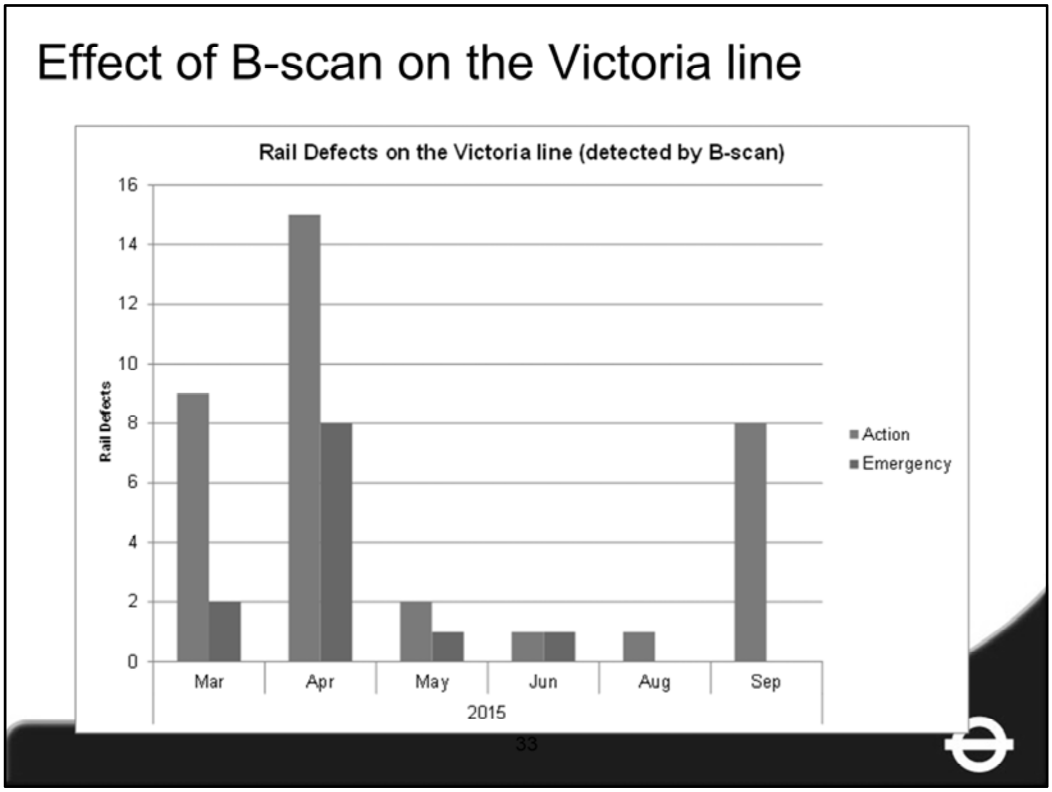
Also, there is evidence that grinding and milling reduces the rate of squat type defect initiation, and I believe that more work can be done to prevent squats through rail and wheel profile work…

