# TRAINSAFE
# SAFE INFRASTRUCTURE WORKSHOP

## DEMONSTRATION OF THE RESEARCH CLUSTER MECHANISM FOR "TRACK DEGRADATION & SUB-STRUCTURE INTEGRITY"

# STAGE 1

# ISSUE HIGHLIGHTED IN THE STATE OF THE ART REPORT

This resulted in the topic of ‘Track Degradation & Sub-Structure Integrity’ forming part of the agenda for the ‘Safe Infrastructure’ workshop.

The following is the relevant extract from the State of the Art Report

### *4.1. Safe Infrastructure in the Railway System*

On 3rd June 1998 in Eschede, Germany, 101 people were killed when a wheel broke on a German high speed train travelling at 200 km/h. This caused the train to derail, and one of the carriages slammed into a bridge. The bridge then collapsed on top of the train and the remaining carriages piled into one another.

On 17th October 2000 at Hatfield in the UK, 4 people were killed when a high speed train derailed following the fragmentation of a rail. The cause of the rail break was determined to be multiple cracks and fractures due to rolling contact fatigue. The derailment resulted in the locomotive and front two passenger coaches remaining on the track, whilst the rear eight coaches derailed. The most seriously damage carriage, and the site of the fatalities, was the buffet car. This had been turned on to its side and had its roof ripped-off following impacts with line side equipment masts.

*Figure 4.1 – Rail fracture at Hatfield.*

On 10th May 2002 at Potters Bar in the UK, 7 people were killed when a regional train derailed just before a station. The subsequent investigation found that nuts on a vital set of points were missing. As the third coach of the train passed over the defective points, the wheels on each axle were forced in opposing directions, derailing the rear of the third coach and the fourth coach entirely. The fourth coach then hit a bridge, separated from the rest of the train and became airborne. The rear bogie and underbody equipment were ripped off, damaging the bridge and showering debris onto pedestrians and vehicles below. The coach slid across the station platforms, struck a waiting room and rolled through 360 degrees before coming to rest wedged under the canopy roofs.

The above are some recent examples of crash situations in which the railway infrastructure played a significant role. There are examples of situations in which deficiencies in the infrastructure (particularly track) were the direct cause of the crash. There are also examples of situations in which collisions with line side objects following a derailment caused the accident to be more severe than it otherwise might have been. Here, a state of the art review of safe infrastructure is presented as the first part of TRAINSAFE's investigation into this field.

A derailment constitutes a very dangerous situation in which a rail vehicle is no longer constrained by the track and consequently undergoes a non-controlled movement. The possibility of derailment cannot be avoided with absolute certainty. Therefore, the consequences of derailment should be considered, and the likelihood of derailment reduced with appropriate measures.

There are many factors that can affect the likelihood of a derailment including the track geometry (curvature, camber, etc.), the design of the vehicle (number of axles, distance between axles, carriage length, etc.), the relative profiles of the wheel and the railhead, component degradation, sub-structure stability and the quality of track support conditions.

The main causes of derailment can be summarised as:

- The climbing of the wheel flange over the rail due to abnormal lateral forces (Figure 4.2), particularly when negotiating curves or experiencing excessive velocity.
- Points failure.
- Variation of track support stiffness.
- Track gauge variation.
- Dynamic wheelset unloading – pitching of a vehicle
- Material or mechanical failure of the track.

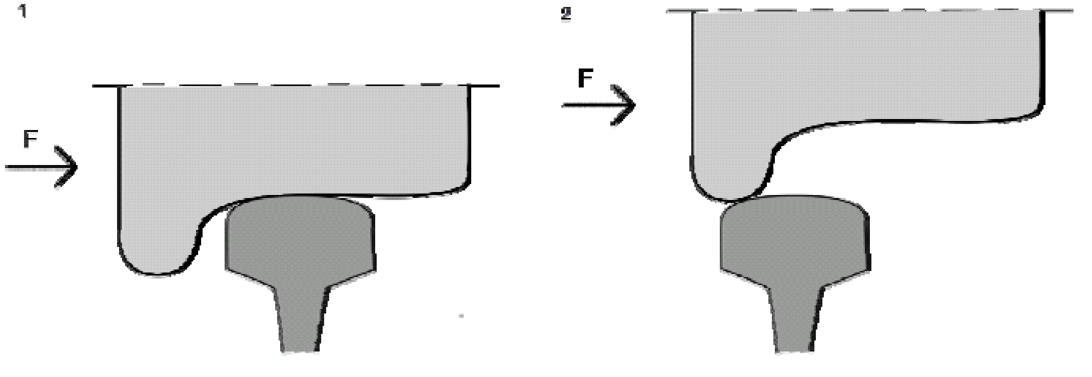



*Figure 4.2 - Climbing of the wheel flange over the rail as a cause of derailment.*