B-Scan Ultrasonic Rail Flaw Detection

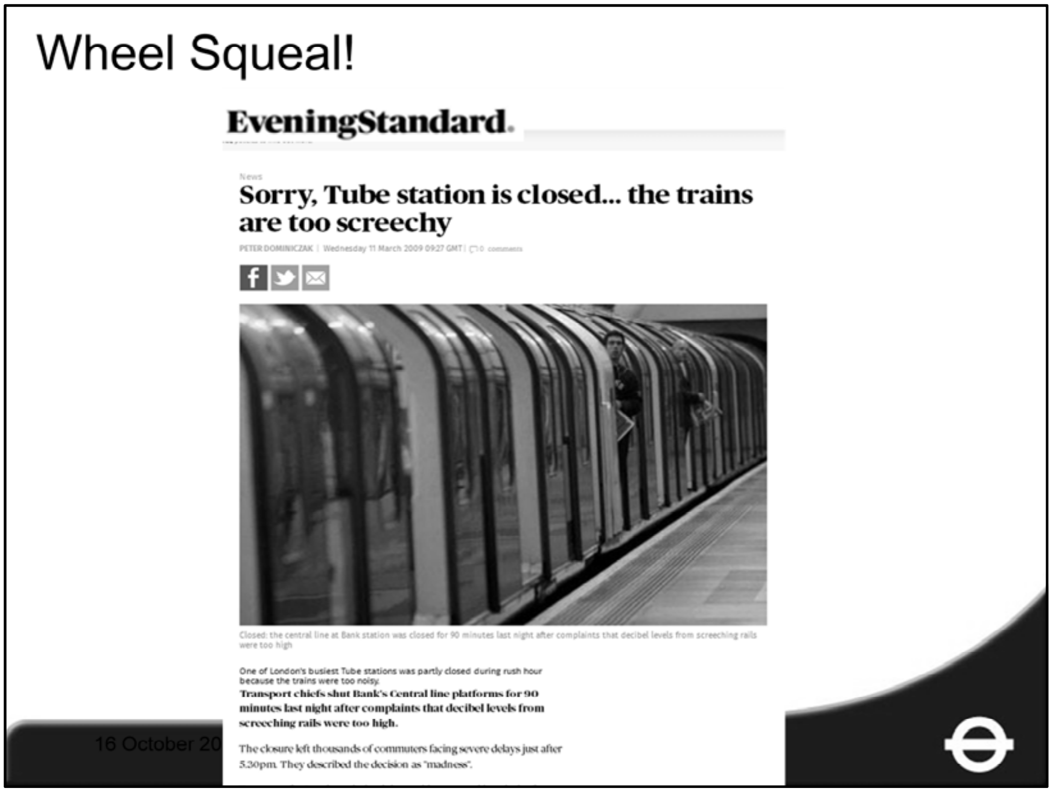
All this rail defect work has been aided by the introduction on Cater B-scan ultrasonic technology on LU. While the B versus A scan just refers to how the ultrasonic data is displayed, the key change is that the ultrasonic data is recorded and can be analysed after the shift. This has meant and improved process, better defect detection rates and the ability of monitor defect growth.



Here is an example of the rate of growth on the Victoria line. Hopefully you can just about see on the top scan, there is no rail defect. However 28 days later, a transverse defect is visible on the scan. It actually turned to be a crack through most of the rail head – high tonnage and wheel profiles being contributing factors.



The benefits of B-scan testing is very obvious. Introduced in late March there was ‘bow-wave’ of defects, and a lot of emergency defects – big cracks which require immediate removal. However, since then the number decreased. So much so that in the last two months, no emergency defects were detected. We are now detecting defects before they become serious.