The primary measure for providing an acceptable degree of derailment safety is the fulfilment of good dynamic conditions between the wheel and the rail. In particular, European standards such as prEN 13232.3 must be satisfied that regulate the maximum lateral forces for a given axle load.

Where risk of derailment is increased as a result of the need for route deviations, i.e. Switch and Crossing layouts, or where the consequences of a derailment are especially severe (e.g. on bridges and during construction work) check rails can be installed (Figure 4.3). These help to avoid unconstrained lateral movements of the rail vehicle. They are placed parallel to the regular rails at a calculated offset, and are normally steel but can sometimes be wooden beams

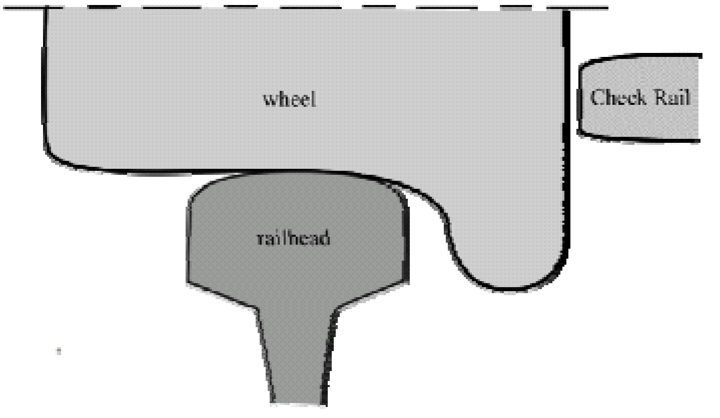



*Figure 4.3 - The use of check rails.*

The disadvantage of using long sections of checkrail is that if the rail vehicle did become derailed, the presence of the checkrail can impair deceleration compared to running on ballast.

#### *4.2.1.2. Track*

Conventional railway track construction is generally considered to be made up of two sub-systems:

- The substructure – ballast, sub-ballast and formation layer. This group can also include earthworks and drainage.
- The superstructure – consisting of rails, pads, fastenings and sleepers.

##### *4.2.1.2.1. The Sub-Structure*

Figure 4.4 illustrates the components of a traditional railway track sub-structure.

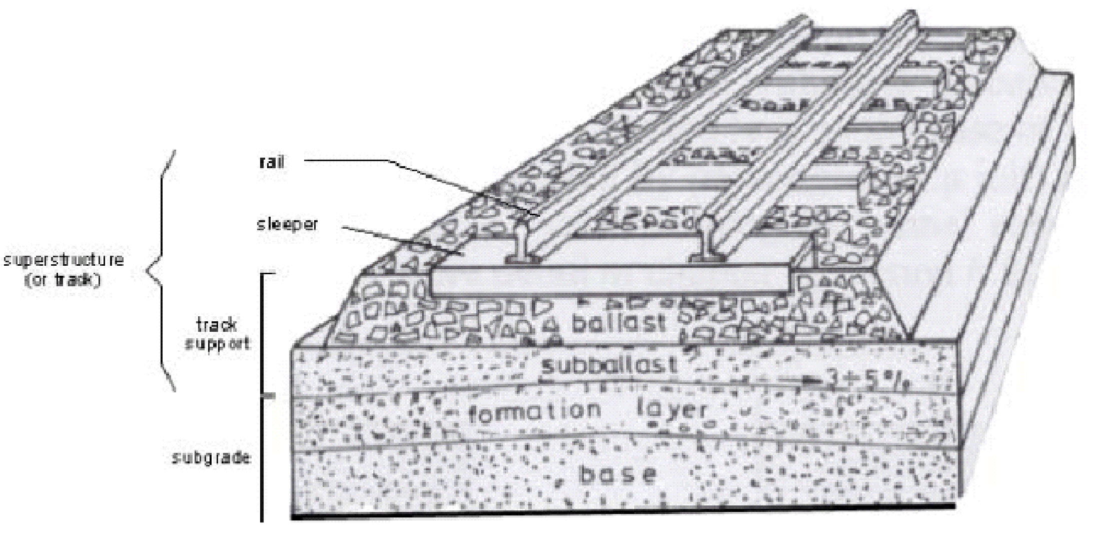



*Figure 4.4 - The traditional construction of a railway track sub-structure[3].*

*4.2.1.2.2. The Superstructure*

Rail metallurgy: In general, the three key causes of a rail requiring rectification or being cascaded down or removed from service are:

• Loss of transverse section and/or longitudinal profile.

• Loss of rail integrity through fatigue (rolling contact and bending fatigue).

• Increased risk of rail breakage from internal quality, residual stresses, surface quality and / or welding.

Although the rate of rail degradation is a function of many system variables, rail metallurgy provides the baseline for the optimisation of life. As shown in Figure 8, a number of rail steels have been developed through systematic and dedicated metallurgical research over the decades, and these demonstrate increasingly attractive properties when assessed in the laboratories. Currently, the family of available rail steels extends to hardness levels well beyond 400 HB (Brinell Hardness).

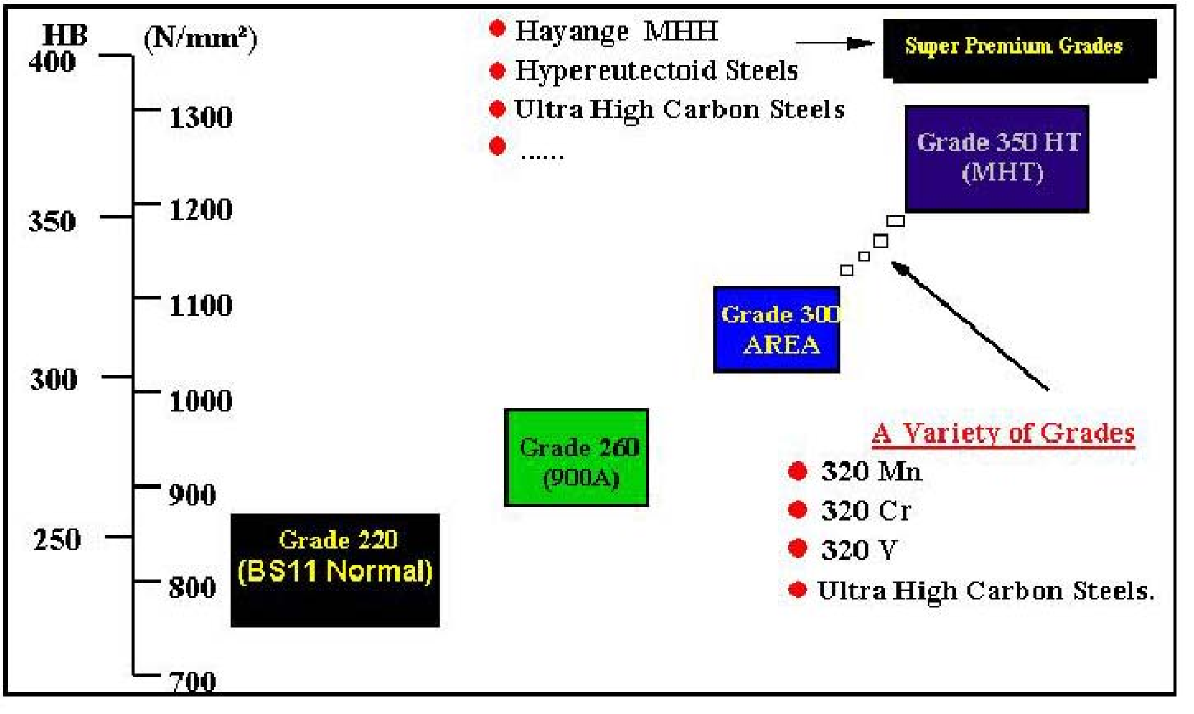



*Figure 4.7 – The family of rail steels.*

The steels in regular use within all major railways have a pearlitic microstructure of the type shown in Figure 4.8. The key microstructural difference between the various grades is the level of refinement; finer interlamellar spacing provides increased hardness and tensile properties. The strengthening mechanisms employed to

• Chemistry enrichment through both higher carbon contents and the addition of alloying elements to increase hardenability and thereby refine the pearlitic microstructure.