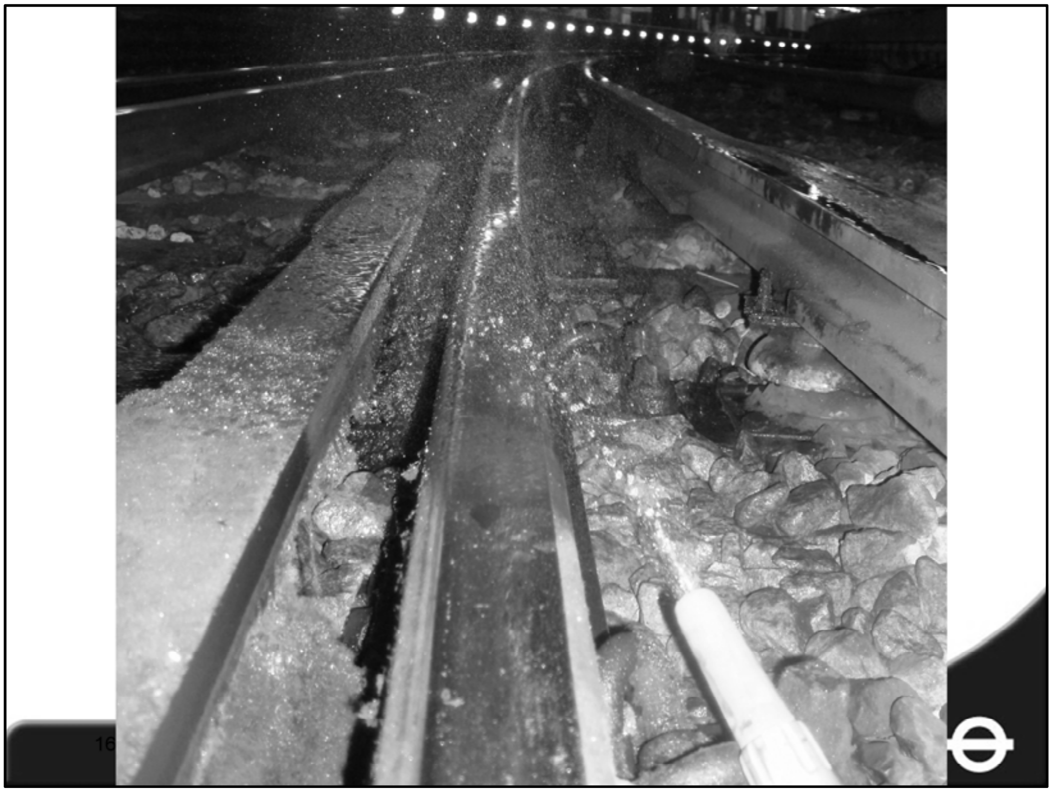


Finally I'd just like to talk through one of own most problematic wheel rail interface issues – wheel squeal. As the tube trains are in a small metal tube, the screech emitted doesn't dissipate, and in the worse cases can cause stations to close.