• Accelerated cooling to refine the pearlitic microstructure.

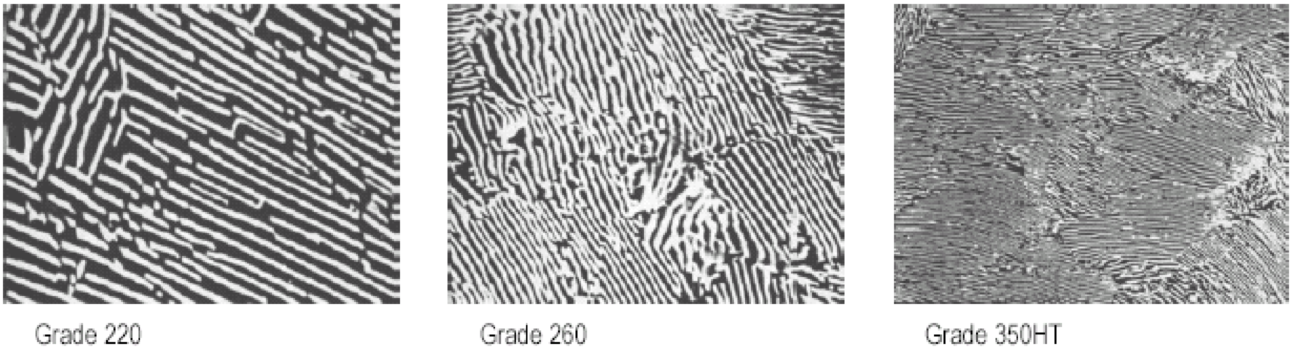



*Figure 4.8 - Scanning electron micrograph (x 5000) of rail steels.*

Other rail steels with hardness values in between that of Grade 260 and the heat-treated Grade 350HT employ additional alloying elements such as chromium and vanadium to achieve the desired level of hardness. In actual fact, there is little difference between the compositions of Grade 260 and Grade 350HT, and yet the latter has significantly greater hardness and tensile strength. These enhanced properties are achieved through controlled accelerated cooling either directly from rolling heat or following subsequent reheating.

Demands for further increases in hardness and strength from some railway organisations have led to twosignificant areas of rail steel development:

- Ultra high carbon or hypereutectoid rail steels.
- Low carbon carbide-free bainitic steels.

Ultra high carbon steels, as the name suggests, rely on the high strengthening coefficient of carbon and therefore employ carbon contents of around 0.95% compared to the ~0.75% for Grade 260 or 350HT. Although such steels have been supplied into the Canadian rail network, they have not been introduced into the main European railways.

Bainitic rail steels have been a research topic for well over a decade and although a number of trial sites have been established in both Europe and North America, they are yet to be made commercially available. They offera more wear resistant microstructure than that of pearlitic steels. The design of the bainitic steel chemistry is governed by the choice of alloy additions and their relative proportions. Resultant bainitic steels can be manufactured within a hardness range of 320HB to 450HB.

In practical terms, the UK has always favoured the use of the pearlitic Grade 220, which is the most widely used grade in both tangential and curved track and until recently has been believed to have provided relatively long rail life. The current usage of this grade is likely to account for more than 90% of the UK's total. Grade 260 is the most widely used grade throughout Europe and elsewhere in the world. The adoption of the heat-treated grade 350 HT was slow in the late eighties but increased steadily to approximately 6,500 tonnes in 1999, reaching a cumulative supplied tonnage of approximately 40,000 tonnes.

Clearly the choice of rail steels available to the industry is vast and it goes without saying that all these steels will have been evaluated in the laboratories against one of the recognised rail steel specifications. Hence the key metallurgical question that must be answered is "*how do laboratory determined properties influence the inservice performance issues that are responsible for the curtailment of rail life or the increased cost of track maintenance?*". Although this question does not consider the wheel side of the interface, it cannot be overemphasised that any benefits to track accrued from optimising rail metallurgy are also beneficial to the wheel and the vehicle system. Equally, optimising wheel metallurgy is beneficial to the track and is a subject in its own right.

***Rail wear and crack growth:***

The wear of rails, and the formation and propagation of cracks within rails, has been extensively studied. Individually, these sciences are fairly well understood. Wear can actually be beneficial in inhibiting crack growth; the removal of material from the surface of a railhead is an effective means of reducing the lengths of any cracks. Grinding is the intentional erosion of material from the railhead, and can have the added benefit of moving the wheel / rail contact patch. It has been shown that careful grinding can dramatically reduce crack growth rate. If managed optimally, the maximum life of a rail is the delicate balance of wear, grinding and fatigue (Figure 4.9).

"Whole life" rail models consider the interaction between wear and crack growth, and also take account of variations in traffic, axle loads and vehicle dynamics. Work continues to refine these models.

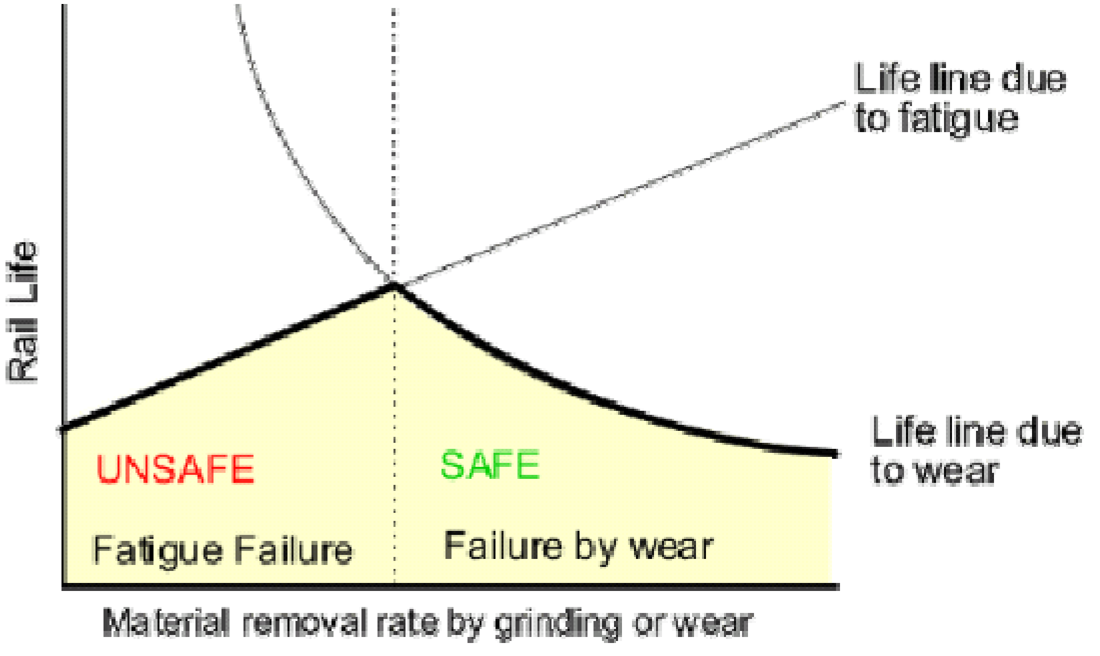



*Figure 4.9 – Maximising rail life is a balance between failure by fatigue and wear[6].*

# STAGE 2

# DISCUSSION PRESENTATION FROM TRACK DEGRADATION & SUB-STRUCTURE INTEGRITY EXPERTS

A brief five minute presentation to introduce the topic to the workshop delegates. This defined the topic scope and highlighted the key specific issues to be addressed.