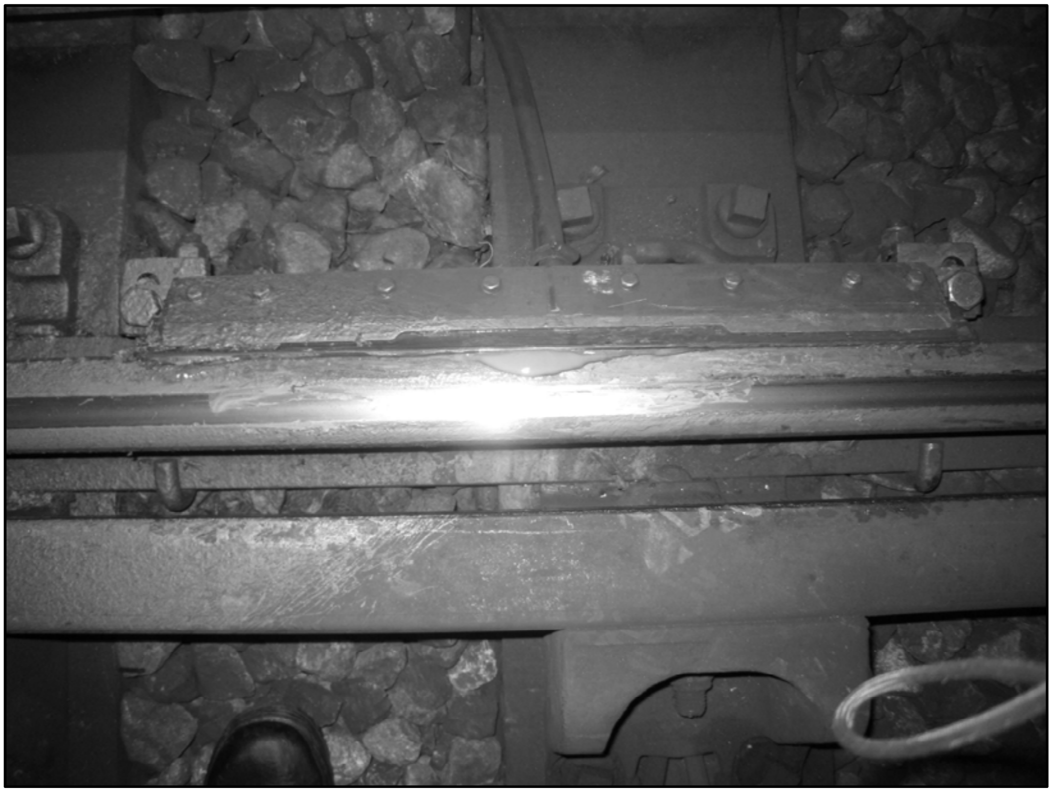
Wheel Squeal

- Caused by the LOW rail

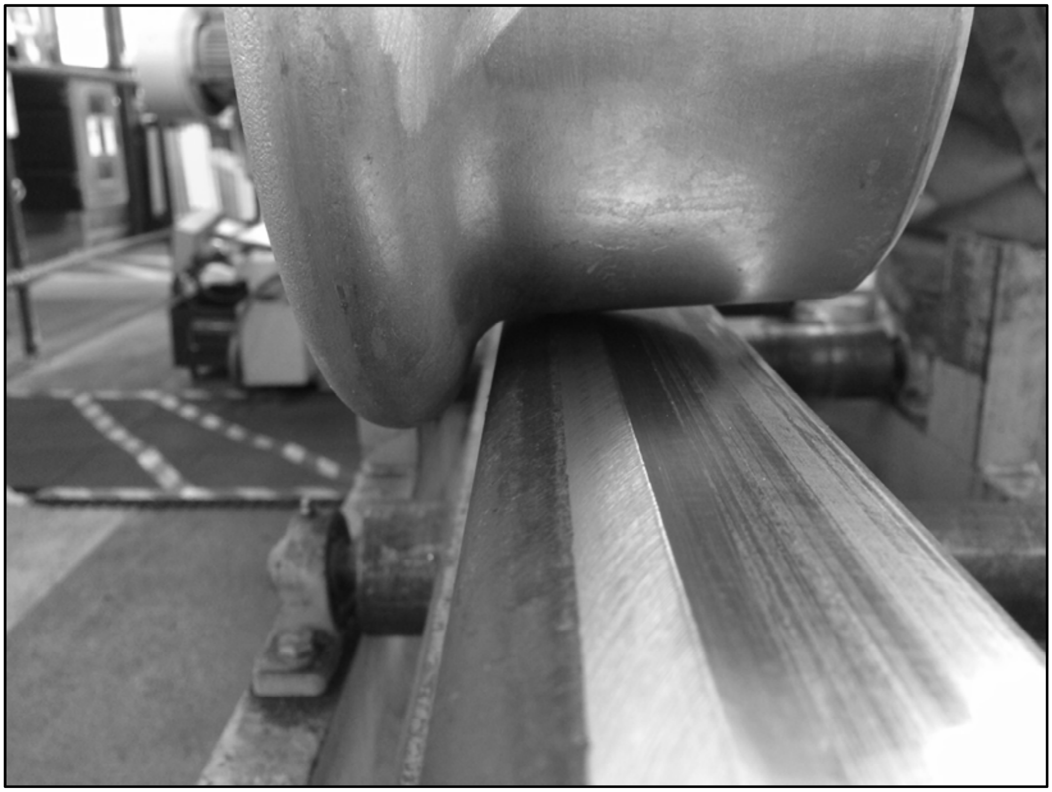
The first thing I’d like to say about wheel squeal is how it is caused – as there can be some confusion over this. It is caused by the low rail – the slip/stick, or slip/roll as I prefer, behavior of the wheel around tight curves can cause the wheel to resonate – almost acting like a speaker. It’s this resonance that cause the high pitch sound. Are we sure? Yes. We did a water spray trial at Baker Street, spraying each rail separately. When we sprayed the high rail – the squeal continued. When we spray the low rail it stopped.