# TRAINSAFE – SAFE INFRASTRUCTURE WORKSHOP

## Understanding Track Degradation for Enhanced Network Performance

October 29th & 30th 2003

Dr. Jay Jaiswal
Corus Rail Technologies
jay.jaiswal@corusgroup.com

## SAFE INFRASTRUCTURE

The Track System – Scope

**Defining the Track System?**

- **Rail – Plain Line**
- **S&C**
- **Welds**
- **Pads**
- **Fastening**
- **Sleepers**
- **Ballast & Support Structure**



## SAFE INFRASTRUCTURE

Understanding Degradation of Components

| Track System Component | Symptoms/Causes of Degradation |
|---|---|
| **Rail** → | **Loss of Transverse Section and/or Longitudinal Profile** |
| S&C | **Loss of Rail Integrity Through Fatigue – Rolling Contact and Bending Fatigue.** |
| Welds | **Rail Breakage from Internal Quality, Residual Stresses, Surface Quality, Weld Repair** |
| Pads | |
| Fastenings | |
| Sleepers | |
| Ballast | |



## SAFE INFRASTRUCTURE

Understanding Degradation of Components

| Track System Component | Symptoms/Causes of Degradation |
|---|---|
| Rail | **Differential Wear – "Cupping"** |
| S&C | **Dipping** |
| **Welds** → | **Rolling Contact Fatigue** |
| Pads | **Internal or External Flaws: Fatigue & Fracture** |
| Fastenings | |
| Sleepers | |
| Ballast | |

## Understanding Degradation - The Algorithms

**Track Integrity Index =**

**ƒrail deg + ƒwelds deg + ƒrail breaks & defects + ƒpad deg +**

**ƒfastening deg + ƒsleeper deg + ƒballast deg**

Where:

**Rail deg.** = **ƒtraffic + ƒwear$_{Vert,g}$ + ƒRCF + ƒcorrugation +**
**+ ƒweld repair + ƒcorrosion**

**Pad deg.** = **ƒtraffic + ƒtrack curvature + ƒrail wear**

**Weld deg** = …………





## Understanding Degradation – The Tools

- The Track System & Vehicle Track Interactions are Complex
- Requires a multi-disciplinary approach & a variety of tools
- The CRT Tool Box Contains:
  - Intelligent Data Analysis
  - Practical Experience: Site Monitoring & Detailed Failure Investigations
  - System Modelling:
    - Vehicle Dynamics
    - Track System Model
    - Rolling Contact Fatigue Initiation & Growth
    - Modelling Fatigue & Fracture
  - Knowledge of Rail Metallurgy & Materials Technology





## Understanding Track Degradation - Conclusions

- Understanding Track Degradation requires a Systems Approach
  - Determination of degradation of key components
  - Effect of interaction between components
- Variety of modelling tools developed
- Validation and refinement of CRT tools via continued monitoring of System behaviour
- Work progressing to collate the understanding into:

Track Integrity Index = ƒrail deg + ƒwelds deg + ƒrail breaks & defects + ƒpad deg + ƒfastening deg + ƒsleeper deg + ƒballast deg





SAFE INFRASTRUCTURE WORKSHOPS

**Theme 1**

**TRACK DEGRADATION**

**T Tivey**

**Eurotunnel Track Technologies Engineering Manager**



# SAFE INFRASTRUCTURE

## Introduction to Theme 1

**>> Track Quality/Condition Deterioration <<**

- Classification of degradation
- Influences of usage
- Possible strategies

**Current Situation**

The railway industry in the UK is in the midst of yet more fundamental changes with respect to who conducts maintenance activities. However the real issue is not by whom, but how are these resources to be targeted effectively and efficiently? Infrastructure maintenance and renewals to correct the effects of deterioration, represents the dominant cost in many railway operations and therefore require the development of adequate strategies to deliver safe and economical viability.



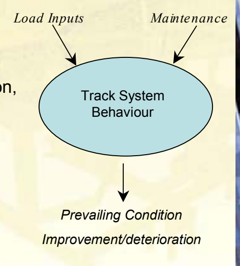
# SAFE INFRASTRUCTURE

► Degradation of the infrastructure needs to be separated into levels of damage which are classified as normal or abnormal

- within original design parameters
- maintenance regime respected

► To be able to establish emerging track condition, need to know :-

- effect of maintenance
- interdependency of component behaviour
- loads applied through wheel/rail interface






# SAFE INFRASTRUCTURE

► **Influence of Usage**

Metrics used to represent loading magnitude and frequency :

a. MGT or EMGT - traditional global classification. Are they appropriate in describing degradation ?

b. Load Vs cyclic effects - structural strength, contact patch conditions. How much, how often ?

c. Environmental and Ageing - influence of natural decay

d. Generic or Different - all railways claim to be special cases, it this really the case? laws of physics do not change, but parameter values do ?