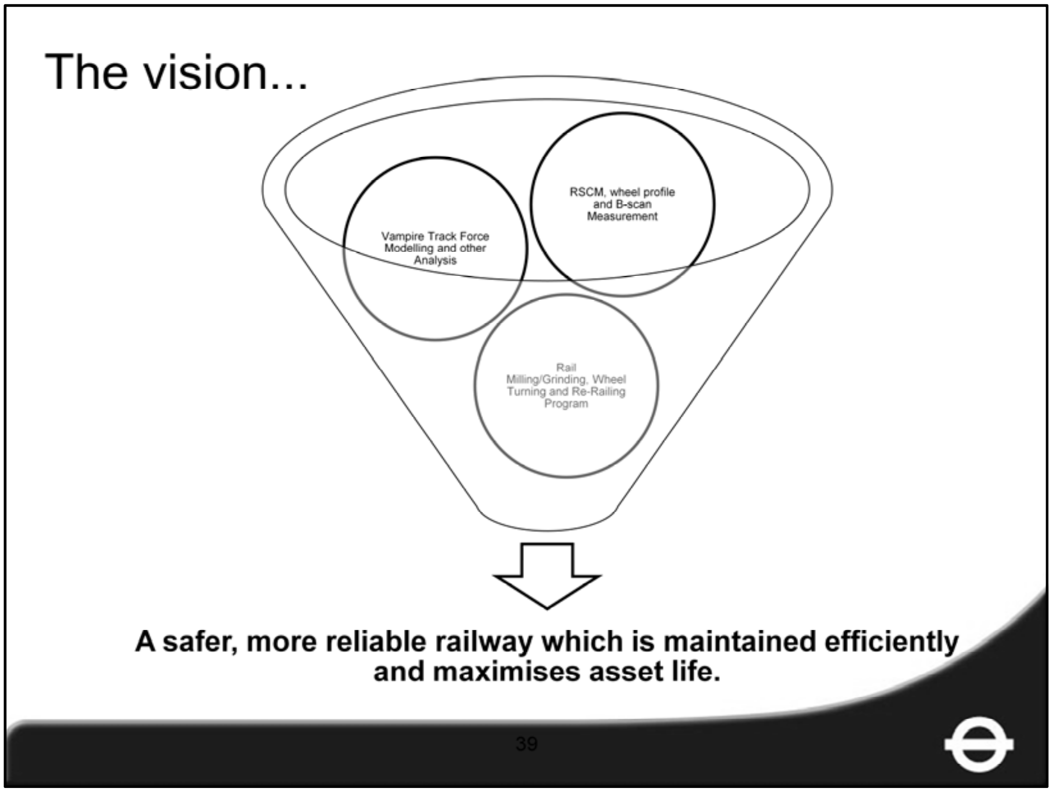
There’s photo of the low rail being sprayed. A simple but effective trial.



How are we addressing it? Top of Rail friction modification has found to be effective – on/off trials have proven that it reduces squeal. However, on some lines which have multiple squeal site (the Bakerloo line!) we have found that brake block contamination occurs as the fluid builds up and dries on the block. This led to some unusual wheel profile wear and so the use of friction modification had to be adjusted.



Our latest solution is to use anti-squeal asymmetric rail. As you can see on the photo, the field side of the rail has been machined. What this means is the contact patch is shifted from near the outside of the rail to closer to the flange. This shift in contact patch aims to prevent the wheel from resonating. So far it has been installed at Bank on the Central line and Piccadilly Circus on the Bakerloo line, with positive results.



So to conclude – I hope you've now got an idea of the WRI challenges that LUL face, some of consequences of those challenges but also some of the solutions we are putting into practice. The vision for WRI is that we become more data driven, and in turn more predictive- using data and vehicle modeling to determine when maintenance intervention should occur. We also aim to continue the collaboration between the wheel people and the rail people – it's improving but there's some improvement to be made! Overall we want:

A safer, more reliable railway which is maintained efficiently and maximises asset life.

I’m done – thanks for listening

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My shifts done – thank you.