# SAFE INFRASTRUCTURE

**Strategic Issues –**

*subject:* Establish asset whole life approach

*aim:*
- Integration of usage factors to key track parameters
- Develop bespoke approach to track sections

*suggestion:* Ensure that data manipulation tools provide actionable information ?

*subject:* Wheel/Rail contact specification

*aims:*
- Determine range of acceptable contact conditions
- Limit static and dynamic track loading

*suggestion:* Introduce track section specific condition criteria ?



# SAFE INFRASTRUCTURE

**Research & Development Needs**

Development of track condition evaluation matrix

able to:

- account for vehicle types and condition
- establish chronological residual life
- calculate safety risk index
- identify type and location of specific remedial works

# THEME 7
# Sub – Structure Integrity

Alan Stirling
University of Birmingham

## Foundation of the track

Mostly built before 1900
Not designed
Increased loading
- increased speed
- increased axle load
- increased tractive power

## Layers

Ballast
Sub-ballast
Formation layer/subgrade

How do we assess the contribution of each of these structural layers?

## Key Performance Criteria

Strength – to avoid settlement

Resilient elastic modulus/stiffness – to avoid transient deformations as a train passes

## Other areas

Drainage
Embankments
Transition zones
Ground improvement techniques
Bridges and culverts

# STAGE 3

# RESULTS OF FACILITATED DISCUSSION AT THE SAFE INFRASTRUCTURE WORKSHOP

The output from a two hour session, which was then presented to the other workshop delegates for comment.

# Track Degradation and Substructure Integrity

Safe Infrastructure Workshop
29th – 30th October 2003
Leamington Spa, UK

## 1. What are the critical passive safety issues relating to the topic?

- Whole system approach – combination of just in spec leading to failure
- WHAT IS TRACK FOR? IT'S THE FORCES!
- How do vehicles contribute to track degradation?
- Stiffness of track / dynamic / freq.
- Stiffness variation (data needed)
- Sub-structure analysis
- Interoperability as a catalyst or focus
- Duty requirements of various vehicles – catalogue
- Reference wheel / rail profiles
- Maintenance criteria - ref. intervention. Tolerances – measure how? Effect on operating costs.
- Component quality and interaction, e.g. profile and stiffness.
- Stiffness correction
- Materials, manufacture, designs
- Stress free temperature

## 2. What are the issues relating to standards?

- Operational or safety standards – FOR THE FORCES
- Standards for records to make them useful.
- Existing for wheel and rail profiles – new
- Intervention standards – when to …DO SOMETHING ABOUT THE FORCES!
- STANDARDS not complied with but not changed – lack of communication
- Stick to defined standards and have mechanism for change.
- Standards for: pads
- Specifications or standards?
- Is variation known considered?
- Poor standards – degradation.
- Approach for degradation.

## 3. What are the overall recommendations (solutions) for addressing the critical passive safety issues identified in slide 1?

- Standards taking account degradation IT'S THE FORCES!
- Look at degradation mechanisms and predict geometry THE FORCES
- Infrastructure and life cost – asset management
- Transfer ASSET MANAGEMENT from other sectors
- Maintenance – financial plan, intervention plan
- Provided guidance on "good" substructure
- Use of correct metallurgy – rail steels
- Data analysis techniques
- Infrastructure testing

## 4. What are the business benefits of the proposed recommendations?

- Reduced maintenance costs
- Reduced risk – risk based assessment
- Reduced operator costs
- Work can be prioritised – possession
- Improved system reliability
- Increased track availability

## 5. What are the priorities for future research activity?

- HUMAN, MANAGEMENT & ECONOMIC ISSUES
- GENERALLY ENGINEERING NOT!
- ROLLING CONTACT + ADHESION THEORY
- Infrastructure test methods IT'S THE FORCES!
- Cost-benefit analysis – AND IT'S THE MONEY
- Imposed load definition under different conditions – predict
- Model infrastructure characteristics
- When to intervene – accuracy an issue
- Risk based model
- Pilot railway studies
- Need operator involvement – track
- Reduce track degradation. New structures or components - alternatives